frontiers | Research Topics

Advances in marine environmental protection: challenges, solutions and perspectives

Edited by
Mehran Idris Khan, Yen-Chiang Chang and Wen-Hong Liu

Published in
Frontiers in Marine Science



FRONTIERS EBOOK COPYRIGHT STATEMENT

The copyright in the text of individual articles in this ebook is the property of their respective authors or their respective institutions or funders. The copyright in graphics and images within each article may be subject to copyright of other parties. In both cases this is subject to a license granted to Frontiers.

The compilation of articles constituting this ebook is the property of Frontiers.

Each article within this ebook, and the ebook itself, are published under the most recent version of the Creative Commons CC-BY licence. The version current at the date of publication of this ebook is CC-BY 4.0. If the CC-BY licence is updated, the licence granted by Frontiers is automatically updated to the new version.

When exercising any right under the CC-BY licence, Frontiers must be attributed as the original publisher of the article or ebook, as applicable.

Authors have the responsibility of ensuring that any graphics or other materials which are the property of others may be included in the CC-BY licence, but this should be checked before relying on the CC-BY licence to reproduce those materials. Any copyright notices relating to those materials must be complied with.

Copyright and source acknowledgement notices may not be removed and must be displayed in any copy, derivative work or partial copy which includes the elements in question.

All copyright, and all rights therein, are protected by national and international copyright laws. The above represents a summary only. For further information please read Frontiers' Conditions for Website Use and Copyright Statement, and the applicable CC-BY licence.

ISSN 1664-8714
ISBN 978-2-8325-6291-8
DOI 10.3389/978-2-8325-6291-8

About Frontiers

Frontiers is more than just an open access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers journal series

The Frontiers journal series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the *Frontiers journal series* operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews. Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the *Frontiers journals series*: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area.

Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers editorial office: frontiersin.org/about/contact

Advances in marine environmental protection: challenges, solutions and perspectives

Topic editors

Mehran Idris Khan — University of International Business and Economics, China

Yen-Chiang Chang — Dalian Maritime University, China

Wen-Hong Liu — National Kaohsiung University of Science and Technology, Taiwan

Citation

Khan, M. I., Chang, Y.-C., Liu, W.-H., eds. (2025). *Advances in marine environmental protection: challenges, solutions and perspectives*. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-8325-6291-8

Table of contents

07 Editorial: Advances in marine environmental protection: challenges, solutions and perspectives
Mehran Idris Khan and Yen-Chiang Chang

12 The extraterritorial human rights obligations of Japan in regard to Fukushima nuclear contaminated water
Liang Yu and Weizhuo Xu

21 Technology advancement and international law in marine policy, challenges, solutions and future prospective
Muhammad Bilawal Khaskheli, Shumin Wang, Xin Zhang, Imran Haider Shamsi, Chenghuan Shen, Sanober Rasheed, Zakir Ibrahim and Dost Muhammad Baloch

38 Enhancing the ocean carbon sink capacity of Shandong province, China, under the "dual carbon" goal
Zhengkai Mao, Huirong Liu and Zhijun Zhang

44 China's marine environmental public interest litigation: current situation, challenges, and improvement approach –analysis based on 339 cases
Lei Yang

60 Global analysis of marine plastics and implications of control measure strategies
Ren-Shou Yu, Ying-Fei Yang and Sher Singh

72 Reflections on Japan's participation in negotiations of the global plastic pollution instrument under international environmental law
Qi Xu, Mengxue Zhang and Peng Guo

86 The implementation of the environmental impact assessment in Fukushima contaminated water discharge: an analysis of the international legal framework
Xidi Chen and Qi Xu

102 Coastal cities governance in the context of integrated coastal zonal management: a sustainable development goal perspective under international environmental law for 'coastal sustainability'
Shijun Zhang, Qian Wu, M. Jahanzeb Butt, Yan-Ming Lv and Yan-E- Wang

119 The area-based management tools coordination between IMO and BBNJ agreement regimes and its implications on vessel pollution control
Jinpeng Wang and Yiwei Zhang

133 ChatBBNJ: a question–answering system for acquiring knowledge on biodiversity beyond national jurisdiction
Xiaowei Wang, Mingdan Zhang, Hao Liu, Xiaodong Ma, Yingchao Liu and Yitong Chen

147 Reflections on the European Union's participation in negotiations of the global plastic pollution instrument under international environmental law
Qi Xu, Mingyang Zhang and Shuli Han

165 Study on the relationship between informatization and marine eco-efficiency in China–taking 11 coastal provinces as examples
Baodong Dai, Jifeng Cao, Gonghang Chen and Cheng Ma

178 Revision of China's marine environmental protection law: history, background and improvement
Ruiqiang Liu

191 Toward better governance of the marine environment: an examination of the revision of China's marine environmental protection law in 2023
Lansong Huang, Rui Zhou and Quansheng Wang

204 Research on subject behavior choice of marine carbon sink projects under risk conditions
Yixiong He and Yanwei Wang

220 Manufacturing maritime firms' environmental behaviors: theory and practice
Shuling Mao and Yinxiao Xu

240 Building the rule of law for maritime security in China: a domestic law perspective
Weihai Li

251 Beyond equilibrium thinking: dynamic area-based management tools in a changing ocean
Bastiaan E. Klerk, Katharina Heinrich and Raul Primicerio

265 Connotation analysis and path discussion of China's land-sea coordination policy: based on the interregional externality theory
Yanping Li, Yuping Wang, Dahai Liu and Yuting Hou

283 New perspective on the recent challenges of regional environmental management plans under the background of deep-sea mining: from Northwest Pacific to global
Wencui Zhou, Tianzhao Li and Xuewei Qi

298 Impacts of oyster farms on sediment-associated mercury and methylmercury concentrations and health risks in an estuarine, mangrove forest, Zhanjiang Bay, China
Zike Zhao, Chunliang Chen and Mengqian Feng

310 Reflections on the reform of multi-tiered sea use right in China
Minna Yu and Xinkai Yue

321 China's shipping emissions governance: status and prospects under the dual carbon goal
Mai Hu and Yue Dong

329 A study on the governance pathways of the Law of the Sea in response to climate change
Wanping Zeng and Guihua Wang

343 The rule of law system for China's marine security
Limei Wang

354 The improvement of judicial protection of marine environment in China: based on the analysis of 2,443 judicial cases
Xi Liu, Sijie Liu and Yuting Wang

372 Environmental legislation analysis improvement approach of global marine plastic pollution from the perspective of holistic system view
Shuqing Xu

395 Pathways in the governance of shipping decarbonization from perspective of balancing the conflicting interests
Wenwen Li and Zhengliang Hu

410 The Pakistan-China FTA: legal challenges and solutions for marine environmental protection
Asif Khan and Maseeh Ullah

427 How to possess an electronic bill of lading as information? A comparative perspective of the legislation on the "possession problem" of electronic bills of lading
Siqi Sun and Ran He

438 How "unequal treaties" influenced commission competence: a new perspective on the United Nations Convention on the Law of the Sea (Part XV) in the Timor Sea Conciliation
Ming Jing

456 Legal pathways for China's blue carbon conservation: a perspective of synergizing ocean and climate rule of law
Haitang Li and Yu Liu

474 Reflections on the interpretation and application of the due diligence obligation in international climate litigation: a comparative study of *Daniel Billy* et al. *v. Australia* and the COSIS advisory opinion
Shiqi Liang

488 Impacts of thermal and cold discharge from power plants on marine benthos and its mitigation measures: a systematic review
Qingxue Leng, Ferdaus Mohamat-Yusuff, Khairul Nizam Mohamed, Nazatul Syadia Zainordin and Mohd Zafri Hassan

509 Regulating unmanned aircraft systems in Antarctica: challenges and collaborative solutions
Yitong Chen and Shu Wu

529 Marine protected areas as a tool for environmental justice
Anupa Asokan

536 Towards CO_2 emissions reduction of shipping: $Ca(OH)_2$ based carbon capture system for safeguarding the marine environment
Valentina Bortuzzo, Serena Bertagna, Luca Braidotti and Vittorio Bucci

553 Decarbonizing Arctic shipping: governance pathways and future directions
Yitong Chen and Kaiyue Cheng

566 Analysing Pakistan's fisheries legislation and institutional framework: integrating Sustainable Development Goal 14 within the scope of International Fisheries Law
Liu Lina and Muhammad Murad Zaib Butt

586 Strategic integration of data envelopment analysis and backcasting theories for zero-emission transition in global container shipping companies: pathways and frameworks
Min-seop Sim, Jeong-min Lee, Yul-seong Kim, Dong-ho Jung and Chang-hee Lee

frontiers | Frontiers in Marine Science

TYPE Editorial
PUBLISHED 14 April 2025
DOI 10.3389/fmars.2025.1593179

Check for updates

OPEN ACCESS

EDITED AND REVIEWED BY
Ilaria Corsi,
University of Siena, Italy

*CORRESPONDENCE
Mehran Idris Khan
lfomd@hotmail.com

RECEIVED 13 March 2025
ACCEPTED 02 April 2025
PUBLISHED 14 April 2025

CITATION
Khan MI and Chang Y-C (2025) Editorial: Advances in marine environmental protection: challenges, solutions and perspectives.
Front. Mar. Sci. 12:1593179.
doi: 10.3389/fmars.2025.1593179

COPYRIGHT
© 2025 Khan and Chang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Editorial: Advances in marine environmental protection: challenges, solutions and perspectives

Mehran Idris Khan[1]* and Yen-Chiang Chang[2]

[1]School of Law, University of International Business and Economics, Beijing, China, [2]School of Law, Dalian Maritime University, Dalian, Liaoning, China

KEYWORDS

marine environmental protection, sustainable governance, interdisciplinary research, climate change impacts, marine conservation strategies

Editorial on the Research Topic
Advances in marine environmental protection: challenges, solutions and perspectives

Introduction

Marine environmental protection has become a pressing global priority. Ocean ecosystems face unprecedented threats from climate change (e.g., warming seas, acidification), biodiversity loss, and pollution (Khan et al., 2024b). These challenges are inherently transboundary—pollutants and their impacts extend beyond national jurisdictions—necessitating shared responsibility and cooperation among nations. Issues such as rising ocean temperatures, plastic pollution, noise pollution, and emerging activities like deep-sea mining are disrupting marine ecosystems (Khan et al., 2024a).

The health of the oceans is directly linked to human well-being and sustainable development, particularly for coastal communities and industries that depend on marine resources. Protecting marine environments is not only an ecological imperative but also essential for food security, climate resilience, and economic livelihoods.

In response to these mounting challenges, significant advances in both technology and policy have been made to safeguard the marine environment. Recent developments range from innovative data-driven tools to landmark international agreements. This Research Topic of *Frontiers in Marine Science*, "*Advances in Marine Environmental Protection: Challenges, Solutions, and Perspectives*," brings together a collection of cutting-edge studies and reviews that highlight these advancements. The contributions cover a wide range of topics, including pollution control, climate change mitigation, legal governance frameworks, and the application of emerging technologies—offering timely insights for policymakers and practitioners seeking to bridge science and policy for ocean sustainability.

Addressing marine pollution challenges

One urgent focal point is marine pollution, particularly the widespread issue of plastic waste. Marine plastic pollution has been recognized as a major obstacle to sustainable ocean development (Khan et al., 2024a). Mismanaged plastic from land enters the ocean through rivers, wind, and runoff, making it a truly global problem. Alarmingly, global plastic production is projected to double within the next decade or two, underscoring the urgent need for bold action and strengthened governance. Several articles in this Research Topic tackle this crisis from different angles.

Plastic pollution, both pervasive and persistent, is the area where policy and technology intersect. A global analysis by (Yu et al.) provides a sobering overview of the current state of plastics in our oceans, from macro-debris to microplastics. Their study reveals widespread contamination, threatening marine ecosystems and human health, and underscores the urgency for coordinated international responses. On the policy front, momentum is building toward a new international treaty on plastics. (Xu et al.) reflects on Japan's participation in the ongoing negotiations for a global plastic pollution treaty under the UN. It notes that Japan has adopted a "conservative but proactive" stance—balancing its domestic framework for managing plastics with a cautious approach to ambitious global targets. Understanding such national positions is crucial for practitioners, as it sheds light on the diplomatic challenges of achieving a strong, legally binding agreement to end plastic pollution. Taken together, these contributions emphasize that tackling marine pollution will require both innovative solutions (e.g., improved waste management technologies and data monitoring) and strengthened policies—from local enforcement to global agreements—to turn the tide on ocean contamination.

Similarly, (Yu and Xu) provided their insights into adopting a human rights-based perspective on Japan's controversial plan to release treated Fukushima nuclear wastewater into the Pacific, this approach argues that nations have extraterritorial obligations to prevent transboundary harm and protect the rights of affected communities. It offers a new discourse for holding states accountable and ensuring that such decisions undergo rigorous scrutiny. Complementing this, (Chen and Xu) examines the international legal framework for environmental impact assessments (EIAs) in the Fukushima water release case, finding that treaties such as the UN Convention on the Law of the Sea (UNCLOS) and other environmental agreements obligate Japan to conduct thorough EIAs throughout the decades-long discharge process. Together, these insights underscore the importance of robust legal tools—ranging from human rights protections to EIA requirements—in managing pollution that crosses borders.

Enhancing sustainability and governance innovations

Beyond pollution, the Research Topic also explores how technological advancements and policy measures can promote broader marine sustainability. Climate change mitigation and adaptation in the ocean domain emerge as key themes. Notably, (Mao et al.) highlights the concept of blue carbon, examining how enhancing the ocean's carbon sink capacity can help meet climate goals. Focusing on Shandong Province in China, their perspective piece illustrates how coastal regions can leverage marine ecosystems (such as seagrass beds and salt marshes) to sequester carbon and contribute to national "dual carbon" targets of peaking emissions and achieving carbon neutrality. They argue for a clear roadmap—investing in blue carbon research, establishing carbon trading markets, and integrating ocean-based mitigation into regional planning—steps that could also serve as guidance for policymakers in other coastal jurisdictions. This example underscores a broader point: marine environmental protection is deeply intertwined with climate action, requiring cross-sectoral strategies that link ocean health with emissions reduction and climate resilience.

Strengthening governance is another key aspect of marine environmental protection, and several contributions examine legal and institutional innovations. Yang analyzes China's experience with Marine Environmental Public Interest Litigation (MEPIL), where prosecutors, agencies, and NGOs bring cases to court to enforce environmental laws. Reviewing 339 cases from 2018 to 2023, the study finds that MEPIL has yielded remarkable results in holding polluters accountable and protecting marine ecosystems. This highlights how empowering legal institutions and civil society can drive better compliance with environmental regulations. At the international level, cooperation is expanding through new agreements. (Wang et al.) discusses that in 2023, nations formally adopted the High Seas Treaty, known as the BBNJ Agreement (Chang et al., 2024), to conserve biodiversity in areas beyond national jurisdiction. This agreement introduces tools such as marine protected areas in the high seas, which require coordination with existing regimes. (Wang and Zhang) discuss how area-based management tools under the International Maritime Organization (such as Particularly Sensitive Sea Areas and MARPOL Special Areas) can align with the BBNJ's new protected zones to improve vessel pollution control on the high seas. Such coordination is vital to prevent gaps or overlaps in governance, ensuring that ships and other ocean uses are regulated consistently across jurisdictional boundaries.

Technology is also emerging as a powerful enabler of marine governance. As highlighted in a review by (Bilawal Khaskheli et al.), advances in monitoring and data management—from satellite remote sensing to autonomous sensors—have revolutionized our ability to understand and manage marine environments. These tools enable more evidence-based decision-making and enhance international collaboration by sharing information in real time. However, they also bring new challenges related to data governance, privacy, and the need to update legal frameworks to accommodate innovations. An illustrative example of harnessing technology for policy is presented by (Wang et al.), who introduce "ChatBBNJ," an AI-powered question-answering system designed to help stakeholders navigate the complex text of the BBNJ Agreement. By combining advanced data engineering with large language

models, Chat BBNJ can swiftly provide users—from diplomats to conservation practitioners—with answers about the treaty's provisions. This not only aids understanding but also helps implement the agreement more effectively by informing decisions with up-to-date knowledge. It exemplifies how digital innovations can bridge the gap between extensive environmental legislation and on-the-ground action.

In summary, the articles in this Research Topic set the stage by highlighting both the daunting challenges and inventive solutions in marine environmental protection. They demonstrate that tackling issues like pollution and climate change requires an integrated approach—blending cutting-edge technology, robust legal frameworks, and inclusive governance. As we delve further into these contributions, several cross-cutting themes emerge: the importance of international cooperation, the role of law in enforcing accountability, and the promise of new technologies to enhance our capacity to protect ocean health. These insights provide a foundation for developing more effective policies and practices, which the subsequent sections of this editorial will explore in greater detail.

Continuing from the opening discussion, the next contributions in this Research Topic highlight both innovative technologies and progressive governance approaches driving marine environmental protection. Several papers focus on strengthening legal and policy frameworks at national and international levels. In particular, two studies examine the recent revision of China's Marine Environmental Protection Law, shedding light on how the updated law enhances institutional coordination, pollution control, and biodiversity conservation (Huang et al.; Liu). These analyses underscore that clearer legal mandates—from stricter liability for polluters to new "Land-and-Sea Coordination" mechanisms—can significantly improve marine governance capacity. Another article focuses on policy incentives for industry compliance, finding that the environmental behavior of maritime manufacturing firms is strongly influenced by the stringency of regional regulations and environmental conditions (Mao and Xu). Interestingly, firms in regions with better marine water quality tended to pursue proactive green innovation, whereas those in more polluted areas adopted defensive strategies, such as obtaining ISO 14001 certification to meet minimum standards. This insight suggests that tailored regulatory approaches—combining strict enforcement with positive incentives—can motivate more ambitious environmental action from the maritime sector.

Cutting-edge research in this Research Topic also addresses emerging challenges and technological solutions in ocean governance. With the international seabed mining regime taking shape, one study reviews Regional Environmental Management Plans under the deep-sea mining framework and identifies gaps, such as limited baseline data and the unclear legal force of these plans (Zhou et al.). The authors recommend stronger scientific data collection and clearer rules to balance resource exploitation with conservation in areas beyond national jurisdiction. Another paper explores the intersection of trade and marine protection, using the Pakistan–China free trade agreement as a case study to illustrate how environmental provisions in trade deals could be strengthened to safeguard marine ecosystems (Khan and Ullah). On the high seas, coordination between new and existing regimes remains critical. For example, the IMO's special areas and the forthcoming BBNJ Agreement's marine protected areas must work in tandem for effective vessel pollution control (Wang and Zhang). Technological innovation features prominently as well: one contribution examines the legal status of electronic bills of lading, highlighting how digitalization in shipping can improve efficiency and reduce paper waste, but also necessitates updates to maritime law to address issues of authenticity and "possession" in electronic form (Sun and He). Likewise, bridging the gap between climate technology and ocean health is a recurring theme. A policy review on "blue carbon" strategies argues that integrating ocean-based carbon sinks into climate policy could bolster both greenhouse gas mitigation and marine habitat protection (Li and Liu). Additionally, as climate change intensifies, courts are increasingly called upon to address environmental harms. A comparative analysis of recent climate litigation (e.g., the Daniel Billy case in Australia) interprets states' due diligence obligations under international law to protect the marine environment from climate impacts, potentially setting important precedents (Liang). Finally, a systematic review of thermal discharges from coastal power plants offers a reminder that traditional pollution issues remain central. It catalogues how waste heat alters marine benthic communities and calls for stricter discharge standards and innovative cooling technologies to mitigate ecological damage (Leng et al.). This set of studies collectively illustrates a dynamic interplay between technology and policy: new tools like digital platforms and data-driven models enhance our ability to manage the oceans, while evolving legal frameworks align these innovations with sustainable development goals. Each insight contributes to a more robust, forward-looking approach to marine environmental protection, from local waters to the high seas.

In coastal ecosystems, managing pollution remains a fundamental challenge. For example, researchers studying a mangrove estuary in Zhanjiang Bay, China, found that sediments near oyster farms accumulate mercury and methylmercury, which raises ecological and health concerns (Zhao et al.). Fortunately, their risk assessment indicated that current mercury exposure from consuming local oysters is low, suggesting that aquaculture can coexist with environmental safety if properly monitored (Zhao et al.). Meanwhile, on a global scale, marine plastic pollution is escalating at an unprecedented rate, infiltrating food chains and even human bloodstreams (Xu). The international community has responded with various regulations, but these efforts remain fragmented. A holistic, unified global plastics treaty is needed to effectively curb this pervasive threat.

Climate change mitigation in the maritime sector has become a priority, particularly in the push to cut greenhouse gas emissions from shipping. Under the International Maritime Organization's roadmap, the global shipping industry is under pressure to drastically reduce its carbon footprint (Hu and Dong). China, for instance, has introduced a series of emission reduction policies for its vast shipping fleet in line with its carbon neutrality ambitions, yielding initial progress but also revealing implementation gaps.

Studies suggest that further measures—combining government regulation with market-based incentives and technological innovation—will be needed to reconcile economic growth with the sector's net-zero targets (Li and Hu).

Coordinating climate action with marine governance frameworks is another emerging theme. One analysis highlights that the UN Convention on the Law of the Sea (UNCLOS) and the UN climate regime have historically operated in silos, leaving a gap in addressing ocean-related climate impacts (Zeng and Wang). Given the ocean's crucial role in regulating the climate, the authors argue for bridging this divide by developing agreements that integrate climate change into ocean law and reinterpret UNCLOS in line with the Paris Agreement commitments. Such legal innovation would help tackle challenges like sea-level rise and ocean acidification more effectively under a unified governance approach.

At the national level, governance innovations are being pursued to better balance the development and protection of marine resources. In China, a novel multi-tiered sea use rights system was introduced in 2023 to allocate offshore space more efficiently and sustainably (Yu and Yue). This approach enables layered uses of marine areas and aims to protect resources while supporting a growing ocean economy. Complementing such spatial management, China is also strengthening its legal framework for marine security and environmental stewardship. A recent analysis of China's maritime legislation underscores efforts to consolidate scattered marine laws into a comprehensive "basic law of the sea" and improve enforcement mechanisms (including data governance and specialized courts) for safeguarding maritime rights (Wang).

Strengthening enforcement and judicial capacity is equally vital for marine environmental protection. An extensive review of over 2,400 marine pollution court cases in China (2019–2023) revealed an encouraging decline in cases over time, suggesting improved compliance and governance outcomes (Liu et al.). However, the study also identified gaps and proposed further judicial reforms, such as establishing specific criminal offenses for serious marine pollution and deploying intelligent trial technologies to expedite cases and standardize legal judgments (Liu et al.). Such measures would strengthen the rule of law's ability to deter violators and ensure consistent enforcement of environmental regulations.

International economic cooperation must also align with environmental objectives. A case in point is the Pakistan–China Free Trade Agreement (FTA), which has spurred rapid trade growth but also unintentionally aggravated marine pollution, overfishing, and habitat loss in both countries (Khan and Xu, 2021). Researchers examining this FTA argue that stronger environmental provisions are needed within trade deals to prevent and mitigate such impacts (Khan and Chang, 2021). They recommend concrete steps, such as adding enforceable environmental clauses to the agreement, creating a joint marine environmental commission, and boosting public participation and domestic environmental laws to safeguard ecosystems amid economic expansion (Khan and Ullah). This highlights the importance of "greening" trade agreements through legal and institutional innovations.

Finally, technological innovation is emerging as a key enabler for sustainable ocean governance and industry practices. One example is the ongoing digital transformation of maritime commerce: the shift from paper-based to electronic bills of lading (eB/Ls). This transition promises greater efficiency and reduced paper use but raises legal questions about how to confer traditional property rights onto digital documents (Sun and He). A comparative legal study outlines three approaches that different jurisdictions are taking to solve this "possession problem" for eB/Ls – ranging from expanding existing definitions of possession to embracing new concepts of electronic control or establishing trusted digital registries (Sun and He). Importantly, the trend is converging toward recognizing "control" of an electronic record as the functional equivalent of possession, paving the way for wider adoption of paperless, secure shipping transactions. By modernizing maritime law in this way, trade can become more efficient without compromising legal certainty, illustrating how innovation and environmental efficiency can go hand in hand.

Conclusion and future directions

As this Research Topic has demonstrated, protecting the marine environment requires a multidimensional approach that integrates scientific advancements, regulatory frameworks, and governance innovations. Several contributions have highlighted that while technology-driven solutions—such as carbon capture for shipping emissions, legal mechanisms for blue carbon conservation, and stricter Arctic shipping regulations—hold great promise, their effectiveness depends on robust policy implementation and international cooperation.

One recurring theme in this Research Topic is the urgent need to enhance legal and institutional mechanisms to ensure that technological progress aligns with sustainability goals. For instance, studies on international fisheries law emphasize that while Sustainable Development Goal 14 (SDG 14) provides a framework for fisheries governance, developing nations face significant hurdles in implementing these principles due to institutional fragmentation and a lack of enforcement capacity. Similarly, research on marine protected areas (MPAs) suggests that, beyond their ecological benefits, they can serve as tools for environmental justice by promoting equitable access to ocean resources and distributing conservation benefits more fairly among communities.

Another key insight from this Research Topic is the increasing role of climate litigation and legal accountability in shaping marine governance. The comparative analysis of *Daniel Billy* et al. *v. Australia* and the COSIS advisory opinion illustrates how international courts are expanding the interpretation of due diligence obligations to address climate-related harms to marine environments. Such legal developments underscore the growing recognition that states must take proactive measures to mitigate climate change impacts, or they risk legal liability.

Beyond governance, the Research Topic also explores emerging risks and the need for stronger safeguards. A systematic review of

thermal and cold discharges from power plants demonstrates how industrial pollution continues to degrade marine ecosystems, urging more stringent environmental impact assessments and mitigation strategies. Additionally, the regulation of unmanned aircraft systems (UAS) in Antarctica reflects broader challenges in governing new maritime technologies, highlighting the necessity for comprehensive and internationally coordinated regulatory frameworks.

Looking ahead, it is clear that marine environmental protection must evolve to keep pace with technological advancements and climate challenges. Strengthening legal frameworks, improving enforcement mechanisms, and enhancing cooperation between states, industries, and scientific communities will be critical in achieving sustainable ocean governance. More research is needed on cross-sectoral strategies that integrate marine conservation, climate mitigation, and economic development to ensure that the oceans remain a viable resource for future generations.

This Research Topic serves as a valuable platform for advancing knowledge and fostering dialogue among policymakers, researchers, and practitioners. As the global community continues to confront the mounting pressures on marine ecosystems, collaborative and interdisciplinary approaches will be essential for achieving meaningful progress.

Author contributions

MK: Conceptualization, Writing – original draft, Formal Analysis, Writing – review & editing, Investigation. Y-CC: Writing – review & editing, Supervision.

Acknowledgments

We extend our gratitude to the authors, reviewers, and editorial team for their invaluable contributions to this Research Topic.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that Generative AI was used in the creation of this manuscript. The authors verify and take full responsibility for generative AI in preparing this manuscript, it is used solely to refine the sentence structure, etc. However, the authors critically reviewed, edited and validated it.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Chang, Y., Javid, M., and Khan, M. I. (2024). BBNJ agreement in the purview of developing countries: A case study of Pakistan. *Mar. Policy* 165, 106201. doi: 10.1016/j.marpol.2024.106201

Khan, M. I., and Chang, Y. (2021). Love for the climate in Sino – Pakistan economic romance: a perspective of environmental laws. *Clean Technol. Environ. Policy* 23, 387–399. doi: 10.1007/s10098-020-01938-4

Khan, M. I., Chang, Y., and Liu, W.-H. (2024a). Advances in marine environmental protection: challenges, solutions and perspectives. *Front. Mar. Sci.*

Khan, M. I., Dong, B., He, Q., and Liu, M. (2024b). Navigating the waves of change — Assessing the evolving landscape of China ' s revised marine environmental protection law. *Mar. Policy* 169, 106371. doi: 10.1016/j.marpol.2024.106371

Khan, M. I., and Xu, Q. (2021). An assessment of environmental policy implications under the China-Pakistan economic corridor: A perspective of environmental laws and sustainable development. *Sustainability (Switzerland)* 13, 1–17. doi: 10.3390/su132011223

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 04 September 2023
DOI 10.3389/fmars.2023.1268175

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
Dalian Maritime University, China

REVIEWED BY
Faiza Choudhry,
University of Sialkot, Pakistan
Muneeba Javid,
Dalian Maritime University, China

*CORRESPONDENCE
Liang Yu
yu_liang@tju.edu.cn

RECEIVED 01 August 2023
ACCEPTED 21 August 2023
PUBLISHED 04 September 2023

CITATION
Yu L and Xu W (2023) The extraterritorial human rights obligations of Japan in regard to Fukushima nuclear contaminated water.
Front. Mar. Sci. 10:1268175.
doi: 10.3389/fmars.2023.1268175

COPYRIGHT
© 2023 Yu and Xu. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

The extraterritorial human rights obligations of Japan in regard to Fukushima nuclear contaminated water

Liang Yu* and Weizhuo Xu

Law School, Tianjin University, Tianjin, China

This article adopts a human rights approach to observe Japan's policy on releasing nuclear contaminated water into the Pacific Ocean. It aims to provide a new discourse for stakeholders to push Japan to deal with Fukushima's water in a responsible way. In doing so, it needs to elucidate an important normative question, namely whether a State has extraterritorial human rights obligations, given that international human rights law was traditionally perceived to deal with relationship between a State and its population. This stereotype would frustrate the world people to challenge the Japan's decision based on human rights. In the era of economic globalization, however, there is an increasing need for the extraterritorial application of human rights treaties. Human rights theory and practice have gradually developed the jurisprudence on extraterritorial obligations of States based on an interpretation of jurisdiction. Such an approach has expanded from regulating State overseas military actions to tackling trans-boundary environmental harms. In the latter sense, the Fukushima incident is a good case, which urgently calls for a comprehensive examination of Japan's extraterritorial human rights obligations. This article undertakes such a task by providing a logical interpretation of human rights treaty provisions. It is argued that the release of nuclear contaminated water entails a variety of extraterritorial obligations to respect, protect, and fulfill human rights on the part of Japan.

KEYWORDS

Japan, FUKUSHIMA, nuclear contaminated water, human rights, extraterritorial obligation, marine environment

1 Introduction

On 13 April 2021, the Government of Japan issued its policy on handling of the treated water from "Advanced Liquid Processing System" (ALPS) at the Tokyo Electric Power Company Holdings' Fukushima Daiichi Nuclear Power Station (The Inter-Ministerial Council for Contaminated Water, Treated Water and Decommissioning Issues, 2021). Such a policy indicates that Japan has approved a direct releasing of Fukushima's

contaminated water, which was the byproduct of the 2011 devastating earthquake and its aftermath, into the Pacific Ocean over years. Although the Japanese government repeatedly proclaimed the water under discussion has been processed to safe levels, a couple of States and a large number of stakeholders have protested Japan's decision (Xu and Wilson, 2023; Yamaguchi, 2023). It has been reported that the ALPS process can deal with most radionuclides but it cannot remove radioactive carbon-14 and tritium (Nogrady, 2023). In order to respond to international pressure and reputational damage, the Japanese government seems to have taken a couple of preparatory actions before formally implementing its policy, including getting support from the International Atomic Energy Agency (IAEA) which considered the Japan's decision to be consistent with IAEA Safety Standards (IAEA, 2023). These measures including the IAEA's report, however, do not smooth the worry and anger from neighbouring States especially South Korea and China (Global Times, 2023). China has claimed that the water to be released by Japan is nuclear-contaminated water which is totally different from the water released from normally functioning nuclear power plants (Xinhua, 2023). The continuous controversy over Fukushima's water has successfully raised academic attention, and it calls for not only scientific but also legal response.

The release of Fukushima's water is primarily an international law issue, as the scope of its potential influence is not only within the Japanese territory but also regional and even global through ocean currents and food chain. In this regard, previous research has mainly adopted a State-centered approach, namely exploring State obligations vis-a-vis another State under general international law and international law of sea. For example, some scholars have argued that Japan should "take all necessary measures to prevent the potentially harmful consequences and cooperate with the States likely to be affected" (Wang and Li, 2022; Li et al., 2023). Some have explored State responsibility that Japan might incur due to the discharge of nuclear-contaminated water (Chang et al., 2022; Liu and Hoskin, 2023) and relevant international dispute settlement mechanisms to invoke Japan's responsibility, including seeking an advisory opinion from international tribunals (Chen and Xu, 2022). These research has contributed a lot to the international governance of transnational harms in the context of nuclear accidents. But only State-centered approach is not enough, given that State's willingness to invoke the responsibility of another State sometimes depends on diplomatic considerations. In fact, in the Fukushima incident, many western States, most of whom are Japan's allies and who are probably less influenced by water release, have been silent on Japan's discharge plan (Moretti, 2021; China Daily, 2023). This may substantially reduce the chance of challenging the legality of Japan's discharge before an international tribunal such as the International Court of Justice (ICJ) and an arbitral tribunal established in accordance with Annex VII of United Nations Convention on the Law of the Sea. In this sense, there probably exists a gap between State obligations, such as the duty of cooperation and due diligence, derived from the State-centered approach and their real invocation in international judicial practice.

Another drawback of the State-centered approach is that it is hard to invoke Japan's responsibility of causing trans-boundary harm before a real harm to the environment or human bodies can be proven. At the current stage, Japan has not implemented its releasing plan, although it will soon put the plan into practice (Yeung et al., 2023). It might take time to collect enough evidence of the harm caused by the release of contaminated water. Of course, at this stage, other States can still invoke Japan's responsibility of not discharging some procedural obligations such as exchange of information and prior consultation with stakeholders. But the legal consequences of the breach of these procedural obligations are so feeble that cannot sufficiently deter Japan's releasing.

This article adopts a human rights approach to observe the Fukushima incident, which can complement the prevailing State-centered approach. The advantage of the human rights approach is that it creates State obligations vis-a-vis individuals, in parallel to State obligations vis-a-vis another State which are traditional international law obligations. At this point, individuals might have separate legal interests in the Fukushima incident, which might be different from the stance of his government out of diplomatic considerations. Besides, human rights doctrine and practice have developed a tripartite typology of State obligations, namely "the obligation to respect, to protect and to fulfill" (De Schutter, 2014). The State responsibility in breach of the obligation to protect or to fulfill does not necessarily depend on a real harm caused by the release of water to human bodies. However, the academic research on the Fukushima incident from a human rights perspective is rare. One scholar has analyzed a wide range of rights that could be potentially violated by Japan, including "indigenous peoples' rights", the "right to dignity and culture", the "rights to consultation and free, prior informed consent", and the "right to a safe, clean, healthy and sustainable environment" (Zheng, 2021). However, the aforementioned research is vague on an important normative question: which specific group of persons may claim a right towards Japan? It seems self-evident that the Japanese citizens especially fishermen or people living close to the coast may claim a variety of rights towards Japan in regard to the release of Fukushima's water. But what about foreigners or persons living beyond the Japanese borders? Or to put it another way: what is the scope of Japan's obligations on human rights? These questions are theoretically important because human rights treaties concluded since World War II were originally considered to monitor the relationship between a sovereign State and its own population instead of transnational rights protection (Hathaway, 2011). This article attempts to fill in the above research gap and it adopts an extraterritorial obligation approach, which is an emerging fashion in the area of human rights law, to depict the human rights obligations of Japan in relation to the Fukushima incident. To achieve such a goal, it mainly adopts a treaty interpretation approach rather than a law making approach. To be specific, it provides a reasonable interpretation of the function and meaning of the term 'jurisdiction' or the jurisdiction clause as a whole in human rights law.

2 Human rights treaty provisions

2.1 The elastic definition of rights

There are nine core international human rights treaties, and Japan has joined eight of them, nearly all with the exception of the International Convention on the Protection of the Rights of All Migrant Workers and Members of Their Families (ICMW). At this point, almost all the rights that are already or potentially affected by Japan's decision on the release of contaminated water can find their legal basis in a treaty to which Japan is a State party. These rights include but are not limited to the right to life, the right to health, the right to food, the right to work, and the right to enjoy their own culture. Besides concrete rights, the protection of the enjoyment of rights by vulnerable groups such as women, children, and the persons with disability, is also relevant. It should be noted that the contents of most rights are so expandable and adaptable that they can easily respond to the development of the society. For example, "no one shall be arbitrarily deprived of his life" is the textual expression of the right to life under the International Covenant on Civil and Political Rights (ICCPR) (United Nations, 1983). The literal meaning and the context of the sentence do not indicate the relevance of such a right to environmental damage. However, the Human Rights Committee, which is the monitoring body of the ICCPR, has established a link between the right to life and the environment. It has stated that: "Implementation of the obligation to respect and ensure the right to life … depends, inter alia, on measures taken by States parties to preserve the environment and protect it against harm, pollution and climate change caused by public and private actors" (Human Rights Committee, 2019, para.64.). This example is not an isolated case in the domain of human rights law, and other rights can also be interpreted to adapt to the change of the world. It is implied that the normative content of a concrete right is not a big problem in the context of the Fukushima incident. In fact, UN human rights experts have already established a link between the release of nuclear contaminated water and many affected human rights (United Nations, 2021).

It should be noted that the current human rights law is established on the basis of anthropocentrism. Under human rights treaties, nature or the environmental system is not a right-holder, and there is not an environmental right in human rights treaties either. However, recent posthuman feminist theory has criticized the dualisms of culture/nature, and human/non-human, as well as the presumption that the human and the culture prevail over the nature and other species (Fox and Alldred, 2020). This has urged lawyers to take the nature seriously and simultaneously called for a legal reform for the benefit of the environment. It is also argued that the posthumanist thinking could be addressed in the current human rights system by acknowledging an environment-related right for the time being (Neimanis, 2014). As a response, in 2022, the UN General Assembly adopted a resolution affirming the human "right to a clean, healthy, and sustainable environment" (United Nations General Assembly, 2022). Given the authority of the resolution and continuous academic elaboration of such a right, the right to the environment is becoming an emerging human right which is relevant for the Fukushima case. Such a trend would further push the world people to closely scrutinize, instead of being a bystander, the Japan's move in regard to nuclear contaminated water.

2.2 The precondition of the application of human rights treaties

A tough but often neglected question is the precondition of applying a human rights treaty, or the scope of State obligations as far as the Fukushima incident is concerned. People often hold that everyone enjoys human rights simply because he is a human being. Nevertheless, could everyone assert any right against any State in the world consisting of nearly 200 States? As regard to the Fukushima incident, one may wonder if individuals living in China or Mongolia could assert the right to health, the right to food or whatever right against Japan.

International human rights law is a branch of international law, but it is quite maverick in that most human rights treaties were drafted to supervise how a State treats its own nationals, which is a domestic affair in essence, rather than individuals living in another State. For example, Article 2 of the ICCPR provides that: "Each State Party to the present Covenant undertakes to respect and to ensure to all individuals within its territory and subject to its jurisdiction the rights recognized in the present Covenant" (United Nations, 1983). The Convention on the Rights of the Child (CRC) adopts a less demanding criterion which only refers to "each child within their jurisdiction". The International Convention on the Elimination of All Forms of Racial Discrimination (ICERD), the ICMW, and some regional human rights treaties such as the European Convention on Human Rights (ECHR) and the American Convention on Human Rights (ACHR) contain more or less similar expressions limiting the range of general obligations on human rights. Although several treaties such as the International Covenant on Economic, Social and Cultural Rights (ICESCR) and the Convention on the Elimination of All Forms of Discrimination against Women (CEDAW) do not contain such a limitation, human rights treaties as a whole were traditionally perceived as "regulating the vertical relationship between individuals and their rulers" (Heupel, 2018, p.522). International human rights law, despite containing a word "international", did not necessarily entail "transnational obligations" which are the main course of most international treaties (Skogly and Gibney, 2002). At first sight, the semantic meanings of the above mentioned terms make it difficult for an individual living in China or Mongolia to assert a right against Japan unless he is deemed within the jurisdiction of Japan. But an affirmation of jurisdiction has perplexed a multitude of lawyers and practitioners including judges from the European Court of Human Rights (ECtHR) (Altiparmak, 2004).

The aforementioned phenomenon has aroused academic interests in the extraterritorial application of human rights treaties since 1990s (Meron, 1995). As an active response to economic globalization, in the process of which "the exercise of State power is increasingly having effects on individuals in the

territory of another State" (Yu, 2017), scholars have contended that human rights law can be applied to situations beyond national borders (Gondek, 2009; Coomans, 2011; Wilde, 2013). Since then, human rights academia and practice have mutually promoted the extraterritorial obligation approach of human rights. Although the view that extraterritorial obligations form an integral part of a State's human rights obligations is fairly widespread today (Heupel, 2018), a few States represented by United States and Israel still strongly resist such an approach. For example, Israel has stated in its periodic report to the Committee on Economic, Social and Cultural Rights (CESCR) that "it is Israel's position that the Covenant is not applicable beyond a State's national territory" (Israel, 2019, para.8). What about Japan? No evidence shows Japan has made an explicit statement on its stance concerning the extraterritorial application of human rights treaties. Nor was such an issue raised to Japan during the State reporting procedures of human rights treaty bodies, although many States including Japan's neighboring State China have faced such a problem in monitoring process. In this sense, the issue of the extraterritorial application of human rights treaties not only has academic values but also implies practical significance for Japan's human rights practice. The Fukushima incident provides a good opportunity to review Japan's extraterritorial human rights obligations, and it has potential to develop the extraterritorial obligation approach because its peculiar scenario (marine pollution) is different from most-discussed cases such as occupation and overseas military actions as far as the topic is concerned.

3 The jurisprudence concerning extraterritorial human rights obligations

This section induces the jurisprudence on extraterritorial human rights obligations that is tailored for the Fukushima case through a conceptual analysis of legal terms and by reviewing legal doctrine and the case law of regional human rights courts, human rights treaty bodies, and the ICJ.

3.1 Jurisdiction as a benchmark for extraterritorial obligations

The first question concerns the benchmark for extraterritorial obligations. As is already noted, some treaties such as the CRC and the ECHR adopt a simple term "jurisdiction" as the precondition for application of the treaty. This at least makes the extraterritorial application possible, still difficult though, by finding situations in which a person is beyond a national border but within the jurisdiction of the State. Unlike the CRC and the ECHR, however, a double requirement can be found in Article 2(1) of the ICCPR, respectively "within its territory" and "subject to its jurisdiction" (United Nations, 1983). The extraterritorial application of the ICCPR is seemingly impossible if one is loyal to the semantic meaning which in any case requires a person claiming a right to be within the territory of a State. In fact, a very few States, such as United States, insist on a conjunctive interpreting approach and assert that a State only has obligations towards individuals within its territory and at the same time subject to its jurisdiction (Human Rights Committee, 2006). By contrast, the Human Rights Committee has interpreted Article 2(1) in a disjunctive way that a State has obligations to the individuals within its territory and to the individuals subject to its jurisdiction. (Human Rights Committee, 2004). The ICJ has also adopted "jurisdiction" in a broad sense in place of "territory" criterion. It has stated in the *Wall Advisory Opinion* that: "The International Covenant on Civil and Political Rights is applicable in respect of acts done by a State in the exercise of its jurisdiction outside its own territory" (International Court of Justice, 2004).

The conjunctive interpretation caters to literal meaning, but it may lead to an absurd result that "encourages a State to perpetrate human rights violations on the territory of another State, which it could not perpetrate on its own territory" (Yu, 2017). By contrast, the "disjunctive interpretation has in fact interpreted the term 'and' in the territory and jurisdiction clause as meaning 'or'"(Yu, 2017). Its purpose is to avoid the absurd result that would come according to the conjunctive approach pursued by the United States. The disjunctive interpretation has prevailed in subsequent human rights law practice, and a consensus can be reached among scholars that "jurisdiction" instead of "territory and jurisdiction" serves as the precondition of extraterritorial obligations. In this regard, it is interesting to point out that, some Japanese scholars have also analyzed the extraterritorial reach of human rights treaties by interpreting "jurisdiction" (Yoko, 2015; Toriyabe, 2020).

It should be noted that a few human rights treaties, for example the ICESCR and the CEDAW, do not contain a jurisdictional clause or any other limitation on the scope of application at all. A question arises as to whether the notion of jurisdiction is relevant for the scope of obligations arising out of these treaties. Or to ask in a broad way: Is the extraterritorial application of the ICESCR or the CEDAW self-evident? Or is a State obliged to respect, protect and fulfill the rights of everyone in the world? The answer is probably no, simply because it is hard to expect the United States to provide food, education, health for people living in North Korea. It seems reasonable to require a certain link between a right holder (individual) or the situation in which a right is at stake and the duty bearer (State) guaranteeing the enjoyment of the right. On this basis, the concept of jurisdiction was recalled in analyzing the extraterritorial scope of the ICESCR. Most tribunals have treated human rights treaties without a jurisdictional clause as if they had such a criterion, although the formulas used by different tribunals are slightly different. For example, the Inter-American Commission on Human Rights has affirmed the extraterritorial application of the American Declaration of the Rights and Duties of Man, which lacks a jurisdictional clause, by reading into it a concept of jurisdiction (Inter-American Commission on Human Rights, 1999). The jurisprudence of the ICJ has not distinguished between human rights treaties with a jurisdictional clause and those without such a clause. Recalling the jurisprudence in *Wall Advisory Opinion*, the ICJ has stated in *Armed Activities on the Territory of the Congo* that: "international human rights instruments are applicable in respect of

acts done by a State in the exercise of its jurisdiction outside its own territory, particularly in occupied territories" (International Court of Justice, 2005). The CESCR has adopted the criterion of jurisdiction over a private perpetrator or activities to analyze the extraterritorial obligations to protect human rights (Committee on Economic, Social and Cultural Rights, 2002). It seems to become a mainstream fashion to acknowledge the relevance of jurisdiction to the extraterritorial scope of all human rights treaties, with or without a jurisdictional clause.

3.2 The understanding of jurisdiction in case law and legal doctrine

The second question concerns the assessment of jurisdiction in specific circumstances. It should be noted, first of all, that the treaty term, namely "individuals within their jurisdiction", is used in a way that may easily cause a dilemma, because it seems to indicate an abstract judgment of whether a person is within the jurisdiction of a State irrespective of which specific human rights obligation is invoked by an individual. In this aspect, if the benchmark for extraterritorial jurisdiction is too high, claiming a right in an extraterritorial case would be impossible. If the benchmark is too low, a State would incur unforeseeable or unaffordable obligations. The ECtHR struggled to deal with such a problem in several cases concerning overseas military actions taken by its contracting parties. It failed to advance a coherent definition of jurisdiction, but envisaged extraterritorial jurisdiction on an exceptional basis. According to the ECtHR, a State's jurisdiction is primarily territorial, but there are a number of exceptional circumstances capable of giving rise to an exercise of jurisdiction by a State outside its own territorial boundaries, including "effective control over an area" and "control over individuals" (European Court of Human Rights, 1996; European Court of Human Rights, 2011). Although the ECtHR case law has raised global attention to extraterritorial application of human rights treaties, its jurisprudence has been criticized to be myopic in that it overlooked some important circumstances where the extraterritorial aspects of human rights are imperative (Gondek, 2005). The circumstances overlooked or undiscussed by the ECtHR jurisprudence include, inter alia, transnational investments (whether a home State of business owes obligations to individuals in a host State) and trans-boundary pollution (whether the State of origin owes obligations to individuals abroad). The ECtHR's criteria, either "effective control over an area" or "control over individuals" (European Court of Human Rights, 1996; European Court of Human Rights, 2011), cannot respond to these circumstances.

The unsatisfactory formulation of the ECtHR is rooted in an abstract understanding of jurisdiction. If one sticks to understanding jurisdiction in an abstract way, he or she will probably think that jurisdiction is an "all-or-nothing" matter and that at some point a person can only be within the jurisdiction of one State (Besson, 2012). In today's reality, however, it is common that a person is under the authority of several States at the same time. For example, a person residing abroad usually needs to pay taxes to both the State of nationality and the State where he lives. Now more and more scholars tend to understand jurisdiction in a purpose-driven approach, namely looking for the link between a State and a situation in which a right is at stake. In this regard, the Maastricht Principles represent the academic consensus to date, which define jurisdiction as one of the followings: "situations over which it exercises authority or effective control, whether or not such control is exercised in accordance with international law; situations over which State acts or omissions bring about foreseeable effects on the enjoyment of economic, social and cultural rights, whether within or outside its territory; situations in which the State, acting separately or jointly, whether through its executive, legislative or judicial branches, is in a position to exercise decisive influence or to take measures to realize economic, social and cultural rights extraterritorially, in accordance with international law" (ETO Consortium, 2013). The Maastricht Principles have in fact turned the inquiry of jurisdiction over individuals claiming a right into the inquiry of jurisdiction over a situation or event in which a right needs to be protected. (Shaack, 2014). This approach has been adopted by the CESCR to deal with "business and human rights" issues, for which an influential document called UN Guiding Principles on Business and Human Rights refused to admit the extraterritorial obligations of a home State of transnational corporations (United Nations, 2011). The CESCR has stated that: "Extraterritorial obligations arise when a State party may influence situations located outside its territory, consistent with the limits imposed by international law, by controlling the activities of corporations domiciled in its territory and/or under its jurisdiction, and thus may contribute to the effective enjoyment of economic, social and cultural rights outside its national territory" (Committee on Economic, Social and Cultural Rights, 2017). The CESCR has substantiated the obligations of a home State by concentrating on State's jurisdiction over situations rather than probing State's jurisdiction over individuals in a host State in an abstract way.

The Inter-American Court of Human Rights (IACHR) has adopted a literally different but substantially equivalent approach to deal with trans-boundary environmental damages. Its basic instrument (America Convention on Human Rights) provides that State parties "undertake to respect the rights and freedoms recognized herein and to ensure to all persons subject to their jurisdiction the free and full exercise of those rights and freedoms". In its advisory opinion on State obligations in relation to the environment, the IACHR indicated at the outset that "the State obligation to respect and to ensure human rights applies to every person who is within the State's territory or who is in any way subject to its authority, responsibility or control" (Inter-American Court of Human Rights, 2017). But the court did not probe State jurisdiction over individual right-holders in an abstract way. Instead, when it comes to trans-boundary damage, the IACHR has stated that: "the exercise of jurisdiction by a State of origin is based on the understanding that it is the State in whose territory or under whose jurisdiction the activities were carried out that has the effective control over them and is in a position to prevent them from causing transboundary harm that impacts the enjoyment of human rights of persons outside its territory. The potential victims of the negative consequences of such activities are under the jurisdiction

of the State of origin for the purposes of the possible responsibility of that State for failing to comply with its obligation to prevent transboundary damage" (Inter-American Court of Human Rights, 2017). The IACHR's jurisprudence indicates that State jurisdiction over a perpetrator or activities in a specific context is tantamount to State jurisdiction over potential victims of such activities. This is essentially the same with the Maastricht Principles.

The IACHR's jurisprudence has paved the way for the application of the extraterritorial obligations approach to the field of trans-boundary environmental damages, to which the release of nuclear contaminated water belongs. Trans-boundary environmental harm is believed to be a new scenario for extraterritorial human rights obligations (Raible, 2023). It is interesting to note that a Japanese scholar has also analyzed the extraterritorial obligations concerning environmental damage on the basis of the IACHR's jurisprudence (Toriyabe, 2020). Based on recently doctrinal and practical developments, it can be summarized that the State of origin of trans-boundary pollution has a series of extraterritorial obligations in relation to the prevention and remedy of the trans-boundary damages. Generally, this conclusion is applicable to the Fukushima incident and therefore justifies the existence of extraterritorial obligations on the part of Japan. But the Fukushima incident has something unique in that the Japanese government has asserted that the water to be released is safe and even drinkable. Does this affect the justification of Japan's extraterritorial obligations? Here, a distinction needs to be made between the existence of extraterritorial obligations and the breach of extraterritorial obligations. In the context of trans-boundary environmental damages, a reasonable doubt of risks to the environment or human bodies is sufficient to give rise to a wide range of extraterritorial obligations for the State which has the overall control of the events causing the risks. If it finally turns out to be no harm, it just indicates that the State of origin has not breached its extraterritorial obligation to respect the right to health or environment by permitting the implementation of relevant activities. However, that is just one of the many extraterritorial obligations arising out of a whole event. It can be concluded that the facts that the Japanese government knows or ought to know the risks of the release of Fukushima's water and that it has approved the releasing plan has formed jurisdiction over the whole releasing event, and therefore Japan has extraterritorial obligations to respect, to protect, and to fulfill relevant human rights during the whole process including prior to, during, and in the aftermath of the formal release.

3.3 The enumeration of Japan's extraterritorial obligations in the Fukushima case

Although the main task of this article is not to investigate how Japan violates specific rights by releasing nuclear contaminated water into ocean, it might be interesting to at least enumerate some important obligations that Japan bears due to extraterritorial application of human rights treaties to the Fukushima case. To understand State obligations, it is useful to adopt the tripartite typology as an analytical tool. The notion of tripartite typology is that every human right entails three different types of State obligations: the obligation to respect, to protect and to fulfill. "The obligation to respect requires States to refrain from interfering with the enjoyment of human rights. The obligation to protect requires States to prevent violations of human rights by third parties. The obligation to fulfill requires States to take appropriate legislative, administrative, budgetary, judicial, and other measures towards the full realization of human rights" (Flinterman, 1997). There are a multitude of human rights and corresponding State obligations. It is impractical to envisage all of them before they are actually invoked in combination with factual details. The following paragraph just mentions some, and perhaps they are just a tip of the iceberg.

First of all, Japan has extraterritorial obligations to respect the right to life, the right to health, and the right to the environment. These obligations require Japan to refrain from causing harm to marine environment as well as human beings through the actions or omissions of its agency or the organization it controls. The Tokyo Electric Power Company was a private company at first, but after the 2011 earthquake it was nationalized by the Japanese government. Now Japan has controlling shares in the company (Tokyo Electric Power Company Holdings, 2023). In human rights practice, there is a trend to attribute the behaviors of a State-owned company to the State which has the majority ownership over the company (European Court of Human Rights, 2012; European Court of Human Rights, 2015). Therefore, Japan is obliged to conduct a scientific assessment before releasing the water into ocean by its State-owned company. If the future releasing proves to be harmful, the Japanese government should bear the responsibility of breaching the obligations to respect the right to life, health or the environment. Secondly, Japan has extraterritorial obligations to protect the right to life, the right to health, and the right to the environment. These obligations require Japan to keep monitoring the marine environment that is likely to be affected, separately and in cooperation with other States, during and after its releasing activities. Japan should stop further releasing once any harmful result is detected. Japan should also ensure adequate compensation available to any potential victim. Thirdly, Japan has extraterritorial obligations to respect, protect, fulfill the right to food and other adequate standard of living. These obligations indicate that Japan should refrain from poisoning global seafood. Japan should also tolerate the importing banning policy against Japanese seafood for the purpose of food safety made by other States, and refrain from challenging such a policy in front of the WTO regime. Japan is also expected to make a reparation to fishermen who traditionally make a living in polluted ocean areas for their loss of income due to consumer's worry about seafood safety. It should be noted that the existence of a multitude of extraterritorial obligations

on Japan does not necessarily indicate that Japan has already breached these obligations and that Japan should bear responsibility for the breach of its obligations. Japan may raise several reasons to defend its releasing policy. For example, Japan might argue that it has no other choice to deal with contaminated water; it may also argue that the whole world should provide assistance to Japan and should tolerate Japan's choice for the existence of the nation. However, in any case, Japan should discharge its extraterritorial obligations in good faith, especially by disclosing accurate information, providing scientific evidence, negotiating with other States, and monitoring potential risks in the whole process.

4 Implementation

Now that Japan's extraterritorial obligations have been proven, the next question to be discussed is how to implement these obligations. Usually, individuals care about their own rights and are therefore willing to defend their rights through international or domestic human rights regimes, irrespective of whether their State of origin is willing or not to invoke the responsibility of a perpetrating State. First of all, Japanese domestic courts cannot be counted on. Some research by Japanese scholars shows that Japanese judiciary is not active in enforcing constitutional rights or applying human rights treaties to provide effective remedies to the alleged victims of human rights violations (Yakushiji, 2003; Kuramochi, 2015). Secondly, Japan has not accepted any individual complaint procedure of treaty bodies (United Nations Treaty Body Database, 2023). Thirdly, although Japan is bound by interstate communication procedure of the Committee on Enforced Disappearances and the Committee on the Elimination of Racial Discrimination (United Nations Treaty Body Database, 2023), the treaties monitored by these committees have little relevance to the release of contaminated water.

By process of elimination, State reporting procedures of treaty bodies and the universal periodic review (UPR) procedure of the UN Human Rights Council seem to be possible channels to implement the extraterritorial obligations of Japan. Generally speaking, human rights treaty bodies have been active in pushing the extraterritorial application of human rights treaties, but they have not mentioned extraterritorial obligations in their concluding observations concerning Japan. However, the monitoring gap was filled by the UPR procedure. In the fourth circle of the UPR, Japan's human rights performance was reviewed. In this recent round of review, some States have expressed concerns about Japan's releasing plan, for example China and The Marshall Islands (United Nations Human Rights Council, 2023). Some States have made specific recommendations to Japan. For instance, Samoa has suggested Japan "intensify research, investment and utilization of alternative discharge and storage methods of nuclear waste that minimize harm to human health and environmental damage" (United Nations Human Rights Council, 2023). Timor-Leste has suggested Japan "consider delaying any decision on the dumping of nuclear wastewater for the reactor of Fukushima Daiichi until after proper international consultation has been conducted" (United Nations Human Rights Council, 2023). Vanuatu has stated that: "Do not discharge/dump from Fukushima any nuclear contaminated wastewater and waste from Fukushima nuclear power plant into the Pacific Ocean without providing further satisfactory scientific evidence of the safety of any discharged contaminated waste and materials" (United Nations Human Rights Council, 2023). These recommendations have substantially touched Japan's extraterritorial obligations in relation to the Fukushima incident and the UN Human Rights Council provides a good opportunity to challenge Japan's releasing plan from the perspective of human rights. The interplay between Japan and other States in the process of the UPR may accumulate the evidence of subsequent practice, which is an authentic means of interpretation according to the Vienna Convention on the Law of Treaties and which may take a variety of forms (International Law Commission, 2018), on extraterritorial application of human rights treaties. It is submitted that human rights treaty bodies are also expected in the future to monitor Japan's extraterritorial obligations concerning the release of nuclear contaminated water in their State reporting procedures. In addition to challenging the human rights obligations of the Japanese government, potential victims or environmentalists may also litigate the Tokyo Electric Power Company before a Japanese court by recourse to the fashionable discourse of business and human rights (United Nations, 2011). The corporate human rights duties are beyond the topic of the current article. However, what is relevant for the current topic is that Japan is obliged to guarantee a fair and impartial judicial system for non-residents due to its extraterritorial obligations in the Fukushima incident.

5 Conclusion

The release of nuclear contaminated water by Japan is not only an international environmental law issue, but also an important human rights topic. In the Fukushima incident, the Japanese government owes a variety of human rights obligations to its own population and more importantly to people living abroad according to the human rights treaties to which Japan is a State party. The Fukushima incident urgently calls for a comprehensive examination of Japan's extraterritorial human rights obligations, and it indicates that trans-boundary environmental harm is an emerging scenario of extraterritorial application of human rights treaties. The findings of this article may also lend support to the governance of other

environmental issues such as plastic pollution, deep-ocean mining, and climate change, in the process of which the extraterritorial obligations are concerned. In a world of more interaction and interdependence, one may envisage more and more occasions of extraterritorial application of human rights treaties, which will change the stereotype that human rights law was only about how a State treated its population. In this regard, we may expect that international human rights law would become real international law.

Author contributions

LY: Conceptualization, Writing – original draft, Main Arguments, WX: Data curation, Literature review, Investigation.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Altiparmak, K. (2004). "Bankovic": an obstacle to the application of the European convention on human rights in Iraq? *J. Conflict Secur. Law.* 9, 213–251. doi: 10.1093/jcsl/9.2.213

Besson, S. (2012). The extraterritoriality of the European Convention on Human Rights: why human rights depend on jurisdiction and what jurisdiction amounts to. *Leiden J. Int. Law.* 25, 857–884. doi: 10.1017/S0922156512000489

Chang, Y., Zhao, X., and Han, Y. (2022). Responsibility under international law to prevent marine pollution from radioactive waste. Ocean Coast. Management. 227, 106294. doi: 10.1016/j.ocecoaman.2022.106294

Chen, X., and Xu, Q. (2022). Reflections on international dispute settlement mechanisms for the Fukushima contaminated water discharge. Ocean Coast. Management. 226, 106278. doi: 10.1016/j.ocecoaman.2022.106278

China Daily (2023) Some countries' silence on Japan's discharge plan raises eyebrows. Available at: https://www.Chinadaily.com.cn/a/202307/12/WS64add7dfa31035260b815d48.html (Accessed July 12, 2023).

Committee on Economic, Social and Cultural Rights (2002). General comment No. 15: The right to water. (Geneva).

Committee on Economic, Social and Cultural Rights (2017). General comment No. 24 (2017) on State obligations under the International Covenant on Economic, Social and Cultural Rights in the context of business activities. (Geneva).

Coomans, F. (2011). The extraterritorial scope of the International Covenant on Economic, Social and Cultural Rights in the work of the united nations committee on economic, social and cultural rights. Hum. Rights Law Review. 11, 1–35. doi: 10.1093/hrlr/ngq055

De Schutter, O. (2014). International human rights law: cases, materials, commentary (Cambridge: Cambridge University Press).

ETO Consortium (2013) Maastricht principles on extraterritorial obligations of states in the area of economic, social and cultural rights. Available at: https://www.etoconsortium.org/wp-content/uploads/2023/01/EN_MaastrichtPrinciplesETOs.pdf (Accessed July 12, 2023).

European Court of Human Rights (1996). Loizidou v. Turkey. Chamber, judgment of 18 december 1996.

European Court of Human Rights (2011). Al-skeini and others v. the United Kingdom. Grand chamber, judgment of 7 july 2011.

European Court of Human Rights (2012). Ališić and others v. Bosnia and herzegovina, Croatia, Serbia, Slovenia and the former yugoslav republic of macedonia. Judgment of 6 november 2012.

European Court of Human Rights (2015). Ljubljanska banka d.d. v. Croatia. The press release of 4 June 2015.

Flinterman, C. (1997). Appendix II: The Maastricht guidelines on violations of economic, social and cultural rights. *Netherlands Q. Hum. Rights.* 15, 244–252. doi: 10.1177/092405199701500211

Fox, N., and Alldred, P. (2020). Sustainability, feminist posthumanism and the unusual capacities of (post) humans. *Environ. Sociology.* 6, 121–131. doi: 10.1080/23251042.2019.1704480

Global Times (2023) China expresses 'regret' over IAEA safety report clearing Japan's nuclear-contaminated wastewater discharge plan. Available at: https://www.globaltimes.cn/page/202307/1293736.shtml (Accessed July 12, 2023).

Gondek, M. (2005). Extraterritorial application of the European Convention on Human Rights: territorial focus in the age of globalization. Netherlands Int. Law Review. 52, 349–387. doi: 10.1017/S0165070X05003499

Gondek, M. (2009). The reach of human rights in a globalising world: extraterritorial application of human rights treaties (Antwerp: Intersentia).

Hathaway, O. (2011). Human rights abroad: when do human rights treaty obligations apply extraterritorially. Arizona State Law J. 43, 389–426.

Heupel, M. (2018). How do States perceive extraterritorial human rights obligations? Insights from the universal periodic review. Hum. Rights Quarterly. 40, 521–546. doi: 10.1353/hrq.2018.0030

Human Rights Committee (2004). General comment no. 31: the nature of the general legal obligation imposed on states parties to the covenant. (Geneva).

Human Rights Committee (2006). Concluding observations of the human rights committee (United States of America). (Geneva).

Human Rights Committee (2019). General comment No. 36: Article 6: right to life. (Geneva).

IAEA (2023) IAEA comprehensive report on the safety review of the ALPS-treated water at the Fukushima Daiichi nuclear power station. Available at: https://www.iaea.org/sites/default/files/iaea_comprehensive_alps_report.pdf (Accessed July 12, 2023).

Inter-American Commission on Human Rights (1999). Coard et al. v. United States. (Washington, DC).

Inter-American Court of Human Rights (2017). Advisory opinion OC-23/17 of november 15, 2017. (San José, Costa Rica).

International Court of Justice (2004). Legal consequences of the construction of a wall in the occupied palestinian territory. (The Hague).

International Court of Justice (2005). Armed activities on the territory of the congo (Democratic republic of the congo v. Uganda). Judgment of 19 december 2005. (The Hague).

International Law Commission (2018). Subsequent agreements and subsequent practice in relation to the interpretation of treaties. (Geneva).

Israel (2019). Fourth periodic report submitted by Israel under articles 16 and 17 of the Covenant, due in 2016. (Geneva).

Kuramochi, T. (2015). The protection of human rights and the role of constitutional judicial review in Japan. *King's Law J.* 26, 252–265. doi: 10.1080/09615768.2015.1075769

Li, F., Wang, L., and Zhou, X. (2023). Fulfiling the State duty to cooperate on the discharge of Fukushima nuclear contaminated water: Potential pathways. Mar. Policy. 150, 105546. doi: 10.1016/j.marpol.2023.105546

Liu, D., and Hoskin, M. (2023). Contemporary international Law: Regulating the upcoming fukushima radioactive wastewater discharge. Ocean Coast. Management. 234, 106452. doi: 10.1016/j.ocecoaman.2022.106452

Meron, T. (1995). Extraterritoriality of human rights treaties. *Am. Soc. Int. Law.* 89, 78–82. doi: 10.2307/2203895

Moretti, A. (2021) The West's attitude to Japan's nuclear water dumping plan shows double-standard. Available at: http://www.China.org.cn/opinion/2021-04/21/content_77427287.htm (Accessed July 5, 2023).

Neimanis, A. (2014). Alongside the right to water, posthumanist feminist imaginary. J. Hum. Rights Environment. 5, 5–24. doi: 10.4337/jhre.2014.01.01

Nogrady, B. (2023). Is Fukushima wastewater release safe. *What Sci. says. Nature*. 618, 894–895.

Raible, L. (2023) Justifying extraterritorial human rights obligations and climate change as a counterexample. Available at: https://www.ejiltalk.org/justifying-extraterritorial-human-rights-obligations-and-climate-change-as-a-counterexample/ (Accessed July 15, 2023).

Shaack, B. (2014). The United States' position on the extraterritorial application of human rights obligations: now is the time for change. *Int. Law Stud. Series.* 90, 20–65.

Skogly, S., and Gibney, M. (2002). Transnational human rights obligations. Hum. Rights Quarterly. 24, 781–798. doi: 10.1353/hrq.2002.0040

The Inter-Ministerial Council for Contaminated Water, Treated Water and Decommissioning Issues (2021) Basic policy on handling of ALPS treated water at the Tokyo Electric Power Company Holdings' Fukushima Daiichi Nuclear Power Station.. Available at: https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/bp_alps.pdf (Accessed July 12, 2023).

Tokyo Electric Power Company Holdings (2023) Corporate governance report. Available at: https://www.tepco.co.jp/en/hd/about/ir/management/pdf/gover-e.pdf (Accessed July 15, 2023).

Toriyabe J. (2020). The extraterritorial application of the American Convention on Human Rights in the context of environmental damage: a re-examination of the Inter-American court of human rights' advisory opinion on the environment and human rights. Available at: https://cir.nii.ac.jp/crid/1050285299769584768 (Accessed July 6, 2023).

United Nations (1983). *Treaty series*, Vol. 999. 171. (Geneva).

United Nations (2011). Guiding principles on business and human rights: implementing the united nations 'Protect, respect and remedy' Framework. (Geneva).

United Nations (2021) Japan: UN experts say deeply disappointed by decision to discharge Fukushima water. Available at: https://www.ohchr.org/en/press-releases/2021/04/Japan-un-experts-say-deeply-disappointed-decision-discharge-fukushima-water?LangID=E&NewsID=27000 (Accessed July 5, 2023).

United Nations General Assembly (2022). The human right to a clean, healthy and sustainable environment. (Geneva).

United Nations Human Rights Council (2023). Report of the working group on the universal periodic review (Japan). (Geneva).

United Nations Treaty Body Database (2023). Available at: https://tbinternet.ohchr.org/_layouts/15/TreatyBodyExternal/Treaty.aspx?CountryID=87&Lang=EN (Accessed July 5, 2023).

Wang, L., and Li, F. (2022). State duty to cooperate on the Fukushima nuclear contaminated water release. *Mar. Policy*. 136, 104878. doi: 10.1016/j.marpol.2021.104878

Wilde, R. (2013). Human rights beyond borders at the world court: the significance of the international court of justice's jurisprudence on the extraterritorial application of international human rights law treaties. *Chin. J. Int. Law*. 12, 639–677. doi: 10.1093/chinesejil/jmt039

Xinhua, (2023) Japan's nuclear-contaminated water not equal to nuclear power plants discharged water: spokesperson. Available at: http://www.China.org.cn/China/Off_the_Wire/2023-07/11/content_91944853.htm (Accessed July 12, 2023).

Xu, W., and Wilson, K. (2023) Japan urged to halt release of toxic water. Available at: https://global.Chinadaily.com.cn/a/202306/19/WS648f8421a31033ad3f7bce66.html (Accessed July 12, 2023).

Yakushiji, K. (2003). Domestic implementation of human rights conventions and judicial remedies in Japan. Japanese Annu. Int. Law. 46, 1–45.

Yamaguchi, M. (2023) 'Don't nuke the Pacific': activists rally against plan to release radioactive Fukushima plant water in ocean. Available at: https://www.nbclosangeles.com/news/national-international/dont-nuke-the-pacific-activists-rally-against-plan-to-release-radioactive-fukushima-plant-water-in-ocean/3154052/ (Accessed July 5, 2023).

Yeung, J., Maruyama, M., and Jozuka, E. (2023) Japan will soon release Fukushima radioactive water into the ocean. How worried should we be. Available at: https://edition.cnn.com/2023/07/04/asia/Japan-fukushima-wastewater-explainer-intl-hnk/index.html (Accessed July 6, 2023).

Yoko T. (2015). Extraterritorial application of human rights treaties in armed conflicts.. Available at: https://core.ac.uk/download/pdf/71796858.pdf (Accessed July 6, 2023).

Yu, L. (2017) Home state obligations over multinational corporations in human rights treaties: with special attention to state-owned corporations. Available at: https://cris.maastrichtuniversity.nl/en/publications/home-state-obligations-over-multinational-corporations-in-human-r (Accessed July 16, 2023).

Zheng, X. (2021) Does Fukushima wastewater decision violate our environmental rights. Available at: https://www.ejiltalk.org/does-fukushima-wastewater-decision-violate-our-environmental-rights/ (Accessed July 5, 2023).

frontiers | Frontiers in Marine Science

TYPE Review
PUBLISHED 24 October 2023
DOI 10.3389/fmars.2023.1258924

Check for updates

OPEN ACCESS

EDITED BY
Wen-Hong Liu,
National Kaohsiung University of Science and Technology, Taiwan

REVIEWED BY
Zain Bairq,
Hunan University, China
Nadia Khadam,
Fatima Jinnah Women University, Pakistan
Shih-Ming Kao,
National Sun Yat-sen University, Taiwan

*CORRESPONDENCE
Xin Zhang
11833013@zju.edu.cn

†These authors have contributed equally to this work

RECEIVED 14 July 2023
ACCEPTED 02 October 2023
PUBLISHED 24 October 2023

CITATION
Bilawal Khaskheli M, Wang S, Zhang X, Shamsi IH, Shen C, Rasheed S, Ibrahim Z and Baloch DM (2023) Technology advancement and international law in marine policy, challenges, solutions and future prospective.
Front. Mar. Sci. 10:1258924.
doi: 10.3389/fmars.2023.1258924

COPYRIGHT
© 2023 Bilawal Khaskheli, Wang, Zhang, Shamsi, Shen, Rasheed, Ibrahim and Baloch. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Technology advancement and international law in marine policy, challenges, solutions and future prospective

Muhammad Bilawal Khaskheli[1†], Shumin Wang[1†], Xin Zhang[2*], Imran Haider Shamsi[3], Chenghuan Shen[2,4], Sanober Rasheed[5], Zakir Ibrahim[3,6] and Dost Muhammad Baloch[6]

[1]School of Law, Dalian Maritime University, Dalian, China, [2]School of Marxism, Zhejiang University, Hangzhou, China, [3]Zhejiang Key Laboratory of Crop Germplasm, Department of Agronomy, College of Agriculture and Biotechnology, Zhejiang University, Hangzhou, China, [4]Party School of Jiaxing Xiuzhou, District Level Committee of CPC, Zhejiang, China, [5]Department of International Relations, Karachi University, Karachi, Pakistan, [6]Faculty of Agriculture, Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Pakistan

The use of technology and international law in marine policy is becoming increasingly vital as we seek to address the challenges facing our oceans. Technology has revolutionized our ability to monitor, understand, and manage marine ecosystems, providing valuable tools for data collection, analysis, and decision-making. International law, ocean governance ensuring marine environment represented by the frameworks such as the United Nations Convention on the Law of the Sea (UNCLOS), plays a crucial role in governing the use of technology and establishing guidelines for the sustainable management of marine resources. This paper explores the intersection of technology and international law in marine policy, highlighting the transformative impact of technology on our understanding of the oceans and the legal frameworks that shape our approach to marine conservation. It examines the benefits of technology in enabling evidence-based decision-making and fostering international collaboration, while also addressing the legal and regulatory complexities that arise. The paper emphasizes the need for ongoing dialogue and the development of international legal frameworks to adapt to emerging technologies and discourse ethical considerations, and by harnessing the power of technology and international law, we can work towards effective marine policies that ensure the conservation and sustainable use of our oceans for future generations.

KEYWORDS

marine policy, technology, international law, environmental protection, UNCLOS5

1 Introduction

Marine policy plays a crucial role in the sustainable management of the world's oceans, which are vital to the health of our planet and its inhabitants. In recent years, the intersection of technology and international law has emerged as a powerful force in shaping marine policy and addressing the numerous challenges facing our oceans (Baker et al., 2023). The rapid advancement of technology has not only provided new tools and approaches to monitor and understand marine ecosystems but has also posed unique legal and regulatory challenges that require international cooperation. The role of technology in marine policy has been transformative, enabling scientists, policymakers, and conservationists to gather vast amounts of data on marine environments and species. Satellite imagery, remote sensing technologies, and sophisticated underwater monitoring systems have revolutionized our understanding of the oceans and their interconnected ecosystems (Olabi et al., 2023; Subramanian et al., 2023). These technological advancements have facilitated the development of evidence-based policies and management strategies to address issues such as overfishing, habitat destruction, pollution, and climate change (Yu et al., 2023).

Furthermore, technology has fostered international collaboration by enhancing communication and data sharing among nations. Real-time information exchange and collaborative research efforts have become critical in addressing transboundary challenges, such as the conservation of migratory species and the establishment of marine protected areas (Blasiak et al., 2023). Technology has enabled the development of platforms and networks that facilitate dialogue, coordination, and the harmonization of policies and legal frameworks across borders (Quevedo et al., 2023; Sardá et al., 2023). However, the increasing reliance on technology in marine policy also brings forth legal and regulatory complexities. As new technologies emerge, questions arise regarding their ethical use, potential impacts on marine ecosystems, and the need for international governance. Issues such as data ownership, privacy, intellectual property rights, and liability for damages caused by technology-driven activities in the marine environment require careful consideration and international legal frameworks. International law plays a fundamental role in guiding and governing the use of technology in marine policy. Existing legal frameworks, including the United Nations Convention on the Law of the Sea (UNCLOS), provide a basis for cooperation and regulation in areas such as marine pollution, fisheries management, and the protection of marine biodiversity (Olabi et al., 2023). However, as technology evolves, there is a need to adapt and expand these legal frameworks to address emerging challenges. The development of various technologies has significantly impacted marine policy, reshaping regulations and protection efforts. Innovations such as GPS and satellite technology have enabled better tracking and monitoring of fishing vessels, leading to stricter compliance with fishing regulations and curbing illegal fishing practices. Furthermore, sonar and underwater acoustics have revolutionized marine research and exploration, but their potential impact on marine life has prompted the establishment of guidelines to minimize disturbances to marine mammals. Seabed mining technology has raised concerns about environmental damage, necessitating the formulation of new regulations and international agreements to govern deep-sea mining operations responsibly to establish new international agreements and protocols to address the legal and ethical dimensions of technology in marine policy. The regulation of emerging technologies such as deep-sea mining, marine biotechnology, and autonomous vehicles. Additionally, initiatives are being undertaken to strengthen international cooperation and coordination in the use of technologies for monitoring, surveillance, and enforcement in the maritime domain (Guelker, 2023; Pentz and Klenk, 2023).

The role of technology and international law in marine policy is becoming increasingly intertwined and influential. Technology provides valuable tools and data for evidence-based decision-making and promotes international collaboration. However, it also poses legal and regulatory challenges that necessitate ongoing dialogue and the development of international frameworks. By harnessing the power of technology and establishing robust legal mechanisms, striving towards a more effective marine policy that ensures the sustainability and protection of oceans for future generations (Chen et al., 2023). With boundless possibilities, the integration of technology and international law within marine policy stands as a pivotal tool for addressing the ever-evolving challenges of our oceans. However, the successful implementation of technology and international legal frameworks in marine policy is not without obstacles (Moore, 2021). This article explores the key challenges and complexities that arise in the adoption and implementation of technology and international law in marine policy. It examines issues related to data management, legal harmonization, governance gaps, and the need for enhanced international cooperation. The article emphasizes the importance of addressing these challenges to ensure effective and sustainable management of marine resources amidst advancing technology and global environmental threats (Rozwadowski, 2023).

1.2 Impression of the role of technology and international law

Possessing personal impressions or opinions, however, a general assessment of technology and international law in marine policy highlights their undeniable significance and transformative impact on ocean understanding and management. Through satellite technology, remote sensing, and innovative tools like autonomous underwater vehicles (AUVs), monitor ocean conditions, track marine life, and report environmental challenges. This integration of technology and international law establishes frameworks for sustainable ocean management and conservation efforts, facilitating cross-border cooperation (Gullett, 2023).

Technological advancements have provided scientists, policymakers, and conservationists with powerful tools to monitor and study marine ecosystems, leading to more informed decision-making and evidence-based policies. Technologies such as satellite imagery, remote sensing, and underwater monitoring systems have revolutionized data collection and analysis, enabling

us to address pressing issues like overfishing, habitat destruction, pollution, and climate change (Castillo Rodríguez et al., 2023).

Moreover, technology has facilitated international collaboration and cooperation in marine policy. It has bridged geographical barriers, enabling real-time data sharing, communication, and coordination among nations. This increased connectivity and information exchange have been crucial in addressing transboundary challenges and establishing cooperative frameworks for the conservation and sustainable management of marine resources (Stöbener and Gerritsen, 2023). However, the growing reliance on technology in marine policy also raises legal and regulatory complexities. The ever-changing landscape of technology calls for continuous development and adaptation of international legal frameworks to effectively tackle emerging challenges in various domains. that demands particular attention is marine policy, as advancements in technology pointedly impact understanding and management of the Oceans. As new technologies emerge, such as artificial intelligence, big data analytics, and unmanned marine vehicles, there arises a crucial need to ensure that international laws governing marine activities remain relevant. Questions regarding data ownership, privacy, intellectual property rights, and liability for damages caused by technology-driven activities in the marine environment require careful consideration and international cooperation. International law plays a vital role in guiding and governing the use of technology in marine policy. Existing legal frameworks, such as The United Nations Convention on the Law of the Sea (UNCLOS), provide a foundation for cooperation and regulation in various areas related to the oceans. However, there is a need for ongoing efforts to update and expand these frameworks to encompass the rapidly evolving technological landscape and address emerging issues (Kemp et al., 2023a).

The United Nations Convention on the Law of the Sea (UNCLOS) is a significant international agreement that provides legal guidelines for using and protecting the oceans and seas of the world. It was enacted in 1982, and it became effective in 1994. Regarding the exploitation of marine resources, defining maritime boundaries, and protecting the environment, UNCLOS outlines the different rights and obligations of nations (Kwiatkowska, 1995). The continental shelf, exclusive economic zones (EEZs), territorial sea limitations, and freedom of navigation are a few examples. Through learning more about UNCLOS (Rothwell, 1994). The role of international law is not only to provide regulations and guidelines but also to foster collaboration and consensus among nations. The establishment of new international agreements and protocols is essential to address the legal and ethical dimensions of technology in marine policy effectively. Discussions are underway to regulate emerging technologies, develop guidelines for their use, and strengthen international cooperation in monitoring, surveillance, and enforcement in the maritime domain (Bender et al., 2022; Liu et al., 2023). It is evident that technology and international law play a multidimensional role in maritime policy. The development of new technologies has greatly improved the capacity to study and control marine environments. At the same time, international law plays a pivotal role by setting the stage for collaborative efforts toward regulation and governance of marine-related issues. While technology brings immense benefits, it also presents legal and regulatory challenges that require ongoing dialogue and the development of international frameworks. By leveraging technology responsibly and strengthening international cooperation, we can work towards more effective marine policies that ensure the protection and sustainability of our oceans (Hung et al., 2022; Roessger et al., 2022). The remainder of this paper is organized as follows: Section 2 Methods and Materials, Section 3: Literature review, technologies Section 4 discussion and analysis provides findings on improving Role of International Law in Marine Policy, Section 5 offers conclusions, recommendations and future policies for implementation of technology in Marine Policy and law.

2 Materials and methods

This methodology section outlines the approach and methods employed to investigate the role of technology and international law in marine policy. The study aims to examine how advancements in technology and international legal frameworks contribute to the development and implementation of effective marine policies. The study involves a combination of research methods to gather data, analyze relevant literature, and draw conclusions. Literature review, and an extensive review of academic journals, books, reports, and relevant policy documents was conducted to gather a comprehensive understanding of the role of technology and international law in marine policy. In-depth case studies of specific marine policy initiatives were conducted to examine the practical applications of technology and international law. Thematic analysis was applied to the collected qualitative data, such as interview transcripts and policy documents, to identify key themes, patterns, and relationships. Measures were taken to ensure the anonymity and confidentiality of participants' identities and sensitive information, and the research was adhered to ethical guidelines and regulations. The research was conducted within a specific timeframe, which may limit the scope and depth of the study. Access to comprehensive and up-to-date on specific marine policy initiatives and technological advancements may pose challenges.

To investigate the role of technology and international law in marine policy, can utilize various materials and sources. Academic journals and articles, books and book chapters, reports and policy documents, case studies, official websites, and these materials, encompassing academic research, legal frameworks, case studies, expert opinions, and official reports provide a comprehensive foundation for examining the role of technology and international law in marine policy. This methodology provides a systematic approach to investigating the role of technology and international law in marine policy, by employing a mixed-methods research design and considering ethical considerations, the study aims to generate valuable insights into the interactions between technology, international law, and effective marine policy development and implementation. The findings contribute to the existing body of knowledge on marine governance and inform policymakers, legal experts, and relevant stakeholders in making informed decisions to

address current and future challenges in marine policy, (see Figure 1 below). For example, how should drones be regulated for use in marine surveys and inspections? What are the legal implications of using artificial intelligence to make decisions about marine resource management? These are just some of the questions that marine policy makers need to address in the coming years.

3 Literature review

The role of technology and international law in marine policy has evolved significantly in the past five years. New technologies, such as drones, artificial intelligence, and underwater robotics, have the potential to revolutionize marine resource management and conservation. However, these technologies also raise new legal challenges, as they blur the lines between traditional maritime boundaries and jurisdictions. One of the most significant challenges facing marine policy makers is how to regulate the use of new technologies in the marine environment. Another challenge facing marine policy makers is how to ensure that international law keeps pace with technological change. The United Nations Convention on the Law of the Sea (UNCLOS) is the cornerstone of international law governing the oceans. However, UNCLOS was drafted in the 1970s, and it does not explicitly address many of the new technologies that are now being used in the marine environment. This has led to some uncertainty about how these technologies should be regulated under international law. Despite these challenges, there is a growing recognition of the importance of technology and international law in marine policy are presented in Figure 2. The United Nations General Assembly adopted a resolution on the "Sustainable Use of Marine Technology on December 7 1994." The resolution calls for the development of new international law and standards to regulate the use of marine technology. It also encourages states to cooperate in the development and use of marine technology for sustainable development. The role of technology and international law in marine policy is likely to continue to evolve in the coming years. As new technologies emerge, marine policy makers need to find ways to regulate them in a way that is both effective and sustainable. At the same time, they need to ensure that international law keeps pace with technological change (Nõmmela and Kõrbe Kaare, 2022).

3.1 Challenges in implementing technology and international law in marine policy

Implementing technology and international law in marine policy presents several significant challenges that need to be overcome to ensure their successful integration, and these challenges include.

3.1.1 Data management challenge

The vast amount of data generated by technological tools, such as remote sensing and underwater sensors, can overwhelm existing data management systems. This is because the data is often very

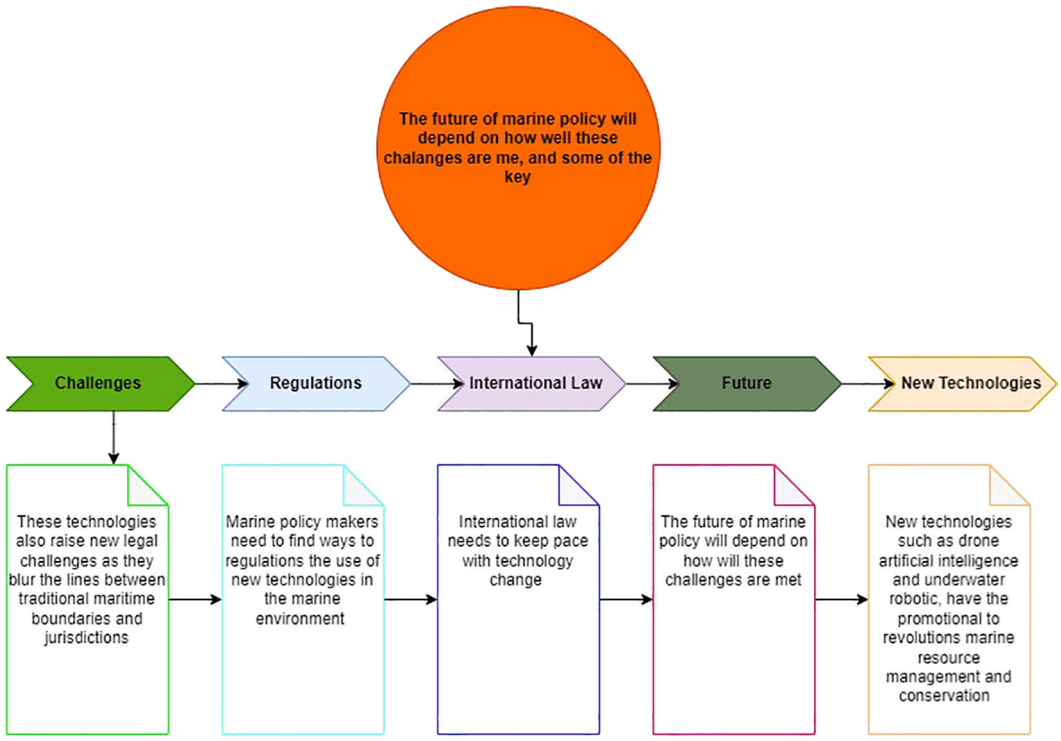


FIGURE 1
This model was created by authors opening about the Key findings on the future of marine policy.

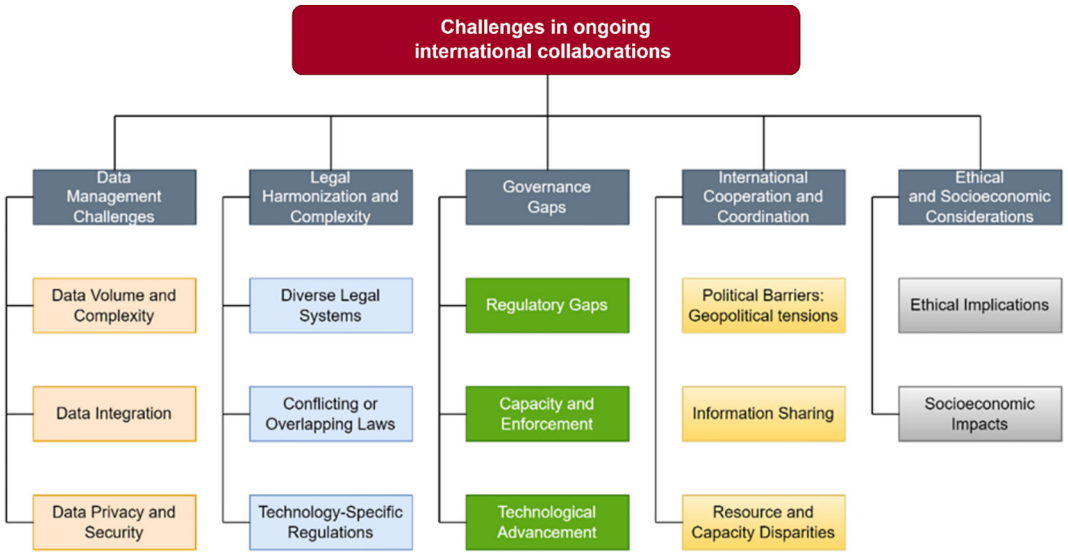


FIGURE 2
This model was created by the authors idea about technological advancements and emerging marine issues under legal frameworks.

large and complex, and it can be difficult to store, process, and analyse efficiently. (Wang et al., 2023b).

Data integration, integrating data from diverse sources and formats, ensuring interoperability, and maintaining data quality standards is a complex task that requires effective data management frameworks (Luecken et al., 2022; Mobashir et al., 2022).

Data privacy and Security, safeguarding sensitive data, protecting privacy rights, and mitigating cybersecurity risks are critical challenges in the context of technology implementation, particularly when multiple stakeholders are involved (Shen et al., 2022).

3.1.2 Legal harmonization and complexity

Diverse legal systems, different countries have varying legal frameworks and approaches to marine policy, leading to discrepancies and inconsistencies that need to be harmonized to enable effective international cooperation (Cox and Van Nostrand, 2023; Gutowski et al., 2023).

Conflicting or overlapping laws, overlapping jurisdictional claims, differing interpretations of international law, and conflicting regulations at regional and national levels can impede the harmonization of legal frameworks (Annisa and Wisnaeni, 2023; Santy, 2023).

Technology-specific regulations, the rapid advancement of technology often outpaces the development of corresponding regulations, resulting in legal gaps and challenges in adapting existing legal frameworks to address emerging marine technologies (McDonald et al., 2023).

3.1.3 Governance gaps

Regulatory gap, existing international governance frameworks, such as UNCLOS, may not comprehensively cover emerging technologies or adequately address evolving marine challenges, necessitating the development of new regulations and governance mechanisms (Hussain and Bhatti, 2023; Kostruba et al., 2023; Moshiul et al., 2023).

Capacity and enforcement, limited capacity to enforce regulations, monitor compliance, and address violations can undermine the effectiveness of technology and international law implementation in marine policy (Assunção et al., 2023; Langlet and Vadrot, 2023).

Technological advancement, The dynamic nature of technology requires agile governance structures capable of adapting to rapidly evolving advancements, ensuring that regulations remain relevant and effective (Baker, 1978; Kemp et al., 2023b).

3.1.4 International cooperation and coordination

Political barriers and geopolitical tensions, conflicting national interests, and divergent priorities among nations can hinder effective international cooperation, making it challenging to establish unified marine policies (Scheelhaase et al., 2019).

Information sharing, balancing the need for open data sharing and collaboration with concerns over data security, intellectual property rights, and national sovereignty poses challenges in promoting transparent and inclusive decision-making processes (Rukanova et al., 2023).

Resource and capacity disparities, unequal access to technology, financial resources, and technical expertise among nations can hinder effective collaboration, exacerbating the challenges in implementing technology and international law in marine policy (Awad et al., 2023; Wang et al., 2023a).

3.1.5 Ethical and socioeconomic considerations

Ethical implications, and the use of technology in marine policy raises ethical concerns related to privacy, equity, consent, and the potential unintended consequences on marine ecosystems and communities (What's in a name? : the ethical implications and

opportunities in diagnosing an infant with neonatal abstinence syndrome (NAS) | Western Sydney University ResearchDirect, n.d.).

Socioeconomic impacts, implementing technology-driven policies should consider potential socioeconomic disparities, ensuring equitable access to benefits, mitigating negative impacts on local communities and traditional practices, and addressing potential economic disruptions (Reducing environmental impacts through socioeconomic transitions: critical review and prospects | SpringerLink, n.d.). Talking these challenges requires ongoing international collaboration, knowledge sharing, capacity building, and the development of robust legal frameworks that can keep pace with technological advancements and emerging marine issues (Hussain and Bhatti, 2023; A Review Article on an Appraisal of Maritime Laws as a Mechanism of Community Governance for Sustainable Development Goals | Pakistan Journal of Humanities and Social Sciences, n.d.). By overcoming these challenges, the effective integration of technology and international law can contribute to sustainable marine policies that promote the conservation and preservation of our oceans for future generations (Narayanan et al., 2023).

3.2 Technology

3.2.1 Technology and international marine policy

Technology plays a crucial role in shaping international marine policy and addressing the complex challenges faced by our oceans. The advancement of technology has significantly improved our ability to monitor, manage, and protect marine resources. For instance, satellite-based remote sensing and tracking systems provide real-time data on ocean temperatures, currents, and the movement of marine species (Pyć, 2023). This information helps policymakers make informed decisions regarding conservation measures, fisheries management, and the establishment of marine protected areas. Moreover, technological innovations have greatly enhanced our understanding of the impacts of human activities on the marine environment. Advanced underwater robots, known as remotely operated vehicles (ROVs), enable scientists to explore and document previously inaccessible ocean depths, studying marine ecosystems and identifying areas of vulnerability (Mori et al., 2023). Additionally, advanced modelling and simulation tools help policymakers assess the potential consequences of different policy options, such as the implementation of offshore renewable energy projects or the introduction of new shipping routes (Stoll et al., 2023).

International collaboration and cooperation are essential in developing effective marine policies, and technology plays a vital role in facilitating such efforts. Communication and information-sharing technologies enable scientists, policymakers, and stakeholders from different countries to collaborate and exchange knowledge and data on a global scale. This collaboration allows for the development of coordinated policies and strategies to address transboundary issues such as overfishing, pollution, and climate change. Furthermore, emerging technologies like blockchain offer opportunities for improved transparency and traceability in global seafood supply chains, helping combat illegal, unreported, and unregulated fishing practices. Technology and international marine policy are deeply intertwined. Technological advancements provide crucial tools for monitoring and understanding the marine environment, supporting evidence-based decision-making processes. Furthermore, technology facilitates international collaboration and cooperation, enabling countries to work together in protecting and sustainably managing our oceans (Lubchenco and Haugan, 2023). As we continue to face environmental challenges, the responsible and innovative use of technology plays a pivotal role in shaping effective and forward-thinking marine policies.

3.2.2 Types of technology used in marine policy

Various types of technology are utilized in marine policy to address environmental challenges, promote sustainable practices, and protect marine ecosystems (Lee and Zhang, 2023). These technologies enable policymakers to gather data, monitor activities, and implement effective measures, and blue color are some examples of technology commonly used in marine policy (see in the Figure 3).

Remote sensing and satellite imaging, satellite-based remote sensing systems provide valuable data on ocean parameters such as sea surface temperature, chlorophyll levels, and ocean currents. This information helps monitor changes in the marine environment, track the spread of harmful algal blooms, identify fishing hotspots, and detect illegal activities such as illegal fishing or oil spills (Oloruntobi et al., 2023).

Underwater robotics and autonomous vehicles, and remotely operated vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs) allow scientists to explore and collect data from the deep sea and other inaccessible areas (JMSE | Free Full-Text | Estimation and Control of a Towed Underwater Vehicle with Active Stationary and Low-Speed Maneuvering Capabilities, n.d.). These robotic systems are equipped with sensors and cameras that provide detailed insights into marine ecosystems, helping assess biodiversity, habitat health, and the impacts of human activities.

Acoustic monitoring and telemetry, acoustic technologies, such as hydrophones and passive acoustic monitoring, are used to track the movements and behavior of marine species. This information aids in understanding migration patterns, reproductive behaviors, and the impact of noise pollution on marine life (Sanderson et al., 2023). Telemetry systems, including tags and sensors attached to marine animals, provide real-time data on their movements, feeding habits, and habitat preferences.

Geographic information systems (GIS), GIS technology combines spatial data with analytical tools to visualize and analyze marine data. It helps policymakers identify vulnerable areas, plan marine protected areas, and assess the potential impact of development projects on marine ecosystems. GIS also facilitates the integration of various datasets, allowing for a comprehensive understanding of complex marine processes (Zhao et al, 1997).

Oceanographic monitoring systems, these systems include buoys, floats, and gliders equipped with sensors that measure parameters such as temperature, salinity, pH, and nutrient levels in the ocean. These real-time data sources provide critical information for understanding climate change, ocean acidification, and the health of marine ecosystems (Schwing, 2023).



FIGURE 3
These are just a few examples of the wide range of technologies employed in marine policy. Continued advancements in technology hold great potential for enhancing our understanding of the marine environment and improving the effectiveness of policies aimed at sustainable marine resource management (Shi et al., 2023).

Data management and modeling, advanced data management and modeling techniques are essential for analyzing and interpreting vast amounts of marine data. These technologies help policymakers simulate and predict the effects of policy interventions, such as fishing restrictions or the establishment of marine reserves, on ecosystems and fisheries (Dudayev et al., 2023).

3.2.3 Benefits of technology in marine policy

The benefits of technology in marine policy on a global scale are numerous and significant, and explained are some key advantages (See in Figure 4)

Technology enables the collection of extensive and accurate data on various aspects of the marine environment, including water quality, species abundance, and habitat health. This data provides a solid foundation for evidence-based decision-making and policy formulation (Sk, 2023). It allows policymakers to identify emerging trends, monitor the effectiveness of management measures, and assess the impact of human activities on marine ecosystems. Advanced technologies such as underwater robotics, satellite imaging, and acoustic monitoring provide scientists and policymakers with unprecedented access to marine environments. This enhanced understanding of marine ecosystems helps identify vulnerable species, detect habitat degradation, and uncover ecological interactions (Subsurface Science and Search for Life in Ocean Worlds - IOPscience, n.d.). With a more comprehensive understanding, policymakers can develop targeted and effective policies to protect marine biodiversity and promote sustainable resource use. Technology has greatly facilitated international collaboration and cooperation in marine policy. Through communication and information-sharing technologies, scientists, policymakers, and stakeholders from different countries can connect, exchange knowledge, and collaborate on a global scale. This collaboration leads to the development of coordinated strategies and policies to address transboundary issues, such as overfishing, marine pollution, and climate change (Hongdao et al., 2019). Technology also enables the sharing of best practices, lessons learned, and scientific research, fostering a collective global effort to protect and sustainably manage our oceans.

Technology plays a crucial role in enforcing marine regulations and combating illegal activities. Satellite-based monitoring systems, electronic surveillance, and real-time tracking tools help authorities detect and prevent illegal fishing, poaching, and other unauthorized activities in marine protected areas and exclusive economic zones (Aprilia et al., 2023). These technologies provide valuable evidence

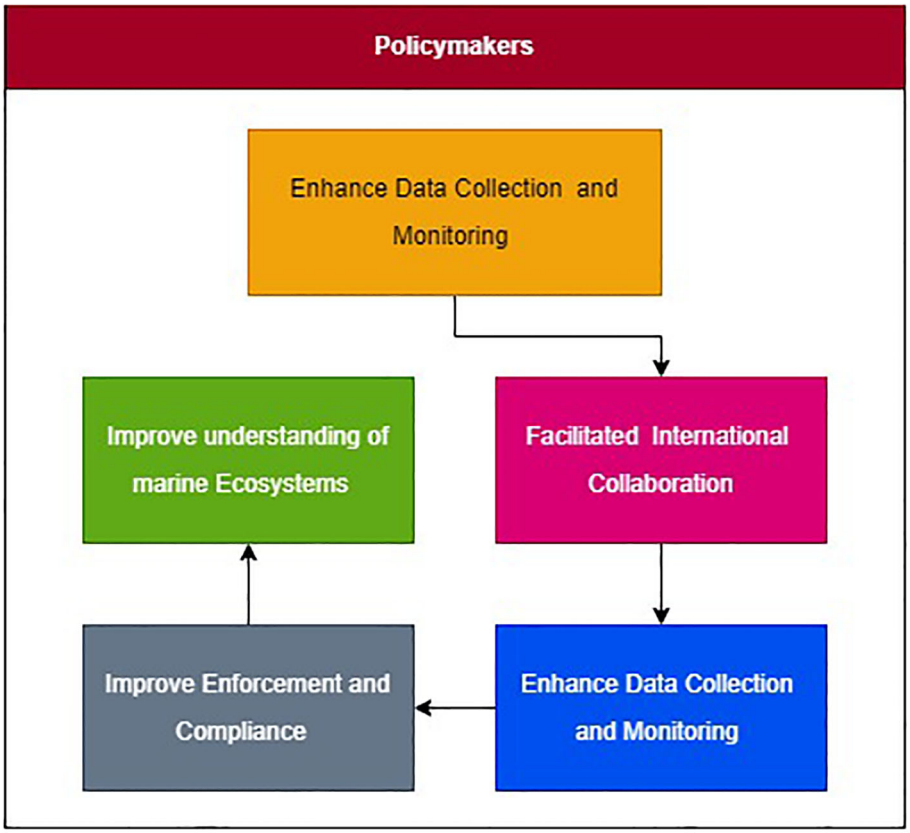


FIGURE 4
The benefits of technology in marine policy are far-reaching and have the potential to drive positive change worldwide, by harnessing the power of technology, policymakers can make informed decisions, protect marine ecosystems, and ensure the sustainable use of marine resources for future generations (Wang et al., 2022).

for prosecution, act as deterrents, and contribute to the sustainable management of marine resources (Ao et al., 2023). Technology drives innovation in marine policy by introducing new solutions and approaches. Emerging technologies, such as blockchain and artificial intelligence, offer opportunities for improved traceability, transparency, and accountability in seafood supply chains. They enable the verification of sustainable fishing practices and support efforts to combat illegal, unreported, and unregulated fishing. Additionally, advancements in renewable energy technologies, such as offshore wind and wave power, contribute to the transition to a more sustainable and low-carbon blue economy (Illia et al., 2023).

4 Discussion and analysis

4.1 International maritime law

International maritime law, also known as admiralty law or the law of the sea, is a body of legal principles, conventions, and treaties that govern activities and relationships on the world's oceans and other navigable waters. It provides a framework for regulating various aspects of maritime affairs, including navigation, shipping, marine resources, environmental protection, and international trade (Ehrhart, 2023). International maritime law encompasses both customary international law, which is derived from longstanding practices and accepted norms among nations, as well as international treaties and conventions that have been adopted by countries to establish specific rules and regulations. The United Nations Convention on the Law of the Sea (UNCLOS), adopted in 1982 and ratified by most countries, is the primary treaty that governs maritime affairs and serves as the cornerstone of international maritime law (García-Carriazo, 2023), key areas covered by international maritime law include (see to Figure 5).

It establishes the sovereignty of coastal states over a belt of water extending from their shores, typically up to 12 nautical miles. Within these waters, coastal states have the authority to enforce their laws and regulations, including customs, immigration, and environmental regulations (Falahzadeh et al., 2023). The EEZ extends up to 200 nautical miles from a coastal state's baselines and provides the state with exclusive rights to explore, exploit, and manage the natural resources, both living and non-living, within that zone. Coastal states also have jurisdiction over activities such as marine scientific research and environmental protection within their EEZ (Wiraputra et al., 2022).

The International Maritime Organisation (IMO) is a specialised UN body in charge of overseeing maritime shipping. It was founded in 1948 and seeks to ensure safe, secure, and ecologically friendly

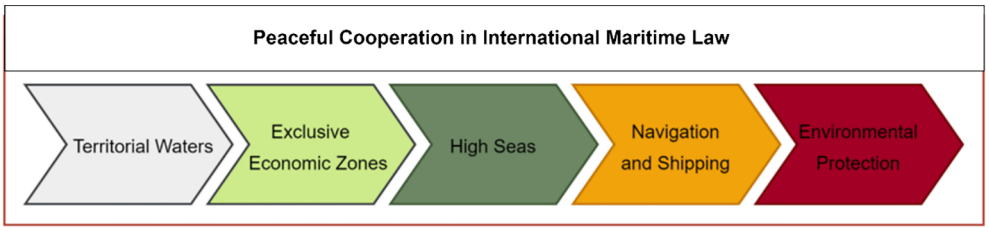


FIGURE 5
The primary objective of international environmental law is to promote environmental protection and sustainable development at the global level. By establishing common standards and frameworks, it fosters cooperation, knowledge sharing, and collective action to address pressing environmental issues that transcend national boundaries (Soininen and Romppanen, 2022). The implementation of international environmental law requires the active participation and collaboration of governments, international organizations, non-governmental organizations, and other stakeholders to achieve effective environmental governance on a global scale.

shipping throughout the world (Peters et al., 2012). The IMO creates and upholds a broad range of laws addressing topics like shipbuilding, crew training, pollution prevention, and maritime security, and readers a better grasp of how the IMO affects maritime policy and practises thru elaborating on the organisation's mission and duties (Brief History of IMO, n.d.).

The high seas refer to areas beyond national jurisdiction, where no state has sovereign rights. International maritime law governs activities on the high seas, including freedom of navigation, piracy suppression, marine scientific research, and conservation of marine resources (Zupruk, 2022). International maritime law regulates the rights and obligations of vessels and seafarers, including rules on vessel registration, safety standards, crew qualifications, collision avoidance, and liability for maritime accidents (Osaloni and Ayeni, 2022). The International Maritime Organization (IMO), a specialized agency of the United Nations, plays a central role in establishing and promoting international standards in shipping.

International maritime law addresses environmental issues, such as pollution prevention, control of vessel-source pollution (e.g., oil spills), and the protection of marine ecosystems. It includes regulations on ballast water management, disposal of waste, and the conservation of marine biodiversity (Dong et al., 2022). International maritime law is crucial for promoting peaceful cooperation, ensuring the sustainable use of ocean resources, and resolving disputes between nations. It provides a legal framework that balances the rights and interests of coastal states, flag states, and the international community, aiming to safeguard the marine environment and promote the safety and efficiency of maritime activities (Coelho and Rogers, 2023).

4.2 International environmental law

International environmental law refers to the body of legal principles, treaties, conventions, and agreements that aim to address environmental challenges at the global level. It provides a framework for cooperation and coordination among nations to protect and conserve the environment, prevent pollution, and promote sustainable development. International environmental law encompasses a wide range of issues, including climate change, biodiversity conservation, marine pollution, air pollution, hazardous waste management, and the protection of natural resources (Andreone, 2022; Yan et al., 2022 1), there some key characteristics of international environmental law include in (See the Figure 6).

International environmental law relies on multilateral cooperation among nations. It involves the negotiation and adoption of international treaties and conventions, where countries agree on common goals, principles, and standards to address global environmental challenges (Hassanali, 2022). Examples include the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), and the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (Legal Lamination to Transboundary Movement of Plastic Pollutants - IOS Press, n.d.). The principle of common but differentiated responsibilities recognizes that all countries have a shared responsibility to protect the environment but acknowledges that developed and developing countries have different capacities and historical contributions to environmental issues. This principle allows for differentiated obligations and commitments based on countries' respective capabilities and circumstances (Pata and Balsalobre-Lorente, 2022). International environmental law includes mechanisms for monitoring compliance with environmental obligations and enforcing their implementation. These mechanisms can involve reporting obligations, monitoring programs, dispute settlement procedures, and sanctions for non-compliance (Koh et al., 2022). International organizations, such as the United Nations Environment Programme (UNEP) and regional bodies, play a role in facilitating compliance and enforcement efforts (Baste and Watson, 2022; Qalati et al., 2022).

Technological advancement refers to the relentless progression of innovations and improvements in various fields, driven by human ingenuity and research, and constant growth of inventions and advancements across a range of industries, motivated by human intellect and study, is referred to as technological advancement. It includes innovations in automation, medicine, and other fields that influence communities and economy. These developments have altered the way we live, work, and interact, from the introduction of the internet to artificial intelligence. Questions about ethics, sustainability, and equitable access are raised as technology advances. To ensure that these developments improve

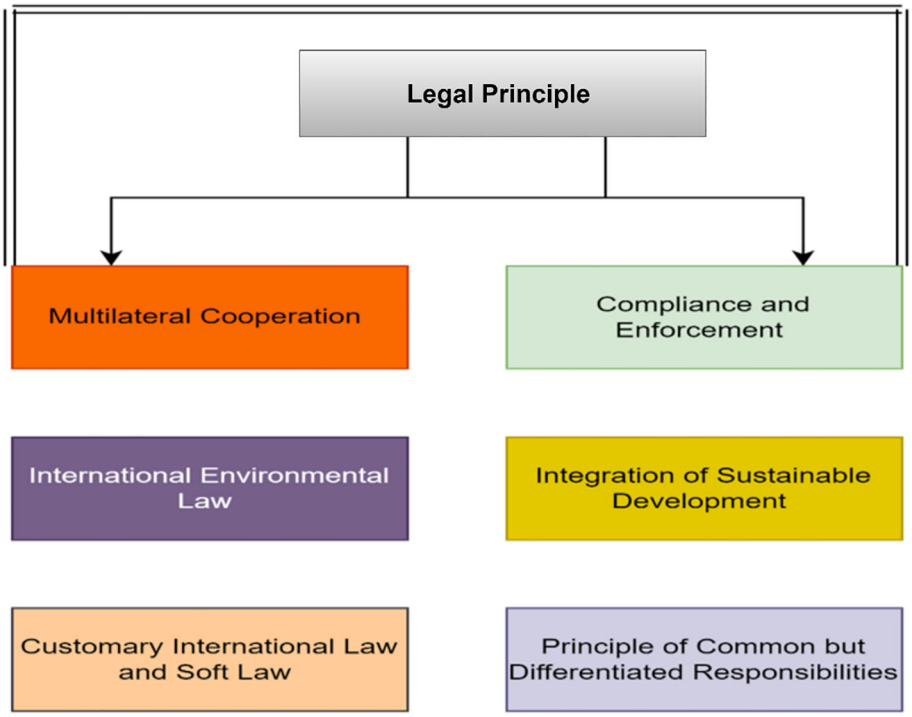


FIGURE 6
The body of International environmental law encompasses a wide range of issues, including climate change and International law.

human well-being, address global concerns, respect ethical boundaries, and protect the future, growth and responsible development must be balanced.

International environmental law seeks to integrate environmental concerns with social and economic development. It recognizes the interdependence of environmental protection and sustainable development, aiming to balance environmental conservation with the needs and aspirations of present and future generations (Sand and McGee, 2022). In accumulation to legally binding treaties and conventions, international environmental law may also include customary international law, which arises from established state practices and accepted norms. Soft law instruments, such as declarations, guidelines, and non-binding agreements, can also contribute to the development and implementation of environmental norms (Nyekwere et al., 2022).

4.3 Role of international law in marine policy

International law plays a crucial role in shaping and guiding marine policy at the global level. It provides a legal framework and establishes rules, principles, and standards that govern the use, conservation, and management of the world's oceans and marine resources (Hassanali and Mahon, 2022). The role of international law in marine policy can be seen in several key aspects, (See in the Figure 7).

International law, particularly the United Nations Convention on the Law of the Sea (UNCLOS), serves as the primary legal instrument for governing maritime activities. UNCLOS provides a comprehensive framework that sets out the rights and responsibilities of states in their use and protection of the oceans. It defines maritime boundaries, establishes rules for navigation, regulates exploitation of marine resources, and sets forth principles for environmental protection (Barnes, 2022). By providing a clear legal framework, international law helps ensure consistency, predictability, and stability in the development and implementation of marine policies.

International law plays a vital role in the conservation and sustainable use of marine biodiversity. The Convention on Biological Diversity (CBD) sets forth principles and guidelines for the conservation and sustainable management of marine and coastal ecosystems. It promotes the establishment of marine protected areas, the conservation of endangered species, and the sustainable utilization of marine genetic resources. International legal instruments also address specific issues such as the protection of migratory species, the prevention of marine pollution, and the regulation of activities that may harm marine habitats (Dobush et al., 2022).

International law provides a framework for regulating various maritime activities, including shipping, fishing, offshore oil and gas exploration, and marine scientific research. Treaties and conventions establish rules and standards to ensure safety at sea, protect the marine environment, prevent pollution, and promote responsible practices. For example, the International Maritime Organization (IMO) develops and enforces international regulations on maritime safety, security, and environmental protection (Karim, 2022). These legal instruments help harmonize

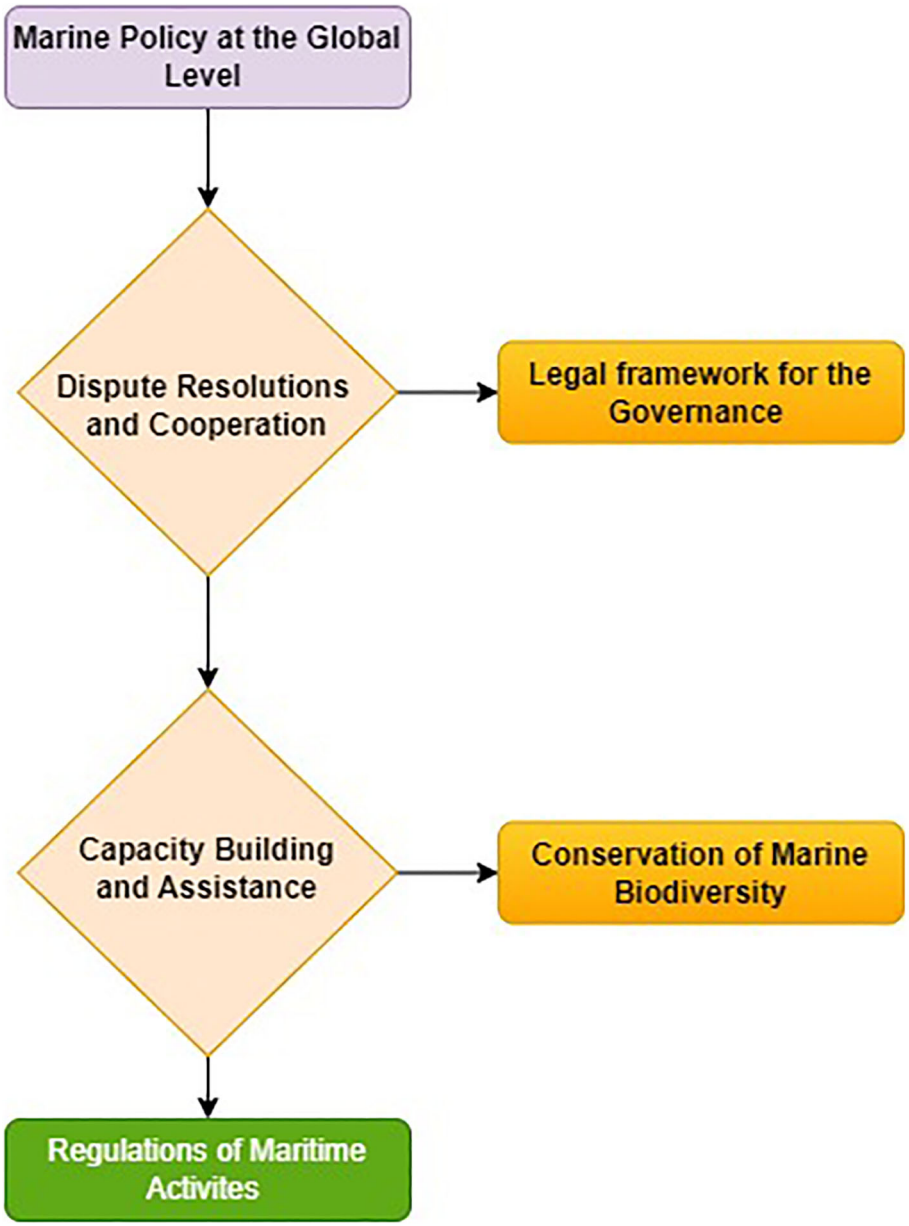


FIGURE 7
International law plays a pivotal role in marine policy by providing a legal framework, establishing rules and standards, facilitating cooperation, and promoting the conservation and sustainable use of marine resources. It provides a foundation for harmonizing national policies, resolving disputes, and fostering global efforts to protect and sustainably manage the world's oceans for present and future generations (Krabbe, 2022).

national policies and practices, promote cooperation, and address common challenges in marine industries.

International law provides mechanisms for the peaceful resolution of disputes among states regarding marine issues. It establishes procedures for the settlement of disputes, such as arbitration or adjudication through international tribunals. Notably, the International Tribunal for the Law of the Sea (ITLOS) provides a forum for resolving disputes related to the interpretation and application of UNCLOS. Additionally, international law fosters cooperation among states by promoting dialogue, negotiation, and collaboration in addressing shared challenges, such as the sustainable management of fish stocks or the response to marine pollution incidents (Fahy, 2022).

International law promotes capacity building and technical assistance to help states implement and comply with marine policies (Harden-Davies et al., 2022). International organizations and programs, such as the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF), support developing countries in building their capacity to implement international marine law and strengthen their national policies and institutions.

4.4 Challenges in implementing and maintaining technology

Implementing and maintaining technology can present several challenges, particularly in the context of marine policy, and we discuss challenges below.

Technology implementation often involves significant costs, including the purchase of equipment, software, and infrastructure, as well as ongoing maintenance and operational expenses. Limited financial resources can pose a challenge, especially for developing countries or organizations with constrained budgets. Securing funding and allocating resources for technology implementation and maintenance can be a hurdle, requiring careful planning, prioritization, and long-term sustainability strategies (Chen and Popovich, 2003). Effective technology implementation requires skilled personnel with expertise in operating and maintaining the chosen technologies. Training and capacity-building efforts are essential to ensure that users possess the necessary technical skills. In some cases, specialized knowledge may be required for complex systems such as underwater robotics, satellite data analysis, or data modeling (Amini and Jahanbakhsh Javid, 2023). Acquiring and retaining qualified staff, as well as addressing the technology skills gap, can be challenging, particularly in regions with limited access to training programs or a shortage of skilled professionals.

Technology generates vast amounts of data, and effective management and integration of this data pose challenges. Handling large datasets, ensuring data quality and integrity, and establishing protocols for data sharing and interoperability are essential. Integrating data from various sources and platforms can be complex, requiring compatibility and standardization. Additionally, addressing data privacy and security concerns is crucial to protect sensitive information and ensure compliance with applicable regulations (Francolini et al., 2023). Implementing and maintaining technology requires skilled personnel who can operate and manage the technology effectively. Building and maintaining the necessary technical skills and knowledge among staff members can be a challenge, particularly in regions or sectors where there is a shortage of trained personnel (Chuah et al., 2023). Continuous training and capacity-building efforts are essential to ensure that users can leverage the full potential of the technology.

Technology evolves at a rapid pace, and what may be cutting-edge today can become outdated in a short period. This presents challenges in terms of keeping up with technological advancements, ensuring compatibility with newer systems, and managing the lifecycle of technology. Regular updates, upgrades, and replacement of outdated technology can be necessary but may also incur additional costs (Kucharski, 2021). Introducing new technology and integrating it into existing workflows and processes may encounter resistance from stakeholders. Individuals or organizations may be reluctant to change established practices or may perceive technology as a threat to their roles or job security (Hegab et al., 2023). Overcoming resistance to change and fostering a culture of technological innovation and adoption can be challenging. Technology in marine policy raises ethical and legal considerations, such as privacy concerns, data protection, and potential misuse of technology. Adhering to ethical principles, ensuring compliance with legal frameworks, and addressing potential risks and vulnerabilities are critical to maintain trust, credibility, and the responsible use of technology (Pagallo et al., 2023). These challenges require a comprehensive approach that includes strategic planning, adequate funding, capacity building, stakeholder engagement, and ongoing evaluation and adaptation of technology initiatives. Collaborative efforts between policymakers, technology experts, and end-users are necessary to overcome these challenges and maximize the benefits that technology can bring to marine policy (Aghabalayev and Ahmad, 2023; Bennett et al., 2023).

4.5 Challenges in applying and enforcing international law

Applying and enforcing international law can present several challenges due to the complex nature of the international legal system and the diverse interests and perspectives of states.

Sovereignty and Consent: International law relies on the consent and cooperation of states to be effectively applied and enforced. States have the sovereign right to accept or reject international legal obligations, which can hinder the universal application of certain laws and treaties. In cases where states do not recognize the jurisdiction of international courts or tribunals, enforcing international law becomes challenging (Väyrynen, 2022). Non-compliance with international law is a significant challenge. States may choose not to comply with their obligations due to various reasons, including conflicting domestic laws, political considerations, resource constraints, or a lack of enforcement mechanisms. The voluntary nature of international law often limits the effectiveness of enforcement measures and may lead to a culture of non-compliance among some states (Brauers and Oei, 2020).

Power imbalances among states can impact the application and enforcement of international law. Powerful states may exert influence or selectively apply international law to suit their interests, while smaller or less influential states may face challenges in holding powerful states accountable (Simó-Soler and Peña-Asensio, 2022). This can undermine the universality and impartiality of international law and weaken its effectiveness. International legal instruments are subject to interpretation, which can lead to divergent understandings and conflicting interpretations among states. Disputes over the interpretation and application of international law can arise, requiring resolution through international courts or tribunals. However, the limited jurisdiction of these bodies and the consent of the parties involved can pose challenges to achieving binding resolutions (Munim et al., 2021).

Unlike domestic legal systems, international law often lacks strong enforcement mechanisms. While some international courts and tribunals can issue judgments, their ability to enforce those judgments can be limited (Hongdo et al., 2019). Reliance on state cooperation, diplomatic pressure, economic sanctions, or collective action by the international community can be challenging to

mobilize, resulting in a gap between legal norms and their enforcement. International law traditionally focuses on regulating the behavior of states. However, the involvement of non-state actors, such as multinational corporations, non-governmental organizations, and individuals, in global affairs poses challenges for applying and enforcing international law. Non-state actors may not be bound by the same legal obligations as states, making it difficult to hold them accountable for violations of international law (Pappa, 2019).

The international legal system often struggles to keep pace with rapidly evolving and emerging issues, such as cyber warfare, climate change, and emerging technologies (Filbee-Dexter and Smajdor, 2019). Adapting existing legal frameworks or developing new norms and rules to address these complex and dynamic challenges can be a slow and arduous process, resulting in gaps in international law's effectiveness and relevance. These challenges require strengthened international cooperation, enhanced compliance mechanisms, increased capacity building, and continued efforts to promote the universality, transparency, and accountability of international law. Engaging in dialogue, promoting the rule of law, and reinforcing the mechanisms for dispute resolution and peaceful settlement of disputes are essential for the effective application and enforcement of international law (Pickering et al., 2020).

5 Conclusions

The technology and international law play crucial roles in shaping and advancing marine policy at the global level. Technology offers numerous benefits, including improved data collection and analysis, enhanced surveillance and monitoring capabilities, and increased efficiency in managing marine resources. It enables better decision-making, promotes sustainable practices, and strengthens collaboration among stakeholders. However, challenges such as cost constraints, technical complexity, and data management must be overcome to ensure successful implementation and maintenance of technology in marine policy. International law provides the legal framework and principles necessary for effective governance and cooperation in marine affairs. It establishes rules and standards for navigation, resource exploitation, environmental protection, and dispute resolution. International environmental law specifically addresses the conservation and sustainable use of marine resources, promoting biodiversity conservation and pollution prevention. International maritime law governs activities on the seas, including navigation, shipping, and territorial rights. However, challenges in applying and enforcing international law, such as sovereignty issues, non-compliance, and power imbalances, must be addressed to ensure its effective implementation (Majid et al., 2023). In combination, technology and international law have the potential to create a powerful synergy in marine policy. Technology provides tools and solutions to address complex challenges, improve compliance monitoring, and enhance enforcement efforts. International law provides the legal framework and principles that guide the responsible and sustainable use of technology, ensuring that its benefits are harnessed for the collective good. By leveraging technology within the framework of international law, governments, organizations, and stakeholders can work together to safeguard marine ecosystems, protect resources, and promote the long-term health and sustainability of our oceans.

5.1 *Recommendations and future policies for implementation in marine policy and law*

Improving the implementation of technology and international law in marine policy requires concerted efforts and collaboration among various stakeholders. Here are some suggestions to enhance their effectiveness. Invest in training programs and capacity-building initiatives to enhance the technical skills and knowledge of personnel involved in marine policy implementation. This includes training in technology usage, data management, legal expertise, and policy implementation. Through equipping individuals with the necessary skills, they can effectively leverage technology and navigate international legal frameworks. Facilitate collaboration among governments, international organizations, academia, and industry to share best practices, experiences, and lessons learned. Establish platforms for knowledge sharing, such as workshops, conferences, and online forums, to promote dialogue and exchange of information. Collaborative initiatives can enhance the understanding and implementation of technology and international law in marine policy. Develop clear and comprehensive regulatory frameworks that govern the use of technology in marine policy. These frameworks should address issues such as data management, privacy, security, and accountability. Thru establishing transparent and consistent regulations, stakeholders can confidently adopt and implement technology solutions while ensuring compliance with international legal obligations. Implement robust data management systems that ensure the collection, storage, analysis, and sharing of high-quality data. This includes establishing data standards, protocols, and infrastructure that facilitate interoperability and accessibility. Efficient data management enables evidence-based decision-making, enhances monitoring and enforcement efforts, and supports compliance with international reporting requirements.

Strengthen international cooperation and coordination mechanisms to address transboundary marine challenges effectively. Encourage information exchange, joint research initiatives, and collaborative projects among nations to tackle shared issues. International partnerships can foster innovation, promote technology transfer, and enhance the implementation of international law in marine policy. Promote public awareness and stakeholder engagement as a raise public awareness about the importance of technology and international law in marine policy. Foster stakeholder engagement through public consultations, involvement of non-governmental organizations, and partnerships with local communities. Encouraging public participation and inclusivity can improve policy implementation, enhance

accountability, and garner support for the effective use of technology and international law.

Encourage research and innovation about the Invest in research and development to drive innovation in technology solutions and advance the understanding of international legal frameworks related to marine policy. Foster interdisciplinary collaborations between scientists, technologists, legal experts, and policy-makers to explore new approaches, technologies, and legal mechanisms for addressing emerging challenges in marine governance (Bilawal Khaskheli et al., 2023), by implementing these suggestions, policymakers and stakeholders can enhance the implementation of technology and international law in marine policy. This research contributed to more effective and sustainable management of marine resources, protection of marine ecosystems, and the promotion of equitable and responsible practices on a global scale. Foster public awareness about the importance of technology and international law in marine policy and engage stakeholders in decision-making processes. Promote education and outreach initiatives to increase understanding of the value of marine ecosystems and the role of technology and international law in their protection (Khaskheli et al., 2023). Foster partnerships with civil society organizations, local communities, and indigenous groups to incorporate diverse perspectives and ensure inclusive and participatory marine policy development and implementation.

5.2 The future direction of limitation policy

The future direction of limitation policy concerning technology usage and international law in marine policy will focus on adapting to technological advancements and developments while maintaining compliance with international laws and agreements. Policymakers will have to deal with the challenges presented by these cutting-edge maritime technologies in order to lessen the potential environmental harm that deep-sea mining and autonomous ships could cause. In order to manage marine resources sustainably, combat illicit fishing, and minimize pollution, it will be necessary to strengthen regulatory frameworks and promote collaboration between states. Responsible practices and marine environment conservation for future generations rely heavily on encouraging data and technology exchange, capacity building, and inclusive decision-making. The international community will have the resources it needs to protect our oceans if it embraces innovation and transparency.

It will become increasingly important for countries to encourage the sharing of data and technologies in order to monitor and manage maritime ecosystems efficiently. Better understanding and concerted action to address global marine concerns can result from the promotion of open data regulations and the transfer of technology. New methods of exploration, extraction, and transportation may become available in the marine industry if technological development continues at its current rate. Future limiting regulations must assess and address the potential environmental consequences and hazards of cutting-edge technologies like deep sea mining, autonomous vessels, and cutting-edge fishing gear. Compliance with international laws and agreements pertaining to marine activities will be emphasized, as will the need to ensure that technical improvements are in line with sustainability goals and environmental preservation. In order to efficiently manage marine resources, combat illicit fishing, avoid marine pollution, and protect biodiversity, nations may need to strengthen their regulatory frameworks and collaborate on transboundary concerns.

Author contributions

MK: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. SW: Conceptualization, Supervision, Writing – original draft. XZ: Data curation, Formal Analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. IS: Funding acquisition, Resources, Writing – review & editing. CS: Investigation, Formal Analysis, Writing – review & editing. SR: Methodology, Data curation, Writing – review & editing. ZI: Investigation, Writing – review & editing. DB: Methodology, Formal Analysis, Investigation, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by the Sino-Pakistan Project NSFC (31961143008), the National Natural Science Foundation of China, the International (Regional) Cooperation and Exchange Program, the Research Fund for International Young Scientists (31750110462 and 32250410280), a project of Zhejiang University Excellent Teaching Post B (Professional), and the Jiangsu Collaborative Innovation Center for Modern Crop Production (JCIC-MCP), China.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

A review article on an appraisal of maritime laws as a mechanism of community governance for sustainable development goals (Accessed June 19, 2023).

Aghabalayev, F., and Ahmad, M. (2023). Does innovation in ocean energy generations-related technologies in G7 countries reduce carbon dioxide emissions? Role of international collaboration in green technology development and commercial and monetary policies. *Environ. Sci. pollut. Res.* 30, 14545–14564. doi: 10.1007/s11356-022-23081-x

Amini, M., and Jahanbakhsh Javid, N. (2023) *A multi-perspective framework established on diffusion of innovation (DOI) theory and technology, organization and environment (TOE) framework toward supply chain management system based on cloud computing technology for small and medium enterprises*. Available at: https://papers.ssrn.com/abstract=4340207 (Accessed August 28, 2023):11(8).

Andreone, G. (2022) Legal patchwork and national borders in the Mediterranean Sea. *CNR Case histories Blue Planet Economy*. 113–124.

Annisa, M., and Wisnaeni, F. (2023). Polemic of law no. 23 of 2019 concerning management of national resources for national defense formation of reserve components. *Int. J. Soc. Sci. Res. Rev.* 6, 122–131. doi: 10.47814/ijssrr.v6i1.885

Ao, L., Bansal, R., Pruthi, N., and Khaskheli, M. B. (2023). Impact of social media influencers on customer engagement and purchase intention: A meta-analysis. *Sustainability* 15. doi: 10.3390/su15032744

Aprilia, W., Sutanto, R., Prakoso, L. Y., Priyanto, P., and Adriyanto, A. (2023). The efforts of the maritime security agency in preventing transnational crime at the state frontier are viewed from the strategic position of the riau islands. *Int. J. Soc. Sci.* 2, 2253–2260. doi: 10.53625/ijss.v2i5.4962

Assunção, J., Gandour, C., and Rocha, R. (2023). DETER-ing deforestation in the amazon: environmental monitoring and law enforcement. *Am. Economic Journal: Appl. Economics* 15, 125–156. doi: 10.1257/app.20200196

Awad, C. S., Deng, Y., Kwagyan, J., Roche-Lima, A., Tchounwou, P. B., Wang, Q., et al. (2023). Summary of year-one effort of the RCMI consortium to enhance research capacity and diversity with data science. *Int. J. Environ. Res. Public Health* 20, 279. doi: 10.3390/ijerph20010279

Baker, A. (1978). Finite element concepts in computational aerodynamics:5(2).

Baker, S., Constant, N., and Nicol, P. (2023). Oceans justice: trade-offs between sustainable development goals in the Seychelles. *Mar. Policy* 147, 105357. doi: 10.1016/j.marpol.2022.105357

Barnes, R. (2022). "Global solidarity, differentiated responsibilities and the law of the sea," in *Netherlands yearbook of international law 2020: global solidarity and common but differentiated responsibilities Netherlands yearbook of international law*. Eds. M. den Heijer and H. van der Wilt (Netherlands: The Hague: T.M.C. Asser Press), 107–146. doi: 10.1007/978-94-6265-527-0_5

Baste, I. A., and Watson, R. T. (2022). Tackling the climate, biodiversity and pollution emergencies by making peace with nature 50 years after the Stockholm Conference. *Global Environ. Change* 73, 102466. doi: 10.1016/j.gloenvcha.2022.102466

Bender, M., Bustamante, R., and Leonard, K. (2022). Living in relationship with the Ocean to transform governance in the UN Ocean Decade. *PloS Biol.* 20, e3001828. doi: 10.1371/journal.pbio.3001828

Bennett, N. J., Alava, J. J., Ferguson, C. E., Blythe, J., Morgera, E., Boyd, D., et al. (2023). Environmental (in)justice in the anthropocene ocean. *Mar. Policy* 147, 105383. doi: 10.1016/j.marpol.2022.105383

Bilawal Khaskheli, M., Wang, S., Hussain, R. Y., Jahanzeb Butt, M., Yan, X., and Majid, S. (2023). Global law, policy, and governance for effective prevention and control of COVID-19: A comparative analysis of the law and policy of Pakistan, China, and Russia. *Front. Public Health* 10, 1035536.

Blasiak, R., Jouffray, J.-B., Amon, D. J., Claudet, J., Dunshirn, P., Søgaard Jørgensen, P., et al. (2023). Making marine biotechnology work for people and nature. *Nat. Ecol. Evol.* 7, 482–485. doi: 10.1038/s41559-022-01976-9

Brauers, H., and Oei, P.-Y. (2020). The political economy of coal in Poland: Drivers and barriers for a shift away from fossil fuels. *Energy Policy* 144, 111621. doi: 10.1016/j.enpol.2020.111621

Brief history of IMO. Available at: https://www.imo.org/en/About/HistoryOfIMO/Pages/Default.aspx (Accessed August 5, 2023).

Castillo Rodríguez, R., Jiménez, J., Arce, K. A., and Thompson, K. R. (2023). An analysis of policy options available to the international maritime organization to protect the Costa Rica thermal dome: building the case for a particularly sensitive sea area. *Mar. Policy* 148, 105375. doi: 10.1016/j.marpol.2022.105375

Chen, I. J., and Popovich, K. (2003). Understanding customer relationship management (CRM): People, process and technology. *Business Process Manage. J.* 9, 672–688. doi: 10.1108/14637150310496758

Chen, X., Xu, Q., and Li, L. (2023). Illegal, unreported, and unregulated fishing governance in disputed maritime areas: reflections on the international legal obligations of states. *Fishes* 8, 36. doi: 10.3390/fishes8010036

Chuah, L. F., Mokhtar, K., Mhd Ruslan, S. M., Bakar, A. A., Abdullah, M. A., Osman, N. H., et al. (2023). Implementation of the energy efficiency existing ship index and carbon intensity indicator on domestic ship for marine environmental protection. *Environ. Res.* 222, 115348. doi: 10.1016/j.envres.2023.115348

Coelho, L. F., and Rogers, R. (2023). "The use of marine autonomous systems in ocean observation under the LOSC: maintaining access to and sharing benefits for coastal states," in *Smart ports and robotic systems : navigating the waves of techno-regulation and governance studies in national governance and emerging technologies*. Eds. T. M. Johansson, D. Dalaklis, J. E. Fernández, A. Pastra and M. Lennan (Netherlands: Cham: Springer International Publishing), 111–131. doi: 10.1007/978-3-031-25296-9_6

Cox, J. M., and Van Nostrand, R. D. (2023). Wielding the gavel or balancing the scales? Domestic legal systems and post-conflict justice. *J. Conflict Resolution* 67, 122–149. doi: 10.1177/00220027221110581

Dobush, B.-J., Gallo, N. D., Guerra, M., Guilloux, B., Holland, E., Seabrook, S., et al. (2022). A new way forward for ocean-climate policy as reflected in the UNFCCC Ocean and Climate Change Dialogue submissions. *Climate Policy* 22, 254–271. doi: 10.1080/14693062.2021.1990004

Dong, J., Zeng, J., Yang, Y., and Wang, H. (2022). A review of law and policy on decarbonization of shipping. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.1076352

Dudayev, R., Hakim, L. L., and Rufiati, I. (2023). Participatory fisheries governance in Indonesia: Are octopus fisheries leading the way. *Mar. Policy* 147, 105338. doi: 10.1016/j.marpol.2022.105338

Ehrhart, A. (2023). Navigating underrepresentation and gendered barriers to women's political power: Narratives and experiences of women parliamentarians in Turkey. *Front. Political Sci.* 4. doi: 10.3389/fpos.2022.1075462

Fahy, L. A. (2022). Fostering regulator–innovator collaboration at the frontline: A case study of the UK's regulatory sandbox for fintech. *Law Policy* 44, 162–184. doi: 10.1111/lapo.12184

Falahzadeh, A., Toma, D. M., Francescangeli, M., Chatzievangelou, D., Nogueras, M., Martínez, E., et al. (2023). A new coastal crawler prototype to expand the ecological monitoring radius of OBSEA cabled observatory. *J. Mar. Sci. Eng.* 11, 857. doi: 10.3390/jmse11040857

Filbee-Dexter, K., and Smajdor, A. (2019). Ethics of assisted evolution in marine conservation. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00020

Francolini, E. M., Mann-Lang, J. B., McKinley, E., and Mann, B. Q. (2023). and abrahams, M Stakeholder perspectives on socio-economic challenges and recommendations for better management of the Aliwal Shoal Marine Protected Area in South Africa. *I. Mar. Policy* 148, 105470. doi: 10.1016/j.marpol.2022.105470

García-Carriazo, Á. (2023). Building capacity in the law of the sea: the IMO international maritime law institute's experience. *Int. Law Stud.* 100.

Guelker, D. (2023). Fishers and seafarers in international law – Really so different? *Mar. Policy* 148, 105473. doi: 10.1016/j.marpol.2022.105473

Gullett, W. (2023). The contribution of the law of the sea convention to marine environmental protection: 40 years of shimmering seas or high hopes dashed against juridical rocks? *Mar. Policy* 149, 105498. doi: 10.1016/j.marpol.2023.105498

Gutowski, E. R., Freitag, S., Zhang, S., Thompson, M. P., and Kaslow, N. J. (2023). Intimate partner violence, legal systems and barriers for african american women. *J. Interpers Violence* 38, 1279–1298. doi: 10.1177/08862605221090561

Harden-Davies, H., Amon, D. J., Chung, T.-R., Gobin, J., Hanich, Q., Hassanali, K., et al. (2022). How can a new UN ocean treaty change the course of capacity building? *Aquat. Conservation: Mar. Freshw. Ecosyst.* 32, 907–912. doi: 10.1002/aqc.3796

Hassanali, K. (2022).). Participating in negotiation of a new ocean treaty under the law of the sea convention – experiences of and lessons from a group of small-island developing states. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.902747

Hassanali, K., and Mahon, R. (2022). Encouraging proactive governance of marine biological diversity of areas beyond national jurisdiction through Strategic Environmental Assessment (SEA). *Mar. Policy* 136, 104932. doi: 10.1016/j.marpol.2021.104932

Hegab, H., Shaban, I., Jamil, M., and Khanna, N. (2023). Toward sustainable future: Strategies, indicators, and challenges for implementing sustainable production systems. *Sustain. Materials Technol.* 36, e00617. doi: 10.1016/j.susmat.2023.e00617

Hongdao, Q., Bibi, S., Khan, A., Ardito, L., and Khaskheli, M. B. (2019). Legal technologies in action: The future of the legal market in light of disruptive innovations. *Sustainability* 11. doi: 10.3390/su11041015

Hongdo, Q., Khaskheli, M. B., Rasheed, R., and Mukhtar, H. (2019). The role of China in influencing indo-pak relations in contemporary era. *Eur. J. Economics Law Politics* 6, 55–74.

Hung, L.-Y., Wang, S.-M., and Yeh, T.-K. (2022). Collaboration between the government and environmental non-governmental organisations for marine debris policy development: The Taiwan experience. *Mar. Policy* 135, 104849. doi: 10.1016/j.marpol.2021.104849

Hussain, M., and Bhatti, S. H. (2023). A review article on an appraisal of maritime laws as a mechanism of community governance for sustainable development goals. *Pakistan J. Humanities Soc. Sci.* 11, 1–10. doi: 10.52131/pjhss.2023.1101.0325

Illia, L., Colleoni, E., and Zyglidopoulos, S. (2023). Ethical implications of text generation in the age of artificial intelligence. *Business Ethics Environ. Responsibility* 32, 201–210. doi: 10.1111/beer.12479

JMSE *Free full-text | Estimation and control of a towed underwater vehicle with active stationary and low-speed maneuvering capabilities*. Available at: https://www.mdpi.com/2077-1312/11/6/1176 (Accessed June 19, 2023).

Karim, M. S. (2022). Maritime cybersecurity and the IMO legal instruments: Sluggish response to an escalating threat? *Mar. Policy* 143, 105138. doi: 10.1016/j.marpol.2022.105138

Kemp, P. S., Subbiah, G., Barnes, R., Boerder, K., O'Leary, B. C., Stewart, B. D., et al. (2023a). Future advances in UK marine fisheries policy: Integrated nexus management, technological advance, and shifting public opinion. *Mar. Policy* 147, 105335. doi: 10.1016/j.marpol.2022.105335

Kemp, P. S., Subbiah, G., Barnes, R., Boerder, K., O'Leary, B. C., Stewart, B. D., et al. (2023b). The future of marine fisheries management and conservation in the United Kingdom: Lessons learnt from over 100 years of biased policy. *Mar. Policy* 147, 105075. doi: 10.1016/j.marpol.2022.105075

Khaskheli, M. B., Wang, S., Yan, X., and He, Y. (2023). Innovation of the social security, legal risks, sustainable management practices and employee environmental awareness in the China–Pakistan economic corridor. *Sustainability* 15. doi: 10.3390/su15021021

Koh, N. S., Ituarte-Lima, C., and Hahn, T. (2022). Mind the compliance gap: how insights from international human rights mechanisms can help to implement the convention on biological diversity. *Transnational Environ. Law* 11, 39–67. doi: 10.1017/S2047102521000169

Kostruba, A., Haliantych, M., Iskra, S., Dryshliuk, A., and Коструба, А. В. (2023) *Legal Gaps: Concept, Content, Problems of the Role of Legal Doctrine in Overcoming them*. Available at: http://194.44.152.155:8080/handle/123456789/14803 (Accessed June 19, 2023).

Krabbe, N. (2022). "High seas marine protected areas: impact on shipping and the IMO," in *Regulation of risk (Brill nijhoff)* Germany, 392–417. doi: 10.1163/9789004518681_014

Kucharski, J. (2021). Modernizing it procurement: one small step towards progress, one giant leap for federal contracting. *Pub. Cont. L.J.* 51, 299.

Kwiatkowska, B. (1995). The new international law of fisheries: UNCLOS 1982 and beyond. By william T. Burke. Oxford monographs in international law, general editor ian brownlie. Oxford: clarendon pres Pp. xxvii, 373. Index. $95. *Am. J. Int. Law* 89, 674–677. doi: 10.2307/2204196

Langlet, A., and Vadrot, A. B. M. (2023). Not 'undermining' who? Unpacking the emerging BBNJ regime complex. *Mar. Policy* 147, 105372. doi: 10.1016/j.marpol.2022.105372

Lee, K. L., and Zhang, T. (2023). Revolutionizing supply chains: unveiling the power of blockchain technology for enhanced transparency and performance. *Int. J. Technology Innovation Manage. (IJTIM)* 3, 19–27. doi: 10.54489/ijtim.v3i1.216

Legal lamination to transboundary movement of plastic pollutants - IOS press. Available at: https://content.iospress.com/articles/environmental-policy-and-law/epl219025 (Accessed June 21, 2023).

Liu, Y., Han, L., Pei, Z., and Jiang, Y. (2023). Evolution of the coupling coordination between the marine economy and urban resilience of major coastal cities in China. *Mar. Policy* 148, 105456. doi: 10.1016/j.marpol.2022.105456

Lubchenco, J., and Haugan, P. M. (2023). "The human relationship with our ocean planet," in *The blue compendium: from knowledge to action for a sustainable ocean economy*. Eds. J. Lubchenco and P. M. Haugan (Netherlands: Cham: Springer International Publishing), 393–443. doi: 10.1007/978-3-031-16277-0_11

Luecken, M. D., Büttner, M., Chaichoompu, K., Danese, A., Interlandi, M., Mueller, M. F., et al. (2022). Benchmarking atlas-level data integration in single-cell genomics. *Nat. Methods* 19, 41–50. doi: 10.1038/s41592-021-01336-8

Majid, S., Zhang, X., Khaskheli, M. B., Hong, F., King, P. J. H., and Shamsi, I. H. (2023). Eco-efficiency, environmental and sustainable innovation in recycling energy and their effect on business performance: evidence from european SMEs. *Sustainability* 15. doi: 10.3390/su15129465

McDonald, J., Brent, K., McCormack, P., and McGee, J. (2023). Greenhouse gas removal in Australian climate law: A positive role for negative emissions. *Univ. Of New South Wales Law J.* 46, 79–110. doi: 10.3316/informit.984616432167719

Mobashir, M., Turunen, S. P., Izhari, M. A., Ashankyty, I. M., Helleday, T., and Lehti, K. (2022). An approach for systems-level understanding of prostate cancer from high-throughput data integration to pathway modeling and simulation. *Cells* 11. doi: 10.3390/cells11244121

Moore, C. (2021). *Freedom of navigation and the law of the sea: warships, states and the use of force* (London: Routledge: Elsevier). doi: 10.4324/9780429425745

Mori, A. S., Suzuki, K. F., Hori, M., Kadoya, T., Okano, K., Uraguchi, A., et al. (2023). Perspective: sustainability challenges, opportunities and solutions for long-term ecosystem observations. *Philos. Trans. R. Soc. B.* doi: 10.1098/rstb.2022.0192

Moshiul, A. M., Mohammad, R., and Hira, F. A. (2023). Alternative fuel selection framework toward decarbonizing maritime deep-sea shipping. *Sustainability* 15. doi: 10.3390/su15065571

Munim, Z. H., Duru, O., and Hirata, E. (2021). Rise, fall, and recovery of blockchains in the maritime technology space. *J. Mar. Sci. Eng.* 9, 266. doi: 10.3390/jmse9030266

Narayanan, R., Sreelekshmi, K., and T R, K. (2023). "Marine resources and sustainable utilization," in *Conservation and sustainable utilization of bioresources sustainable development and biodiversity*. Eds. S. T. Sukumaran and K. T R (Singapore: Springer Nature), 581–596. doi: 10.1007/978-981-19-5841-0_24

Nõmmela, K., and Kõrbe Kaare, K. (2022). Maritime policy design framework with ESG performance approach: case of Estonia. *Economies* 10, 88. doi: 10.3390/economies10040088

Nyekwere, E. H., Okogbule, I. C. S., and Agwor, D. O. N. (2022). Understanding the principles of international environmental law and their reflections in international environmental treaties and non-binding soft law instruments. *J.L. Pol'y Globalization* 123, 73.

Olabi, A. G., Alami, A. H., Ayoub, M., Aljaghoub, H., Alasad, S., Inayat, A., et al. (2023). Membrane-based carbon capture: Recent progress, challenges, and their role in achieving the sustainable development goals. *Chemosphere* 320, 137996. doi: 10.1016/j.chemosphere.2023.137996

Oloruntobi, O., Mokhtar, K., Mohd Rozar, N., Gohari, A., Asif, S., and Chuah, L. F. (2023). Effective technologies and practices for reducing pollution in warehouses - A review. *Cleaner Eng. Technol.* 13, 100622. doi: 10.1016/j.clet.2023.100622

Osaloni, O. S., and Ayeni, V. O. (2022). The development of maritime autonomous surface ships: regulatory challenges and the way forward. *Beijing L. Rev.* 13, 544. doi: 10.4236/blr.2022.133035

Pagallo, U., Bassi, E., and Durante, M. (2023). The normative challenges of AI in outer space: law, ethics, and the realignment of terrestrial standards. *Philos. Technol.* 36, 23. doi: 10.1007/s13347-023-00626-7

Pappa, M. (2019). Forcible acts by states towards non-state actors operating in disputed waters: beyond the limits of international law. *Legal Issues J.* 7, 29.

Pata, U. K., and Balsalobre-Lorente, D. (2022). Exploring the impact of tourism and energy consumption on the load capacity factor in Turkey: a novel dynamic ARDL approach. *Environ. Sci. pollut. Res.* 29, 13491–13503. doi: 10.1007/s11356-021-16675-4

Pentz, B., and Klenk, N. (2023). Will climate change degrade the efficacy of marine resource management policies? *Mar. Policy* 148, 105462. doi: 10.1016/j.marpol.2022.105462

Peters, W., Belenky, V., Bassler, C., Spyrou, K., Umeda, N., Bulian, G., et al. (2012). The second generation intact stability criteria: an overview of development. *Transactions-The Soc. Naval Architects Mar. Engineers* 119, 225–264.

Pickering, J., Bäckstrand, K., and Schlosberg, D. (2020). Between environmental and ecological democracy: theory and practice at the democracy-environment nexus. *J. Environ. Policy Plann.* 22, 1–15. doi: 10.1080/1523908X.2020.1703276

Pyć, D. (2023). Global ocean governance: Towards protecting the ocean's rights to health and resilience. *Mar. Policy* 147, 105328. doi: 10.1016/j.marpol.2022.105328

Qalati, S. A., Zafar, Z., Fan, M., Sánchez Limón, M. L., and Khaskheli, M. B. (2022). Employee performance under transformational leadership and organizational citizenship behavior: A mediated model. *Heliyon* 8, e11374. doi: 10.1016/j.heliyon.2022.e11374

Quevedo, J. M. D., Lukman, K. M., Ulumuddin, Y. I., Uchiyama, Y., and Kohsaka, R. (2023). Applying the DPSIR framework to qualitatively assess the globally important mangrove ecosystems of Indonesia: A review towards evidence-based policymaking approaches. *Mar. Policy* 147, 105354. doi: 10.1016/j.marpol.2022.105354

Reducing environmental impacts through socioeconomic transitions: critical review and prospects (SpringerLink). Available at: https://link.springer.com/article/10.1007/s11783-023-1624-1 (Accessed February 9, 2023).

Roessger, J., Claudet, J., and Horta e Costa, B. (2022). Turning the tide on protection illusions: The underprotected MPAs of the 'OSPAR Regional Sea Convention.'. *Mar. Policy* 142, 105109. doi: 10.1016/j.marpol.2022.105109

Rothwell, D. R. (1994). Navigational rights and freedoms in the asia pacific following entry into force of the law of the sea convention. *Va. J. Int'l L.* 35, 587.

Rozwadowski, H. M. (2023). *Wild blue: the post-world war two ocean frontier and its legacy for law of the sea*. Germany doi: 10.3197/096734021X16245313029949

Rukanova, B., van Engelenburg, S., Ubacht, J., Tan, Y.-H., Geurts, M., Sies, M., et al. (2023). Public value creation through voluntary business to government information sharing enabled by digital infrastructure innovations: a framework for analysis. *Government Inf. Q.* 40, 101786. doi: 10.1016/j.giq.2022.101786

Sand, P. H., and McGee, J. (2022). Lessons learnt from two decades of international environmental agreements: law. *Int. Environ. Agreements* 22, 263–278. doi: 10.1007/s10784-022-09572-9

Sanderson, B. G., Bangley, C. W., McGarry, L. P., and Hasselman, D. J. (2023). Measuring detection efficiency of high-residency acoustic signals for estimating probability of fish–turbine encounter in a fast-flowing tidal passage. *J. Mar. Sci. Eng.* 11. doi: 10.3390/jmse11061172

Santy, S. (2023). The role of the job creation law (Omnibus law) on the welfare of female workers in the industries organization. *Int. J. Soc. Manage. Stud.* 4, 117–121. doi: 10.5555/ijosmas.v4i2.291

Sardá, R., Pogutz, S., de Silvio, M., Allevi, V., Saputo, A., Daminelli, R., et al. (2023). Business for ocean sustainability: Early responses of ocean governance in the private sector. *Ambio* 52, 253–270. doi: 10.1007/s13280-022-01784-2

Scheelhaase, J., Maertens, S., and Grimme, W. (2019). Synthetic fuels in aviation – Current barriers and potential political measures. *Transportation Res. Proc.* 43, 21–30. doi: 10.1016/j.trpro.2019.12.015

Schwing, F. B. (2023). Modern technologies and integrated observing systems are "instrumental". *to fisheries oceanography: A Brief history ocean Data collection Fisheries Oceanography* 32, 28–69. doi: 10.1111/fog.12619

Shen, S., Zhu, T., Wu, D., Wang, W., and Zhou, W. (2022). From distributed machine learning to federated learning: In the view of data privacy and security. *Concurrency Computation: Pract. Exp.* 34, e6002. doi: 10.1002/cpe.6002

Shi, J., Zhu, Y., Feng, Y., Yang, J., and Xia, C. (2023). A prompt decarbonization pathway for shipping: green hydrogen, ammonia, and methanol production and utilization in marine engines. *Atmosphere* 14, 584. doi: 10.3390/atmos14030584

Simó-Soler, E., and Peña-Asensio, E. (2022). From impact refugees to deterritorialized states: Foresighting extreme legal-policy cases in asteroid impact scenarios. *Acta Astronautica* 192, 402–408. doi: 10.1016/j.actaastro.2021.12.015

Sk, Z. (2023). Temperate with maritime climatic regions: hub of technology and production with auspiciousness of habita to temperate & Maritime climate countries. *J. Multidiscip. cases (JMC) ISSN 2799-0990* 3, 32–40. doi: 10.55529/jmc31.32.40

Soininen, N., and Romppanen, S. (2022)The relative normativity of international environmental law. In: *Research handbook on fundamental concepts of environmental law* (Edward Elgar Publishing). Available at: https://www.elgaronline.com/edcollchap/book/9781839108327/book-part-9781839108327-16.xml (Accessed June 21, 2023).

Stöbener, S., and Gerritsen, A. (2023). "Co-designed research partnerships to bridge the gap between marine research, policy, and management: the meerWissen initiative," in *Science, technology and innovation diplomacy in developing countries: perceptions and practice research for development*. Eds. V. Ittekkot and J. K. Baweja (Netherlands: Singapore Springer Nature), 329–336. doi: 10.1007/978-981-19-6802-0_21

Stoll, J. S., Risley, S. C., and Henriques, P. R. (2023). A review of small-scale marine fisheries in the United States: Definitions, scale, drivers of change, and policy gaps. *Mar. Policy* 148, 105409. doi: 10.1016/j.marpol.2022.105409

Subramanian, A., Mosur Nagarajan, A., Vinod, S., Chakraborty, S., Sivagami, K., Theodore, T., et al. (2023). Long-term impacts of climate change on coastal and transitional eco-systems in India: an overview of its current status, future projections, solutions, and policies. *RSC Adv.* 13, 12204–12228. doi: 10.1039/D2RA07448F

Subsurface science and search for life in ocean worlds - IOPscience. Available at: https://iopscience.iop.org/article/10.3847/PSJ/aca6ed/meta (Accessed June 21, 2023).

Väyrynen, R. (2022). "International stability and risky states: the enforcement of norms," in *Raimo väyrynen: A pioneer in international relations, scholarship and policy-making: with a foreword by olli rehn and a preface by allan rosas pioneers in arts, humanities, science, engineering, practice*. Ed. R. Väyrynen (Netherlands: Cham: Springer International Publishing), 369–390. doi: 10.1007/978-3-031-13627-6_14

Wang, X., Fan, X., Shi, P., Ni, J., and Zhou, Z. (2023b). An overview of key SLAM technologies for underwater scenes. *Remote Sens.* 15. doi: 10.3390/rs15102496

Wang, Z., Guo, Y., and Wang, H. (2022). Review on monitoring and operation-maintenance technology of far-reaching sea smart wind farms. *J. Mar. Sci. Eng.* 10, 820. doi: 10.3390/jmse10060820

Wang, Q., Zhang, H., Huang, J., and Zhang, P. (2023a)The use of alternative fuels for maritime decarbonization: Special marine environmental risks and solutions from an international law perspective (Accessed July 7, 2023).

Wiraputra, A., Bawono, S. K., and Ponco Aji, K. (2022) *Coastal state responsibility and rights in regard to fisheries resources in EEZ*. Available at: https://papers.ssrn.com/abstract=4240863 (Accessed August 28, 2023).

What's in a name? : the ethical implications and opportunities in diagnosing an infant with neonatal abstinence syndrome (NAS) (Western Sydney University ResearchDirect). Available at: https://researchdirect.westernsydney.edu.au/islandora/object/uws:68742/ (Accessed June 19, 2023).

Yan, W., Yaoyang, W., Hanglin, Y., Zhongwen, C., and Bingxin, F. (2022) Research on interpersonal trust and security among college students1. *Int. J. Soc. Sci. Universities* 31493, 1.

Yu, M., Huang, Y., and Fu, Q. (2023). Sustainable management of marine biodiversity in areas beyond national jurisdiction by establishing protected areas on the high seas: A chinese perspective. *Sustainability* 15. doi: 10.3390/su15031927

Zhao, D. A. Q., Lam, N. S.-N., Hong-Lie, Q., and Wei, (1997). "Image characterization and modeling system (ICAMS): A geographic information system for the characterization and modeling of multiscale remote sensing data," in *Scale in remote sensing and GIS (Routledge)* Germany.

Zupruk, B. (2022). The legality and ramifications of high seas seizures of foreign merchant vessels for violating U.S. Sanctions. *Tul. Mar. L.J.* 46, 349.

frontiers | Frontiers in Marine Science

TYPE Perspective
PUBLISHED 21 November 2023
DOI 10.3389/fmars.2023.1305035

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
Dalian Maritime University, China

REVIEWED BY
Yi-Che Shih,
National Cheng Kung University, Taiwan

*CORRESPONDENCE
Zhijun Zhang
lzuzhangzhijun@163.com

RECEIVED 30 September 2023
ACCEPTED 07 November 2023
PUBLISHED 21 November 2023

CITATION
Mao Z, Liu H and Zhang Z (2023) Enhancing the ocean carbon sink capacity of Shandong province, China, under the "dual carbon" goal. *Front. Mar. Sci.* 10:1305035. doi: 10.3389/fmars.2023.1305035

COPYRIGHT
© 2023 Mao, Liu and Zhang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Enhancing the ocean carbon sink capacity of Shandong province, China, under the "dual carbon" goal

Zhengkai Mao[1], Huirong Liu[1] and Zhijun Zhang[2]*

[1]School of Law, Ocean University of China, Qingdao, China, [2]Institute of Marine Development, Ocean University of China, Qingdao, China

The ocean is a key component of the global carbon cycle. As climate change becomes increasingly severe, enhancing the ocean's carbon sink capacity is of great significance to achieving the "dual carbon" goal for China. As a major maritime province, Shandong is in an advantageous position to utilize the ocean to respond to climate change and achieve the national goals of carbon peaking and carbon neutrality. Focusing on consolidating and enhancing ocean carbon sink capabilities, Shandong needs to formulate a clear timetable and roadmap to promote blue carbon technology research and development, actively cultivate a blue carbon trading market, and tap the inner potential of ocean carbon sink. Shandong should also strengthen international cooperation to jointly construct a carbon-neutral global community.

KEYWORDS

ocean carbon sink, "dual carbon" goal, blue carbon market, Shandong province, China

1 Introduction

Ocean carbon sink ("blue carbon") is an important approach for ecosystems to improve their sustainability. It mainly uses marine and coastal ecosystems to bind and store carbon (Wang et al., 2016). In 2009, the United Nations Environment Program, the Food and Agriculture Organization of the United Nations and the Intergovernmental Oceanographic Commission jointly released "Blue carbon: the role of healthy oceans in binding carbon", confirming the irreplaceable role of the marine ecosystems in global climate change and carbon cycle processes (UN, 2009). The ocean is the largest carbon storage site on Earth, and blue carbon has obvious advantages over green carbon (i.e., using the photosynthesis of terrestrial green plants to absorb carbon dioxide) in carbon capture and storage. The amount of carbon captured by marine organisms per unit sea area is ten times that of forests and 290 times that of grasslands (Wei, 2022). Therefore, ocean carbon sink can provide strong support for the realization of the "dual carbon" goal of China and can be an important driving force for the high-quality development of the marine economy.

Shandong is a major maritime province located in an important geographical area on the eastern coast of China with a relatively developed marine economy. There are a large number of manufacturing enterprises located near the sea, with strong production capacity and strong demand for economic growth. Free trade pilot zones and international seaports in Shandong are well developed as support points for external exchanges. The marine resource abundance index of the province ranks first in the country. All these favorable conditions give Shandong a huge advantage in implementing ocean carbon sink and can thus provide strong support for the province to make full use of its marine resources to achieve ecological protection and economic development simultaneously. Therefore, the development of ocean carbon sink in Shandong will not only help the province accelerate the transformation and upgrading of its traditional marine industries toward a low-carbon and high-quality track, but also open up a new path for creating a novel economic growth engine. This article adopts the method of normative analysis and empirical analysis to study the relevant policies and current development status of ocean carbon sink in Shandong Province, and summarizes its shortcomings and practical problems. On this basis, multiple paths are proposed for how Shandong Province can further develop ocean carbon sink by implementing the sustainable concept of coordinating ecological protection and economic development.

2 Development status of ocean carbon sink in Shandong province

"Promoting green and low-carbon development of industries" is one of the four major development goals determined by the State Council of the People's Republic of China in its "Opinions on Supporting Shandong to Deepen its Transition from Old to New Drivers of Growth and Promote Green, Low-Carbon and High-Quality Development" (The State Council of the People's Republic of China, 2022). To accomplish this important mission entrusted to Shandong by the central government, the province adheres to the coordinated advancement of carbon reduction, pollution reduction, afforestation, and economic development. By giving full play to its unique maritime advantages, great progress has been made in the construction of ocean carbon sink. However, it should be noted that in order to achieve carbon peaking and carbon neutrality with high quality, Shandong Province still needs to improve relevant policy guidelines and practical applications to guide the further development of ocean carbon sink.

2.1 System construction: adequate from a macro perspective, insufficient in details

The 14th Five-Year period (2021-2025) is a critical period of opportunity for China to implement its "dual carbon" goal. With the aim of promoting the construction of a "strong marine province," Shandong attaches great importance to ocean carbon sink and has issued a series of policies to provide clear guidance for its development and utilization at the macro level. "Shandong's Action Plan for Building a Strong Marine Province" clearly states the requirement to actively develop and conduct in-depth research on ocean carbon sink (Shandong Provincial People's Government, 2022a). The "Implementation Plan for Carbon Peaking in Shandong Province" announced ten major projects for achieving carbon peaking, including consolidating and improving carbon sink capabilities, which clearly requires "vigorously developing marine ecosystem carbon sink" (Shandong Provincial People's Government, 2022b). The "Three-Year Action Plan for Building a Green, Low-Carbon and High-Quality Development Pioneer Area in Shandong Province (2023–2025)" clearly stipulates that it is necessary to strengthen the investigation and evaluation of natural ecosystem carbon sink, and Shandong should carry out carbon sink background surveys, carbon storage assessments and analyses, and construct the system of "resource survey, storage assessment, potential assessment, and technical standards" for natural ecosystem carbon sink (Shandong Provincial People's Government, 2023).

Although some results have been achieved at the macro-planning level, the institutional design of ocean carbon sink in Shandong Province is still insufficient at the detailed level, and the policy's potential remains to be deeply explored. For example, existing policies are not highly targeted and lack guidelines on clear implementation and specialized arrangements for ocean carbon sink. Shandong has not yet formed a dedicated action plan for enhancing its ocean carbon sink capacity. Policies on ocean carbon sink are usually included as part of the "marine ecological environment protection" category in Shandong's official papers. In contrast, Zhejiang, another coastal province in China, has issued "Guiding Opinions on Improving Ocean Carbon Sink Capacity in Zhejiang Province" (Department of Natural Resources of Zhejiang Province, 2023) and has made targeted and specialized arrangements for ocean carbon sink. Furthermore, the management and supervision mechanisms for ocean carbon sink in Shandong are insufficient. There is a clear lack of planning and coordination mechanism between maritime-related industries and government departments, and a regulatory system with clear responsibilities for different sectors has not yet been formed. All these have reduced the efficiency of policy implementation.

2.2 Technology research and development: initial breakthroughs have been made, but in-depth research is still needed

Shandong Province adheres to the principle of utilizing the sea scientifically and developing ocean resources through science and technology. The province strongly supports scientific institutions that conduct research in the field of ocean carbon sink, which can provide reliable basis for the scientific utilization and development of the sea. It has successively established ocean carbon sink research platforms, such as the Bohai and Yellow Sea Blue Carbon Monitoring and Assessment Center and the Sanggou Bay Algae Carbon Sink Laboratory. At the same time, it relies on comprehensive scientific

research institutes, such as the Ocean University of China and the First Institute of Oceanography of the Ministry of Natural Resources, to cultivate high-quality marine talents and strengthen the scientific and technological prowess of the marine province. These institutions are committed to carrying out basic and applied scientific research on ocean carbon sink, and has made significant technological progress in some key areas, such as seagrass bed artificial turf technology and large seaweed carbon sink mechanism research. In addition, the "Accounting Methods for Ocean Carbon Sink" (Ministry of Natural Resources of the People's Republic of China, 2023) formulated by the First Institute of Oceanography of the Ministry of Natural Resources provides a complete set of implementation methods to solve the quantification problem of ocean carbon sink. This scientific system ensures that China's ocean carbon sink accounting work has standards to follow. (Zhao, 2023).

At present, preliminary breakthroughs have been made in some aspects of Shandong Province's research and development (R&D) in ocean carbon sink, but to achieve greater success, the region still needs to overcome the challenges of in-depth optimization to achieve comprehensive innovation. First, some ocean carbon sink technologies are still in the "laboratory" stage and have not matured sufficiently for practical application. Second, insufficient investment in funds, talents, and facilities, among other resources, affects the speed of technological innovation and development. Third, a comprehensive solution that coordinates multiple disciplines is lacking. Ocean carbon sink involves not only multiple subject areas, including ecology, geology, marine environmental science, and so on, but also multiple practical links, such as carbon capture, storage, and monitoring. Therefore, the R&D of ocean carbon sink technology requires the participation of interdisciplinary talents and a comprehensive solution that closely integrates with the upstream and downstream of industrial chains.

2.3 Practical application: just started, still to be improved

From the "blue carbon pool" to the "blue carbon market," Shandong Province has actively promoted the practical application of ocean carbon sink, transforming abundant marine resources and carbon sink potential into effective measures to mitigate climate change and to promote the sustainable development of the marine economy and marine ecology. The province has pioneered in blue carbon applications, it has innovated new models for the diversified development of marine pastures and implemented China's first carbon sink loan for seagrass beds and seaweed fields (Dazhong Daily, 2023). This measure aims to encourage the expansion of ocean carbon sink insurance to enrich the supply of carbon financial products. As an emerging field, the practical application of ocean carbon sink faces uncertainties and challenges in market operations, environmental risk assessment, public participation, and social recognition. Shandong Province is no exception in the practical application of ocean carbon sink, and many aspects still need continuous improvement. As an important area for the application of ocean carbon sink, the blue carbon emissions trading market is still in its preliminary exploration stage, and the market operation mechanism still needs to be perfected. So far, carbon emissions data are not accurate enough, and there is a long way to go to build a sound monitoring and verification system. A price stabilization system is also lacking, and price fluctuations are large. In addition, market transparency is insufficient, information is asymmetric, and market activity is inadequate. Therefore, in-depth research is still needed to find out how Shandong province can better utilize the blue carbon market to balance economic benefits and environmental protection.

3 Suggestions for developing ocean carbon sink in Shandong province

Ocean carbon sink has great potential in achieving carbon neutrality and promoting high-quality economic development in Shandong Province. The region needs to implement new development concepts, innovate and explore key areas where the ocean can unleash its potential, achieve sustainable utilization of ocean resources, and balance the relationship between ocean economic development and ecological protection.

3.1 Coordinate the land and sea

3.1.1 Implement new development concepts

With the goal of achieving carbon peaking and carbon neutrality, Shandong should implement new development concepts in a more resolute, comprehensive and accurate fashion. It should set short-, medium-, and long-term goals and tasks for developing ocean carbon sink based on the current situation and development requirements of the province. The ultimate aim is to guide Shandong's marine-related industries to undergo green and low-carbon transformation to ensure the steady realization of the national "dual carbon" goal. To implement green, low-carbon development, Shandong should strengthen policy support and reform exploration to coordinate environmental conservation and sustainable socio-economic development. The Shandong Provincial Government should effectively implement its macro-control role, improve the overall coordination mechanism among various government departments, strengthen collaboration, clarify the division of responsibilities, and strengthen supervision.

3.1.2 Innovate and explore key areas

Shandong should make full use of multiple innovation platforms in the field of ocean carbon sink in the region and strengthen research on blue carbon technology. China's first Accounting Methods for Ocean Carbon Sink, formulated by the First Institute of Oceanography of the Ministry of Natural Resources in Qingdao, Shandong, has been officially implemented on January 1, 2023. At present, there is an urgent need to use science to clarify carbon storage, and then make decisions on a scientific basis. Coastal ecosystems, such as salt marsh wetlands, seagrass beds, and mangroves, are recognized as blue carbon resources with

extremely high carbon sinking and storing efficiency. These blue carbon ecosystems besides mangroves are widely distributed in the coastal areas of Shandong Province, and they have broad application prospects. However, compared with green carbon, a dedicated observation and evaluation system for blue carbon has not yet been established, making blue carbon resources difficult to be "measurable, reportable, and verifiable" (Yang et al., 2023). Therefore, it is necessary to further strengthen the scientific research and monitoring of ocean carbon sink, establish and perfect its accounting system, and form a systematic set of verification, monitoring and evaluation methods.

3.1.3 Achieve sustainable utilization of ocean resources

Shandong may establish a healthy marine ranch model and expand blue carbon enrichment areas and marine life habitats. Marine ranches use natural bait in the ocean to cultivate seafood through technical means such as placing artificial fish reefs, building algae reefs and algae fields, and releasing fish fry into the sea. This model can achieve the conservation and replenishment of biological resources and effectively reduces the negative impact on the marine environment (Yang et al., 2016). Specifically, it helps to solve problems such as resource depletion caused by seawater pollution and overfishing, and diseases caused by offshore aquaculture (Wang, 2011). It has the function of conserving ecological resources and restoring the ecological environment in waters (Shen and Liang, 2018). The Special Report on the Ocean and Cryosphere in a Changing Climate issued by the Intergovernmental Panel on Climate Change proposed that green development concepts and scientific breeding can turn marine aquaculture from a "pollution source" into a "sink-increasing site." (IPCC, 2019). Study showed that artificially cultivated seaweed alone in China can remove approximately 330,000 tons of carbon from seawater every year (Tang and Liu, 2016), and since Shandong Province has relatively large areas for shellfish, algae, and fishery cultivation, its carbon sink capacity and scale are considerable. Shandong has a developed coastal breeding industry, it can make full use of the gathering of marine scientific and technological talents and strong platform advantages to establish a new model of healthy and modern marine ranching to promote negative ocean emissions and sustainable development (Jiao et al., 2021). Specifically, Shandong should focus on major technical bottlenecks such as the clean production and utilization of original species of economic animals and plants in marine ranches, digital management of fishery resources, automated environmental safety assurance, and efficient quality control of fishery products (Yang, 2016).

3.2 Actively explore application scenarios for ocean carbon sink

3.2.1 Cultivate the blue carbon trading market

Blue carbon trading is an important measure to transform marine resources into carbon trading assets. It can be developed into a standard financial instrument to combine financial capital and the real economy, and guide the real economy to follow the path of low-carbon development through the power of financial capital (Gao, 2022). It is necessary to actively and steadily implement the two action plans of "Innovative Development of Green Financial Products" and "Implementation of Carbon Finance Development" in Shandong Province's "Three-Year Action Plan." In addition, determining the value of blue carbon trading is an important prerequisite for cultivating a carbon trading market. Under the current world rules for carbon sink measurement and standardization, only carbon trading that meets Verified Carbon Standard can gain international recognition and offset emissions (Liu et al., 2019). And Shandong Province should formulate a price stabilization mechanism for blue carbon trading, maintain the contributions of the market to carbon emissions (Sun and Zhang, 2023).

3.2.2 Accelerate the construction of "smart ocean"

The smart ocean, which is deeply integrated with "informatization + industrialization," represents the future direction of ocean development. The construction of a smart ocean will largely reform the upstream and downstream chain of industry-academia-research on ocean carbon sink. First, establishing a comprehensive database and using big data to dynamically calculate and accurately measure ocean carbon sink. Second, developing a pilot blue carbon trading market and further stimulating the realization of the financial value of ocean carbon sink; exploring and developing futures, credit, and other financial products based on ocean carbon sink. Third, creating a blue carbon compensation mechanism, promoting blue carbon equity financing, and providing a basic support platform for carbon financial products. In short, the province should give full play to the fundraising role of the carbon financial market, achieve the dual reduction goals of total carbon emissions and energy consumption, and use market-based means to promote energy structure adjustment (Ma, 2022).

3.3 Embrace the advantages of the opening-up policy and jointly build a carbon-neutral community

3.3.1 Leverage open "special zones" to explore and implement green and low-carbon innovation

First, Shandong should leverage the policy advantages of open "special zones", such as the China (Shandong) Pilot Free Trade Zone and the China-SCO Local Economic and Trade Cooperation Demonstration Area in Qingdao, to explore and implement the cultivation of green and low-carbon innovation. It is worth noting that, from a nationwide perspective, although China has made breakthroughs in the R&D of ocean carbon sink technology, its relatively late start and lack of technical reserves in the field make it lags behind countries such as those in Europe and the United States. Therefore, Shandong should set high standards that match

international economic and trade rules, and promote the innovative development of the entire green and low-carbon industrial chain. Particular attention should be paid to extending the ocean carbon sink industry chain and increasing its added value (Cheng and Chen, 2021). At the same time, Shandong should promulgate laws and regulations related to carbon tax in a timely manner, improve relevant fiscal and taxation mechanisms, utilize trade remedy rules wisely, and actively respond to green trade barriers (Lin, 2023).

3.3.2 Promote international cooperation and jointly build a carbon-neutral community

Blue carbon is a convergence point in global governance hotspots such as climate change, biodiversity protection and sustainable development. It can be classified as an environmental issue related to climate change, and is relatively insensitive in international politics (Zhao and Hu, 2019). There are broad prospects for international cooperation in this area. Promoting international cooperation in the field of blue carbon is in the common interests of all parties, and will greatly enhance the international influence of Shandong and even China in related fields. The UN Ocean Decade Collaborative Center on Ocean-Climate Nexus has been officially established in Qingdao and it provides an important platform for international cooperation on climate change. Also, one of the three sub-forums of the 2023 East Asia Marine Cooperation Platform Qingdao Forum held in June 2023 is the International Blue Carbon Forum. The forum focused on the theme "Blue Carbon Empowers Response to Global Climate Change and Supports High-Quality Development of the Marine Economy". It discussed the current status and development trends of ocean carbon sink, relevant policies and technologies, and the path to realize the value of ocean carbon sink products. Shandong should make full use of the international influence of relevant forums and actively participate in international ocean science exchange programs. Under the United Nations framework, Shandong could develop itself into an international platform for promoting consensus and cooperation in the field of ocean carbon sink, and jointly establish a carbon-neutral community.

4 Conclusions

This study selected Shandong, an important coastal province in China, as the research object and systematically analyzed the feasibility and necessity of developing ocean carbon sink in the region. The authors summarized the achievements and problems in the development of ocean carbon sink in Shandong from three levels: system construction, technology R&D, and practical application. The study asserts that improving Shandong's ocean carbon sink capacity is a key measure for building a strong maritime province. By formulating a clear timetable and roadmap to promote blue carbon technology R&D and cultivate a blue carbon trading market, Shandong is expected to become a pioneer and leader in China in the field of ocean carbon sink. Through sharing experience and technology exchange, Shandong will drive more provinces to cooperate to achieve common development in this field, thereby successfully accomplishing China's "dual carbon" goal. In addition, by leveraging its geographical and policy advantages, Shandong Province may also serve as a vanguard for China to further promote international cooperation and contribute to building a carbon-neutral community.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

ZM: Conceptualization, Writing – original draft. HL: Writing – review & editing. ZZ: Supervision, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by the National Social Science Fund Project of China [Grant no. 20VHQ001].

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Cheng, N., and Chen, C. (2021). Marine carbon sink, carbon tax, and green technology: A research on combination strategy to achieve "Double carbon" goals. *J. Shandong University(Philosophy Soc. Sci.)* 06, 150–161. doi: 10.19836/j.cnki.37-1100/c.2021.06.015

Dazhong Daily (2023) *Changdao Marine Ecological Civilization Comprehensive Experimental Zone: From offshore farming to "algae solidification and fish gathering"*. Available at: sd.people.com.cn/n2/2023/0925/c166192-40583448.html (Accessed 23 October 2023).

Department of Natural Resources of Zhejiang Province (2023) *Guiding Opinions on Improving Ocean Carbon Sink Capacity in Zhejiang Province*. Available at: https://zrzyt.zj.gov.cn/art/2023/3/22/art_1289955_59015480.html (Accessed 23 October 2023).

Gao, X. W. (2022). Study on the mechanism of realizing the value of Marine carbon neutrality in China. *J. Dalian Marit. Univ. (Soc. Sci. Ed.)* 21 (03), 10–15.

IPCC (2019) *Special Report on the Ocean and Cryosphere in a Changing Climate*. Available at: https://www.ipcc.ch/srocc/ (Accessed 23 October 2023).

Jiao, N. Z., Liu, J. H., Shi, T., Zhang, C. L., Zhang, Y. Y., Zheng, Q., et al. (2021). Deploying ocean negative carbon emissions to implement the carbon neutrality strategy (in Chinese). *Sci. Sin. Terrae* 51 (4), 632–643. doi: 10.1360/SSTe-2020-0358

Lin, W. (2023). Learn deeply and apply Xi Jinping ecological civilization thought to accelerate the construction of green, low-carbon and high-quality development pilot zone. *Environ. Sustain. Dev.* 48 (02), 38–43. doi: 10.19758/j.cnki.issn1673-288x.202302038

Liu, F. M., Liu, D. H., and Guo, Z. L. (2019). Study on economic value accounting of ocean carbon sink. *Mar. Sci. Bull.* 38 (01), 8–13+19.

Ma, C. C. (2022). Hainan International Carbon Emission Trading Center came to highlight the marketization of blue carbon products. *China Business News*. 2022-03-21(A06).

Ministry of Natural Resources of the People's Republic of China (2023) *HY/T0349-2022*. Available at: https://www.mnr.gov.cn/dt/hy/202301/t20230112_2772717.html (Accessed 23 October 2023).

Shandong Provincial People's Government (2022a) *Action Plan for Building a Strong Marine Province*. Available at: www.shandong.gov.cn/art/2022/3/3/art_107851_117797.html (Accessed September 13 2023).

Shandong Provincial People's Government (2022b) *Implementation Plan for Carbon Peaking in Shandong Province*. Available at: www.shandong.gov.cn/art/2022/12/28/art_107851_123025.html (Accessed September 13 2023).

Shandong Provincial People's Government (2023) *Three-Year Action Plan for Building a Green, Low-Carbon and High-Quality Development Pioneer Area in Shandong Province, (2023-2025)*. Available at: www.shandong.gov.cn/art/2023/1/3/art_107851_123167.html (Accessed September 13 2023).

Shen, J. S., and Liang, R. F. (2018). Study on the blue carbon sink pricing of marine ranch. *Resour. Sci.* 40 (09), 1812–1821.

Sun, J., and Zhang, X. Y. (2023). Theoretical analysis and path selection of blue carbon development in China. *Sci. Technol. Manage. Res.* 43 (08), 203–209.

Tang, Q. S., and Liu, H. (2016). Strategy for carbon sink and its amplification in marine fisheries. *Strateg. Study CAE* 18 (03), 68–73.

The State Council of the People's Republic of China (2022) *Opinions on Supporting Shandong to Deepen the Conversion of New and Old Momentums to Promote Green, Low-carbon and High-Quality Development*. Available at: https://www.gov.cn/gongbao/content/2022/content_5710611.htm (Accessed September 3 2023).

UN (2009) *Blue carbon: the role of healthy oceans in binding carbon*. Available at: https://wedocs.unep.org/20.500.11822/7772 (Accessed 23 October 2023).

Wang, S. C. (2011). Ocean ranching: a promising new industry. *Seeking* 19, 38–38.

Wang, X. J., Zhang, H. B., and Han, G. X. (2016). Carbon cycle and "Blue carbon" Potential in China's coastal zone. *Bull. Chin. Acad. Sci.* 31 (10), 1218–1225. doi: 10.16418/j.issn.1000-3045.2016.10.012

Wei, Y. (2022). President of the National Institute for South China Sea Studies, Wang Sheng: Seize the international commanding heights in Marine carbon sink research. *Hainan Daily*, 2022–23-8.

Yang, H. S. (2016). Construction of marine ranching in China: reviews and prospects. *J. Fish. China* 40 (07), 1133–1140.

Yang, H. S., Huo, D., and Xu, Q. (2016). Views on modern marine ranching. *Oceanologia Et Limnologia Sin.* 47 (6), 1069–1074.

Yang, T., Gao, F., Zhang, J. B., Zhou, X. Q., Zhao, Y. X., and Zhou, G. J. (2023). Strategy of marine carbon sink development in Yantai based on SWOT-PEST matrix analysis. *J. Zhejiang Ocean Univ. (Nat. Sci.)* 3, 267–273.

Zhao, J. D. (2023). Standardized accounting standards enable blue carbon economy. *China Nat. Resour*. News 2023-01-10(005).

Zhao, P., and Hu, X. D. (2019). International blue carbon cooperation and China's choice. *Mar. Sci. Bull.* 38 (06), 613–619.

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 30 November 2023
DOI 10.3389/fmars.2023.1302190

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Sumedh Lokhande,
Auro University, India
M Jahanzeb Butt,
Shandong University, China

*CORRESPONDENCE
Lei Yang
yanglei_law@sdjzu.edu.cn

RECEIVED 26 September 2023
ACCEPTED 20 October 2023
PUBLISHED 30 November 2023

CITATION
Yang L (2023) China's marine environmental public interest litigation: current situation, challenges, and improvement approach –analysis based on 339 cases.
Front. Mar. Sci. 10:1302190.
doi: 10.3389/fmars.2023.1302190

COPYRIGHT
© 2023 Yang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

China's marine environmental public interest litigation: current situation, challenges, and improvement approach – analysis based on 339 cases

Lei Yang*

School of Marxism, Shandong Jianzhu University, Jinan, China

Marine pollution and ecological damage seriously undermine economic and social development and human life and health and threaten the sustainable development of human society. With the rapid development of industrialization and urbanization and the intense exploitation of marine space and marine natural resources, China's marine ecology is facing serious problems such as pollution of marine waters, the decline of marine plant and animal resources, and the impairment of the ecological function of coastal zones. China's marine environmental public interest litigation (MEPIL) has achieved remarkable results in protecting marine natural resources, safeguarding the marine ecosystem, and preventing marine pollution and ecological damage. The paper closely combines the judicial practice of Chinese MEPIL, exploring 339 legal cases brought by administrative organs, public prosecutors, and non-governmental organizations (NGOs) presented on the China Judgment Online from 2018 to 2023. It can be concluded that three modes of MEPIL, namely civil, administrative, and civil public interest litigation incidental to criminal proceedings, have been constructed. Attempts have been made to confirm the standing of the litigation, improve the pre-litigation procedure, and clarify the types of compensation. However, significant obstacles exist in China's MEPIL. Theoretical clarifications and practical distinctions with other types of proceedings should be made. The current standing should be improved regarding procuratorial organs, administrative authorities, and social organizations. Court jurisdiction systems need to be enhanced. Inconsistencies in the legal provisions on whether MEPIL cases must be under the exclusive jurisdiction of the maritime courts have impeded the efficiency of the handling of cases. The corresponding solutions to the aforementioned obstacles are also analyzed. Clarifying the MEPIL's nature and improving the relevant laws, and regulations, are essential measures. In addition, providing the explicit interpretation of the legal provisions, expanding the standing, and improving the jurisdictional and other legal system should be explored.

KEYWORDS

marine pollution, marine ecology and natural resources, public product, marine environmental public interest litigation, expansion of standing, jurisdictional system

1 Introduction

The protection of the marine environment, the preservation of marine biodiversity, and the sustainable exploitation of marine resources are both in the public interest for the survival and development of human society and a matter of inter-generational equity in terms of the rights of future generations, requiring the joint efforts of the international community (Wang and Chang, 2023). China's national Ocean strategy aims to "protect the marine ecosystem, resolutely safeguard the national rights and interests in the oceans and seas, and build a strong oceanic nation." The proportion of the marine economy in China's national economy has gradually accelerated. Moreover, according to the 2022 China's Marine Economy Statistical Bulletin, the gross marine product was 9,462.8 billion yuan, an increase of 1.9 percent over the previous year and 7.8 percent of the gross domestic product (GDP) (Ministry of Natural Resources of the P.R.C., 2022). However, with the enhancement of the intensity of marine exploitation and utilization, the negative impacts of human activities on the marine ecosystem have increased dramatically (Chen et al., 2017). The carrying capacity of the marine ecosystem has been declining, and the ecological environment has faced challenges. According to the data presented in the 2022 China Marine Environmental Status Bulletin, the marine ecosystem in China's waters is steadily improving (Ministry of Ecology and Environment of the P. R. C., 2022). However, there is still the sub-healthy state of typical marine ecosystems, marine water pollution, biodiversity decrease, and ecological service capacity decline.

Environmental public products refer to the public benefits that the environment carries due to its ecological service functions and ability to satisfy human society's multiple needs (Chu, 2018). The marine environment is a typical public product with obvious non-exclusivity and non-competitiveness, therefore involving the public interests of the unspecified majority. In other words, the benefits of the marine environment should fall into the category of public products. Marine environmental pollution and resource destruction are usually not directly targeted at the unspecified majority (Jiang et al., 2020) and have the characteristics of latency, accumulation, mobility, and complexity. Damage to the marine ecosystem includes negative impacts on the marine environment, such as the water column, the atmosphere, seabed sediments and seabed resources, and marine organisms, such as plants, animals, and micro-organisms, as well as the degradation of the functioning of marine ecosystems composed of the marine environment and marine organisms as a result of the pollution of the environment and the destruction of ecological elements (Ruys, 2021). There is a clear difference with the general environmental infringement. Due to limitations such as the limitation of standing, the cumulative and diffuse nature of environmental aggression, the failure of victims to sue, and the unavailability of preventive consultation, the traditional tort remedies system based on ordinary ownership rights is unable to protect environmental public products promptly. The concept of China's MEPIL remains highly debatable in China. Based on the general theory of the academic community, MEPIL is defined as litigation initiated by citizens, environmental and social organizations, administrative authorities, and procuratorates (Yang, 2013) to safeguard the public interest in the marine environment (Gao and Gao, 2018). The parties authorized by law to bring civil, administrative, and criminal collateral civil actions before the courts against acts that are detrimental to or pose a substantial threat to the marine ecosystem under the jurisdiction of China or against the failure to carry out their obligations or the illegal performance of their duties by the administrative organs (Huang and Wang, 2020; Chu, 2023). The advantages of the MEPIL system lie in its ability to share the litigation costs reasonably, allocate the burden of proof, and extend the statute of limitations so that the public interest in the environment can be effectively safeguarded (Bayraktarov et al., 2016). Those parties authorized by Chinese law include administrative authorities, procuratorial organs, and social organizations (Wang, 2021). The individuals do not have standing in MEPIL in China (Jiang and Faure, 2022).

This paper first analyses the types of cases, geographical distribution, standing, distribution of causes of action, jurisdiction, claims, adjudication, and other elements in 339 cases of MEPIL. Based on the analysis, it is found that China's MEPIL has distinctive characteristics (Jia, 2022) and is designed to protect public interests such as marine ecology and biological resource diversity (Li, 2022), effectively enforces the law (Liu Z., 2020) and enhance sustainable development (Zhai, 2018). In addition, China's MEPIL faces obstacles such as a low record of lawsuits filed by administrative organs, inadequate legal basis for standing of social organizations, under-utilization of the ecological damage compensation (Xie and Xu, 2021), and the defects of the litigation jurisdiction system (Xie and Xu, 2022). At the same time, the research results will provide insights into the current conflict between the legal provisions, academic debates, and judicial practice. The establishment of the Basic Law of the Sea of China should be used as an essential opportunity to establish the exclusive jurisdiction of the maritime court gradually, clarify the standing of the administrative organs, procuratorial organs, and social organizations (Gao and Whittaker, 2019), reduces the conflict of laws, unify the judicial interpretation, and improve the judicial jurisdiction, establish the system of ecological compensation damage and specify the scope of damage compensation, etc.

2 Overview of the status of MEPIL in China

All cases were searched on the China Judgement Online, a professional judgment disclosure and retrieval system set up by the Supreme People's Court of PRC (SPC), to uniformly publish the effective judgment of the people's courts at all levels. To ensure the accuracy and comprehensiveness of the case searches, the terms "marine," "environment," "ecology," "damage," and "public interest litigation" were used as the keywords in the advanced search fields of the website. Moreover, the search scope was set to "full-text search," with no limitation on the type of case. The effective date of the Several Issues Concerning the Trial of Cases of Disputes over Compensation for Damages to Marine Natural Resources and the

Ecological Environment promulgated by the SPC was 15 January 2018. Then the start time was set to 15 January 2018 and the deadline was 1 June 2023 (the search date), with 539 cases retrieved. Moreover, 339 valid cases of MEPIL were obtained after the exclusion of the cases of unlawful land encroachment, illegal hunting, etc. The types of cases, geographical distribution, the standing of litigation, distribution of jurisdiction, litigation claims, and decisions were analyzed comprehensively, using the above collection of judicial documents as samples.

2.1 Types of cases are predominantly by civil suit collateral to criminal proceedings

Through the above analysis, it can be found that in China's judicial practice, MEPIL cases include three main types. First is the civil public interest litigation involving the marine environment brought by the procuratorial organs and social organizations. The second is administrative cases filed by the procuratorial organs against the administrative organs concerned for failing to fulfill their administrative duties to preserve the natural resources of the sea and the ecological environment. The third is the case of Civil Suit Collateral to Criminal Proceedings(CSCCP). Of the 339 decisions, 287 (84.66 percent) were CSCCP cases, 47 (13.86 percent) were civil cases, and 5 (1.47 percent) were administrative cases (see Figure 1 below). From the perspective of safeguarding the public interest, CSCCP is essentially civil, in which the infringers of the public interest in the marine ecosystem and natural resources bear civil liability.

2.2 Geographically widespread and time-concentrated

The distribution of cases of MEPIL is not balanced according to the geographic location of the cases from the north to the south, with 11 cases in Liaoning, 2 cases in Tianjin, 10 cases in Hebei Province, 42 cases in Shandong Province, 37 cases in Jiangsu Province, 10 cases in Shanghai, 76 cases in Zhejiang Province, 29 cases in Fujian Province, 51 cases in Guangdong Province, 46 cases in Guangxi Province, and 29 cases in Hainan Province. The number of cases in Zhejiang, Guangdong, Guangxi, and Shandong exceeded 40, demonstrating the concerns given to marine environmental protection. Overall, the economically developed coastal provinces in the southeast have seen more MEPIL cases.

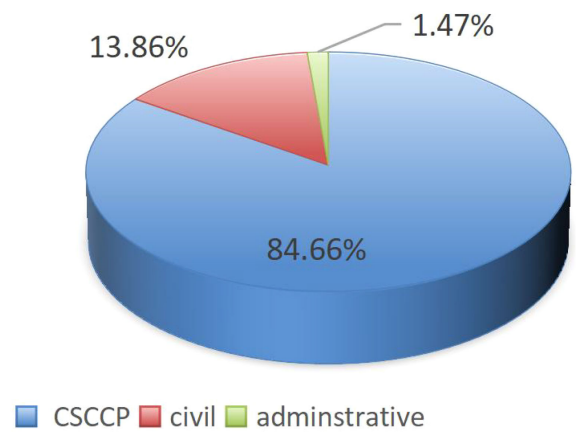


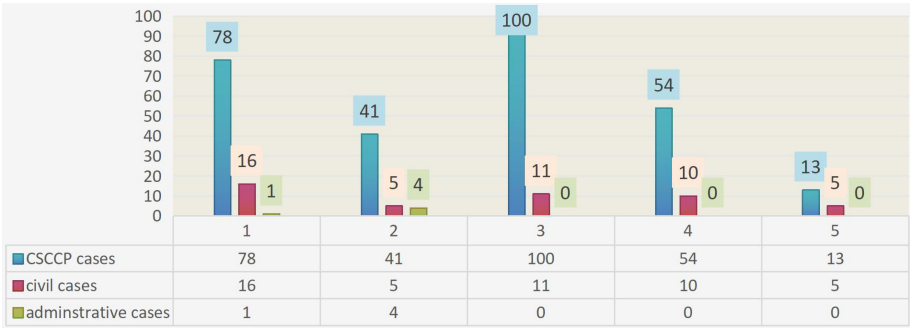
FIGURE 1
Percentage of Different Types of MEPIL Cases.

The main reason is that the public, the Government, and the judiciary are aware of the critical role of MEPIL in protecting marine ecosystems and resources. Regarding time distribution, MEPIL cases are mainly distributed from 2018 to 2021, with a significant drop in 2022. The time of occurrence of cases is shown in Figure 2. Cases of civil litigation incidental to criminal proceedings were 78 cases in 2018, 41 in 2019, 100 cases in 2020, 54 cases in 2021, and only 13 cases in 2022 and 1 case in 2023. Civil cases were 16 in 2018, 5 in 2019, 11 in 2020, 10 in 2021, and 5 in 2022. One administrative case was brought to court in 2018, 4 in 2019, and zero in 2020 and 2022 (see Figure 2 below).

In marine environmental public interest litigation, there has been a rapid increase in the number of cases filed by the Procuratorate and in the number of cases accepted and adjudicated by the People's Courts from 2018 to 2021. This trend is closely related to the implementation of judicial regulations on public interest litigation and the continuous improvement of trial rules (Jiang, 2019). The Interpretation of the Supreme People's Court and the Supreme People's Procuratorate on Certain Issues Concerning the Application of Law to Procuratorial Public Interest Litigation (hereinafter referred to as the Judicial Interpretation of Procuratorial Public Interest Litigation) was promulgated in 2018, which, based on summarizing the procuratorial public interest litigation pilots, stipulates the status of procuratorates, the trial procedures, and the duties of trials.

The trial rules of procuratorial public interest litigation have been continuously improved, such as stipulating that the trial organization of public interest litigation is a seven-member collegiate court composed of people's jurors and judges. The technical experts played important roles in ascertaining the facts of damage, selecting remediation solutions, and inspecting the results of remediation. A system of environmental injunctions was implemented, whereby injunctions were issued to prohibit or restrict polluters from discharging before or in the course of litigation, preventing the expansion of the results of pollution damage (Liu Y., 2020). Another reason for the time-concentrated distribution is that from February 2019 to February 2020, the Supreme People's Procuratorate (SPP, thereafter) launched the Procuratorial Special Activity entitled "Protecting the Oceans". The special operation included five major areas, including the prevention and control of pollution from land-based sources, the conservation and restoration of marine ecology, and the supervision of the administrative management of the marine environment, to set up the framework for the prosecution to initiate MEPIL.

This operation contributed to marine sustainable development (Wang, 2021) even though it received criticism from academic researchers:152 public interest litigation cases were filed, cleaning up more than 332,000 cubic meters of rubbish from beaches, removing 260 outfalls, repairing 25.3 kilometers of coastline and



	1	2	3	4	5
CSCCP cases	78	41	100	54	13
civil cases	16	5	11	10	5
adminstrative cases	1	4	0	0	0

FIGURE 2
The Distribution of Cases of MEPIL.

168 kilometers of river channels, restocking more than 130 million tails of fish resources, and recovering compensation funds of 218 million yuan (The Supreme People's Prosecutor, 2019). After the special operation, the system of public interest litigation in the marine environment initiated by the procuratorial authorities was established to sustain the positive effects of the protection of the marine ecosystem.

2.3 Procurator-led in MEPIL

Procuratorial organs are the dominant force in filing MEPIL suits (Wang and Xia, 2023), with 287 CSCCP cases, 24 civil cases, and 5 administrative cases, accounting for 93.21 percent of the total 339 cases, demonstrating their active fulfillment of the statutory duties of the prosecution and important roles in the protection of the marine ecological environment and resources (Zhang et al., 2023). The scope of public interest litigation cases, the standing, the pre-litigation procedures, and the litigation requirements for civil and administrative public interest cases brought by procuratorial organs were clarified for the first time in 2015. Subsequently, A series of judicial interpretations on public interest litigation initiated by procuratorial organs have been promulgated and implemented, for instance, the Pilot Reform Programme for Public Interest Litigation by Procuratorial Organs, etc. Article 58 of the Civil Procedure Law of the P.R.C (the Civil Procedure Law, thereafter) and Article 25, paragraph 4 of the Administrative Procedure Law of the P.R.C (the Administrative Procedure Law, thereafter) stipulate the specific rules of environmental public interest litigation initiated by the procuratorial organs, as well as the rules of trial procedures.

The direct legal basis for prosecutors to initiate MEPIL is Several Issues Concerning the Handling of Cases of Public Interest Litigation on Marine Natural Resources and the Ecological Environment and Several Issues Concerning the Trial of Cases of Disputes over Compensation for Damages to Marine Natural Resources and the Ecological Environment of the P.R.C, which set out in detail the standing and the requirements for the prosecutors. Regarding behaviors that damage the marine ecological environment and infringe upon national interests and the public interests of society, procuratorial organs may carry out pre-litigation procedures and initiate public interest litigation for the marine ecological environment by the law, if the administrative organ still fails to implement its duties by the law, or if the social organization fails to file a lawsuit (Wang and Chang, 2021).

2.4 Diversity of administrative organs

The Marine Environment Protection Law and the second paragraph of Article 89 of the Civil Procedure Law stipulate that administrative organizations with the authority to supervise and manage marine resources and ecology provided by law may bring public interest actions before the courts. The administrative organs with powers of supervision and management of the oceans and seas include five main categories (see Table 1 below):

First, the Ecological and Environmental Protection Bureau, manages marine environmental protection and pollution prevention and control. Second, the Natural Resources and Planning Bureau, is mainly responsible for developing marine renewable energy, marine biology, and other industries, and managing marine resources, such as the development and use of islands. Third, the Marine Development Bureau, or Marine and Fisheries Development Bureau in some local administrative governments, is mainly responsible for administrative permission and supervision of the right to use the Maritime Space. Fourth, the Agriculture and Rural Affairs Bureau is in charge of the management of marine fishery resources. Fifth, the China Coast Guard and its branches have the right to initiate civil public interest litigation for ecological and environmental damages against infringers who damage the marine ecological environment, by the legal authorization in Article 5 of the Coast Guard Law of the P.R.C.

There were 15 cases brought by administrative organs as follows: eight cases brought by the local Ecological and Environmental Protection Bureau, or Natural Resources and Planning Bureau as the plaintiffs. Five cases were brought by the Marine Development Bureau or Agriculture and Rural Affairs Bureau. For example, the public interest litigation in the dispute over liability for damage caused by marine pollution was filed by the Bureau of Marine and Agricultural Affairs of the Administrative Committee of the Zhuhai Economic and Technological Development Zone—one case by the Xiamen Coast Guard, Fujian province.

TABLE 1 The Administrative Organs of Cases of MEPIL.

Administrative organs	Administrative Regulatory Authorities
Ecological and Environmental Protection Bureau	Marine environmental protection and pollution prevention
Natural Resources and Planning Bureau	Developing marine renewable energy, marine biology and other industries, and managing marine resources
Marine Development Bureau	Administrative permission and supervision of the right to use the Maritime Space, implementation of fisheries fishing licensing and fishing moratorium
Marine and Fisheries Development Bureau (or Marine and Fisheries Bureau)	Conservation and exploitation of fishery resources, aquatic resources, and aquatic wildlife; Fisheries fishing licensing system; aquaculture Licence for Watersheds and Mudflats
Agriculture and Rural Affairs Bureau	Protecting and utilizing fishery resources, maintaining the ecological environment of fishery waters and aquatic wildlife
China Coast Guard and its branches	Supervision and inspection of activities relating to the exploitation of marine resources, protection of the marine ecosystem, and production and operation of marine fisheries

In 2022, the first marine public interest litigation case brought by the Xiamen Coast Guard was heard in Xiamen Maritime Court. A dredging shipping belonging to some Anhui Wuhu company violated the scope of the dumping area delineated in the Marine Dumping Permit for waste, with an area of 115,275 square meters, which seriously endangered the ecological safety of the Xiamen Precious and Rare Marine Species National Nature Reserve. The nature reserve is a national habitat of animals such as the Chinese white dolphin and 12 other kinds of rare marine species. As the marine civil public interest litigation plaintiff, the Xiamen Coast Guard filed a lawsuit, requesting the defendant to compensate for the ecological environment remediation of more than 1.28 million yuan. Xiamen Maritime Court confirmed the standing of the Xiamen Coast Guard, and the offender shall be responsible for marine ecological environment damage compensation. The court prompted both parties to reach a mediation agreement, in which the defendant agreed to take responsibility for compensation of ecological damages and restorations of the National Nature Reserve (Xiamen Maritime Court, 2022).

Moreover, one case was brought by the joint efforts of the Jiaxing Municipal Bureau of Natural Resources and Planning, Ecology and Environment Protection, and Agriculture and Rural Affairs. Multi-departmental public interest litigation can be initiated jointly when marine ecosystems and resources suffer damage due to waste dumping or oil spill accidents. For example, the plaintiff Jiaxing City Natural Resources and Planning Bureau, Jiaxing City Bureau of Ecology and Environment, Jiaxing City Bureau of Agriculture and Rural Affairs (hereinafter referred to as the three plaintiffs) and the defendant of the dispute over the validity of the maritime claims, the Procuratorate of Jiaxing City, Zhejiang Province, in support of the public interest litigation. The court found that the three departments enforced of powers and duties to supervise and manage the marine environment involved in the case. The three plaintiffs had the right to bring MEPIL and claim compensation against the defendant for the damage to the marine ecosystem and fishery resources caused by the oil spill within the maritime area under their jurisdiction.

2.5 The standing of social organizations is controversial

A total of eight marine civil public interest litigation cases were initiated by social organizations, five cases were accepted, and three were ruled to dismiss due to the lack of standing. The main legal basis for determining the standing of social organizations is Article 58 of the Civil Procedure Law of the P. R. C. (amended in 2021, the Civil Procedure Law, thereafter) which stipulates that concerning pollution of the environment and other acts detrimental to the public interest, the relevant organizations prescribed by the law may bring an action in Court. According to Article 58 of the Environmental Protection Law of the P. R. C (EPL), relevant social organizations should meet two basic requirements before they can bring civil MEPIL, including registration at the municipal Civil Affairs Department or above and specialization in environmental protection activities for more than five consecutive years without any record of violation of the law.

For example, in the environmental public interest litigation between Jinhua Green Ecological Cultural Service Centre (plaintiff, appellee)and A Co., Ltd., (defendant, appellant), the appeal court, the High People's Court of Shandong Province (Shandong High People's Court, thereafter), adopted the above reason and ruled that the Jinhua Green Ecological Cultural Service Centre had the standing to bring the lawsuit. However, the trend towards denying social organizations standing to bring civil public interest litigation in the marine environment is strengthening. The ground for the decision to dismiss the standing was article 89, subsection 2, of the Marine Environmental Protection Law of the P.R.C (the Marine Environmental Protection Law, thereafter), which provides that, in the event of substantial damage to marine ecology, aquatic resources or marine protected areas, the administrative organs supervising and managing the marine environment shall, on behalf of the State, could claim damages from those responsible. In addition, some judges considered that the Marine Environment Protection Law was a specific law for the protection of the marine environment. The EPL, on the other hand, is a general law on environmental protection. According to the basic legal principle established in the Legislation Law of the PRC, specific laws take prevalence over general laws, and therefore the standing of maritime litigation about compensation claims is limited to the marine administrative departments.

From the perspective of the interpretation of the legal system, how to interpret the provisions of Article 89 is considerable controversy in both academic and judicial circles. In judicial practice, uncertainty about the standing of social organizations has reduced litigation efficiency, thus seriously hampering marine ecological environmental protection (Huang and Wang, 2020). For example, in 2018, the Friends of Nature Environmental Research Institute in Chaoyang District, Beijing, filed a civil MEPIL case in

Qingdao Maritime Court because the defendants had engaged in illegal fishing during the closed season, damaging the marine ecological environment. The Qingdao Maritime Court dismissed the case, the appeal was denied by the Shandong High People's Court, and the retrial was rejected in 2020 for the same reasons mentioned above.

2.6 Inconsistency of legal provisions of the jurisdiction

The lack of uniformity in the legal provisions on jurisdiction has undermined judicial efficiency. By the provisions of the Maritime Procedure Law of the P.R.C. (Maritime Procedure Law, thereafter), cases of damage resulting from marine pollution caused by ship discharges, manufacturing at sea, and vessel operations are under the exclusive jurisdiction of the maritime courts. However, judicial practice is not consistent regarding the jurisdiction of cases relating to the marine environment and ecological system.

2.6.1 Jurisdiction over civil public interest litigation

There are two types of courts with jurisdiction over civil public interest litigation for the marine environment. Civil MEPIL cases brought by procuratorial and administrative organs, including disputes related to the protection of the marine environment and in navigable waters through the sea, are under the exclusive jurisdiction of the maritime courts. Environmental and ecological pollution occurs on both land and sea, and the jurisdiction of public interest litigation is differentiated according to the place of occurrence. The maritime portion is under the jurisdiction of the maritime courts, while the portion that is not maritime, such as land and mudflats, is under the jurisdiction of the local courts. In some cases, the provincial high people's court may designate centralized jurisdiction (Lv and Zhang, 2017). Disputes have arisen mainly because that Maritime Courts usually do not accept lawsuits brought by social organizations because they are denied having standing.

Consequently, the conflict of jurisdiction under the law leads to an illogical situation in which social organizations have no standing if the pollution harms the marine ecosystem, whereas standing is available if the pollution harms both the marine ecosystem and the terrestrial environment (Chu and Zhao, 2023). For example, the China Biodiversity Conservation and Green Development Foundation (the Green Development Foundation, thereafter) sued the local government of Liushui Town, Fujian Province, and B Company of Pingtan County, in an environmental public interest litigation for ecological damage. The SPC held that the project in question was on mudflats and that mudflats are part of the land. About the environmental civil public interest litigation brought by social organizations against mudflat environmental pollution and ecological damage based on the provisions of Article 58 of the Environmental Protection Law, Article 55 of the Civil Procedure Law, and other laws and judicial Interpretations, the SPC was finally ruled that the Green Development had standing to file the public interest litigation.

2.6.2 Jurisdiction of CSCCP cases

Only two CSCCP cases were heard in maritime courts, while the rest were mainly under the jurisdiction of the local primary courts. For example, in 2021, the Ningbo Maritime Court heard the first CSCCP case involving a national marine special protection area in Zhejiang Province. The two defendants had already been sentenced to prison for the illegal fishing of aquatic products respectively. After the criminal trial, the Zhoushan Municipal Procuratorate filed a separate civil MEPIL to the Ningbo Maritime Court. The main reasons for this are: first, according to article 104 of the Criminal Procedure Law of the PRC, incidental civil litigation should be tried together with criminal cases. Secondly, apart from the Ningbo Maritime Court, which had obtained authorization to hear criminal cases from the SPC, the other maritime courts are unable to hear criminal cases directly and are therefore unable to hear criminal incidental civil litigation together. However, Article 5 of the Judicial Interpretation of Procuratorial Public Interest Litigation and Article 6 of the Judicial interpretation of Environmental Civil Public Interest Litigation stipulate that civil public interest litigation cases of the first instance shall be under the jurisdiction of the Intermediate People's Court. The non-uniformity of the rules applicable to the jurisdiction of CSCCP cases has led to a litigation model that divides civil and criminal trials, the complexity of the litigation procedures, and the waste of litigation resources. The collection and the determination of the evidence in the civil case may be inconsistent with the consequences of the criminal case, and so on. The criminal part needs to be transferred from the police organ to the local prosecutor's office for prosecution and trial in the local court, while the civil part is heard in the maritime court, where the filing of the civil suit, court investigations, and questioning of evidence are needed to be re-examined again.

Therefore, some scholars believe that the current separation of civil and criminal trials in maritime cases in China is a severe waste of judicial resources (Cao X. G., 2017). Moreover, some researchers proposed that the maritime court should be authorized to have the right to adjudicate criminal cases and incidentally to adjudicate civil cases simultaneously, which can save litigation expenses, reduce the number of litigation links, improve the quality of handling cases, effectively combat criminal crimes related to the sea, and improve the maintenance of the marine ecological environment (Wu and Liu, 2019).

2.6.3 Jurisdictional disputes of administrative cases

There are disputes about whether these first-instance cases are handled by the maritime court or by the primary people's court where the administrative organ, the defendant, is located. By articles

14 and 18 of the Administrative Procedure Law, the primary People's Court at the location of the administrative organ that initially conducted the administrative act has jurisdiction over administrative cases of the first instance. Article 5, paragraph 2, of the Judicial Interpretation of Procuratorial Public Interest Litigation, makes the same stipulation.

However, article 81 of Provisions on the Scope of Cases Accepted by the Maritime Courts stipulates that disputes resulting from administrative activities involving the development and utilization of navigable waters to the sea, fisheries, and the protection of the environment and ecological resources, by maritime administrative organs, are to be under the jurisdiction of the maritime courts. Article 2 of the Provisions of the SPC on Jurisdictional Issues in Maritime Litigation (Provisions on Jurisdictional Issues in Maritime Litigation, thereafter)also clearly stipulates that first-instance maritime administrative cases are to be heard by the Maritime Court and that appeals are heard by Provincial High Court(Article 2 of the Provisions on Jurisdictional Issues in Maritime Litigation). The jurisdiction of the first instance directly determines the different courts of appeal. The parties should appeal to the High Court if they fall within the jurisdiction of the Maritime Court, and to the Intermediate People's Court if they are failed in the Primary Court.

Of the five administrative MEPIL cases, only one was heard in the Maritime Court, while the remaining four were in the primary courts. A jurisdictional dispute arose before the Maritime Court in the marine public interest litigation case brought by the People's Procuratorate of Wenchang City, Hainan Province (plaintiff in the first and appellee in the second). The defendant in the first instance (appellant in the second) was the Bureau of Agriculture and Rural Affairs of Wenchang City, Hainan Province, assuming responsibility for protecting and supervising marine fishery resources from the former Bureau of Ocean and Fisheries. The Bureau of Agriculture and Rural Affairs of Wenchang City failed to investigate the large quantity of illegal "fixed nets" in the maritime areas under its jurisdiction and dismantle them within a certain period. The People's Procuratorate of Wenchang City filed a MEPIL suit before the Haikou Maritime Court, requesting confirmation that the administrative organ violated the law and should fulfill its legal duties within six months. The defendant raised a jurisdictional challenge, arguing that the case should be under the jurisdiction of the People's Court of Wenchang City, the primary court where the defendant is located. The Haikou Maritime Court, by the Provisions on the Scope of Cases Accepted by the Maritime Courts, held that the case was a maritime-related administrative public interest litigation case. It also held that the second paragraph of Article 5 of the Judicial Interpretation of Procuratorial Public Interest Litigation was the general provision on the jurisdiction, whereas Article 2 of the Provisions on Jurisdictional Issues in Maritime Litigation was the provision on the specialized jurisdiction of administrative maritime cases, which should be applied. Therefore the case was under the jurisdiction of the Haikou Maritime Court. The jurisdictional challenge filed by the defendant was rejected by the court. Then the defendant appealed to the High People's Court of Hainan Province, but the appeal request was rejected again.

2.7 Diversification of grounds, claims and settlement of cases

As shown in the Figure 3, the criminal charges in the CSCCP were the offenses of illegal fishing of aquatic products in 232 cases, accounting for 80.83 percent. Other offenses include pollution of the environment (mainly dumping toxic and harmful substances), endangering endangered and precious wildlife (marine rare and endangered wildlife), and illegal mining (mainly illegal mining of sea sand). The total number of illegal mining offenses was 17, accounting for a relatively 5.92 percent. The civil claims in the CSCCP were generally to undertake ecological compensation, marine ecological environment or fishery resources restoration costs, assessment fees, appraisal expenses for environmental pollution, or public apologies in the mass media.

The types of civil public interest litigation show diversity, mainly covering a variety of fields such as marine pollution prevention and control, resource protection, ecological protection, etc., and marine environmental pollution liability dispute cases account for about half of the entire MEPIL. Others include environmental pollution liability disputes, maritime commercial disputes, disputes over liability for pollution damage at sea and through sea waters, disputes over liability for pollution damage to the marine environment, and tort liability disputes.

The MEPIL claims were mainly to undertake ecological environment restoration costs, judicial appraisal fees or ecological environment restoration appraisal fees, and public apologies in the media, with a few cases including expert appraisal fees and lawyers' fees. Regarding the results of judgments, mediation was applied to 12 cases, accounting for about half of the cases. The Bureau of Ecological Resources and Environment brought two cases to confirm that claims were upheld. Twenty-four cases brought by the Procuratorate, with claims for payment of environmental pollution and ecological restoration costs, were all supported.

All five administrative public interest litigation cases were initiated by procuratorial authorities, with the claim being to confirm that the relevant administrative authorities had failed to fulfill their statutory duties and to require them to do so within a specified period. Four administrative judgments were rendered, all in favor of the prosecution, and one case was withdrawn. The administrative authorities being sued include the Bureau of Agriculture and Rural Development as the defendant in 1 case for failing to supervise and ban illegal fishing equipment effectively. The Bureau of Ocean Developments was the defendant in two cases, the

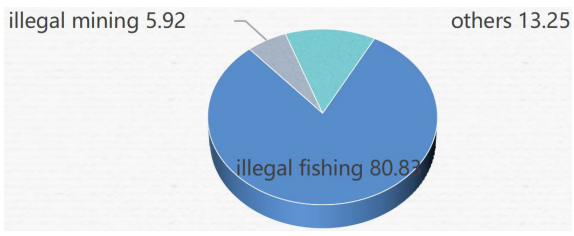


FIGURE 3
Percentage of Different Criminal Offenses in the CSCCP Cases.

Maritime Bureau in one case and the Bureau of Ocean and Fisheries in one case, for not fulfilling its statutory duties relating to the prevention of marine environment pollution, the protection of marine fishery resources, marine ecology, and other resources. Of the 339 MEPIL cases, 17 were settled by mediation, 22 by adjudication, and the rest by verdict. Public interest litigation initiated by procuratorial authorities had a higher probability of winning in litigation, except for withdrawn cases.

3 Obstacles faced by China's MEPIL

In conclusion, as the marine environment public interest litigation has not formed a complete institutional system, the lack of uniformity of legal provisions and the failure to fully reflect the nature of public interest and other problems are apparent. Many aspects, such as the arrangement of the standing and the order of the parties, jurisdiction and claims, reconciliation, conciliation and withdrawal, and the system of ecological damages, still need to be developed. The relationship between ecological damages litigation and MEPIL is still controversial. Taking into account the actual situation of the judicial practice of public litigation in the marine environment in China, the Basic Law of the Oceans to be enacted in the future should contain systematic provisions on the system of public interest litigation in the marine environment, including clearly defining the standing and order of precedence in MEPIL, procedural requirements, jurisdiction, application of legislation, and the methods of adjudication of the cases, and so on.

Many problems have arisen in marine environmental public interest litigation, such as different theoretical interpretations of relevant legal provisions, conflicts in the application of law in judicial practice, disputes over the standing of MEPIL, and jurisdictional disputes. The fundamental reason lies in the controversy over the nature of the National Claims for Marine Ecological Damage Suits(NCMED), the function and positioning of marine environmental public interest litigation are not explicit, and the system of co-management of marine ecological damage is not well-developed.

3.1 Conflicts between the NCMED and the MEPIL

There are many theoretical disputes and inconsistent judicial practices regarding this provision. Article 89, paragraph 2 of the Marine Environmental Protection law provides that departments exercising supervisory and management powers over marine environmental resources by the law shall bring actions to claim compensation on behalf of the State for damage to marine natural resources and ecosystems. In the case of serious damage to the marine environment, the administrative authorities are empowered by law to repair the damage to ecological resources through this legal procedure. Especially where the means of enforcing marine environmental resources, such as administrative penalties and administrative enforcement, are still unable to provide adequate relief, the National Claims for Marine Ecological Damage suits created by the Marine Environment Protection Law for cases of serious damage to the marine environment is intended to provide a complementary function to the damage to ecological resources, with priority to be given to the exercise of the administrative authorities.

Some scholars believe that the article authorizes the maritime administration to exercise that right to bring the compensation claim. By analyzing the content and function of the litigation, the nature of the National Claims for Marine Ecological Damage belongs to the Eco-damage lawsuit (Deng, 2013; Gong, 2019). Some scholars emphasize that the Article should not be used as the legal basis for China's marine environmental public interest litigation (Sun and Jin, 2017). However, many scholars also believe that the National Claims for Marine Ecological Damage Suits belongs to the category of public interest litigation (Zhu, 2015).

It should be emphasized that there are essential differences between the nature of NCMED and MEPIL. In the first instance, the former is in the nature of private-interest litigation for the relief of damage to national natural resources. The latter is a public interest litigation, which aims to remedy environmental public interest litigation in the public interest of society. The theoretical basis for the NCMED, such as the theory of national ownership of natural resources (Wang and Wu, 2021) and the theory of environmental protection supervision power, is defective (Jin and Xu, 2022). Therefore, this paper considers that the NCMED is based on the theory of public trust in natural resources (Brewer and Libecap, 2010), in the case of marine natural resources and the ecological environment suffering from pollution and damage, the marine administrative organs obtain the right to file a lawsuit for compensation for damage to the marine ecology and environment as a plaintiff, and on behalf of the Nation to pursue the legal responsibility of the tortfeasor (Wang X. G., 2018). The NCMED applies to cases where damage to marine aquatic resources or sea areas has caused significant loss to the country, and the object of relief is the national ownership of marine natural resources, while at the same time achieving relief for marine ecological damage. For example, the implementation of illegal reclamation activities destroyed state-owned marine area protection facilities such as island dykes. According to the MEA, the scope of application of national claims for marine ecological damage includes all maritime areas under national jurisdiction, and at the same time, according to the provisions of international treaties, it can also be applied to acts of pollution of the marine environment outside of the national jurisdiction. Funds for NCMED should be paid into the national treasury (Xie, 2021).

Secondly, the purpose of the MEPIL is to remedy the marine environment public interest and the damage caused by the destruction of marine ecology and marine protected areas. Administrative organs as a representative of the public interest, are one of the entities that have the standing. The MEPIL compensation belongs to the compensation fund dedicated to the restoration and protection of the marine ecological environment. Although the marine administrative organs on behalf of the state to exercise on the national marine environmental damage to the infringement of liability for damages lawsuit, cultivated the professional and technical personnel, and has accumulated

abundant professional advantages in the marine damage identification and restoration, and legal experience. But it does not mean that it can deny the standing of the procuratorial agencies and the environmental organs except for the marine ecological damage involving national sovereignty. The MEPIL is capable of achieving legal supervision of administrative behavior. The MEPIL has the preventive function of preventing the occurrence and achieves supplementary relief for marine ecological damage. These unique functions cannot be replaced by national claims for marine ecological damage.

Therefore, in terms of the legal function, structure, and relief results, the MEPIL could not substitute for the National Claims for Marine Ecological Damage Suits. The order of two kinds of litigation should be determined with full consideration of the cost and convenience of lawsuits in judicial practice (Qin and Wu, 2020).

3.2 Theoretical controversies and practical dilemmas over the standing

Some scholars conclude Article 89 of the Marine Environmental Protection Law is an authorization provision and does not exclude the standing of the environmental and social organizations in marine environmental public interest litigation (Duan, 2016). Some scholars also believe that this type of litigation has the composite nature of tort litigation and public interest litigation and suggest that Article can be the legal basis for filing two types of lawsuits, namely, lawsuits for property damage to national resources and lawsuits for the environmental public interest(Li, 2023). However, some researchers still believe that considering the sensitivity of marine issues, the actual capacity of maritime governance, and other factors, this provision excludes the procuratorial organs and other environmental, and social organizations from bringing MEPIL (Yang, 2021).

It's important to provide an explicit interpretation of the provision of Article 89 of the Marine Environment Protection Act (Han, 2018). Under the Marine Environment Protection Act, ecological damage to the marine environment is recoverable only if certain conditions are satisfied. According to Article 247 of the Civil Code of the People's Republic of China, maritime areas are owned by the State. If the natural resources and ecological environment within the maritime areas under the jurisdiction of China are polluted or damaged, resulting in damage to the interests of the State, the departments that have the authority to supervise and manage the area shall, on behalf of the State, recover the responsibility from the infringes. It is only when the damage to the marine ecosystem causes serious losses to the state that the relevant authorities are entitled to claim compensation from the polluter. According to Article 1 and Article 2 of the Measures for Claiming State Losses from Marine Ecological Damage, which were formulated and promulgated by the former State Oceanic Administration(SOA), the competent department of marine administration may claim compensation from the responsible parties for the serious losses caused to the State as a result of the construction projects of coastal engineering, the activities of reclamation, and other activities of sea use, the activities of exploitation of sea islands, and the discharging of pollutants, or radioactive, poisonous and harmful substances, among other activities. The scope of national loss for marine ecological damage includes the cost of disposal measures, abatement of secondary pollution damage, losses during the period of restoration to the original state, professional consultancy fees, and other reasonable costs, which should exceed 300,000 yuan in total.

The provision does not specify the relief for all types and degrees of marine environmental damage, nor does it specify how to file civil public interest litigation for marine ecological damage and environmental pollution incidents other than those stipulated in the provision. There may be other forms of relief in the future. The mainstream view is that the provisions of this Article are authorized norms, rather than exclusive ones. Therefore, this Article 89 does not mean that it is the comprehensive exclusion of other subjects' right to bring MEPIL. At the same time, the provisions of the ecological damage claims as a means of administrative enforcement of the extension of the marine sector should sue but refuse to do, other entities in the case of clearly authorized to supplement. However, the prerequisite should be to ensure that the maritime sector is the first instance (Zhang J. F., 2019).

The MEPIL is part of the legal system of environmental public interest litigation, and the provisions of the Civil Procedure Law and the Environmental Protection Law as well as the relevant judicial interpretations should also be applied. Therefore, the Marine Environmental Protection Law should be amended to be consistent with the regulations of the Environmental Protection Law and the Civil Procedure Law and to include provisions on the standing of the marine environmental public interest litigation, to make it uncontroversial that marine environmental administrative organs, procuratorial organs, and qualified environmental social organizations are authorized to bring marine environmental public interest litigation. In the long run, China should improve the MEIPL system, articulate environmental administrative penalties, coercion, and other administrative regulatory measures for the marine environment and ecology, and rationalize the types and procedures, to achieve the comprehensive objectives including the prevention of marine pollution, conservation of the marine ecological system, public participation in the protection of the marine environment, etc. (Xie and Yu, 2022).

4 The improvement approach

4.1 Marine administrative organs are the first sequence

The MEPIL regime should be positioned as a complementary function to the maritime administrative regulation. The MEPIL is inferior to marine administrative enforcement in specialization, efficiency, and Litigation burden. The Marine Environmental Protection Law should clarify that the marine administrative authorities are to be identified in the first sequence to initiate the civil MEPIL (Cao X. Y., 2017). Qualified environmental organizations shall be in the second sequence to bring MEPIL.

The procuratorial organ shall be in the third sequence in civil MEPIL. (Sun and Zhang, 2020). If the administrative authorities refuse to bring the civil MEPIL cases, the procuratorial organs shall issue the procuratorial recommendation to urge them to initiate the legal proceedings. The public notices are also issued Supervising qualified social organizations to bring civil MEPIL cases. If the marine administrative authorities fail to respond to the procuratorial recommendation after the deadline while no social organs informing the prosecuting authorities within the required time, the procuratorial authorities may directly initiate the civil MEPIL (Wang W. H., 2018).

Firstly, in terms of the legitimacy of representing the public interests in the marine environment, the marine administrative authorities are the supervisory and management organs of marine natural resources, the representative of the State's ownership, and have the primary responsibility for the protection of the public interest in the marine environment. The marine administrative authorities are elected by the legislature (Hu, 2016). The administrative powers and duties of the marine regulatory authority are stipulated by law and strictly constrained, the administrative act has the initiative and is mandatory and the expenses are guaranteed by the state (Zhang, 2021). Therefore, the fact that marine authorities are legal representatives of the public interest determines that organs can directly initiate civil litigation against acts that infringe on the rights and interests of the public or the national environmental resources. Based on administrative action to resolve disputes over the marine environment, MEPIL is a means that can strengthen the ability to claim compensation for marine ecological damage, pollution prevention, ecological modification, and other remedies, to achieve favorable protection of the marine ecological environment and other social public interests.

Secondly, from the litigation capacity, marine administrative organs with professional knowledge and professionals, monitoring technology and equipment, and other obvious advantages, can tackle the complexity and professionalism of marine environmental issues (Li et al., 2015). Compared with land-based pollution, marine pollution is hidden, indirect, complex, and widespread, and the damage is compounded, for example, the dumping of toxic wastes not only causes seawater pollution but also triggers damage to marine resources and long-term damage to marine ecosystem (Landrigan et al, 2020), the death of marine wildlife or the reduction of biodiversity. Marine ecological environment pollution is characterized by complex causes, difficulty in tracing the responsible subject, a high level of professionalism in pollution site investigation and ecological resources damage assessment, and a high cost of restoration. The emergency relief, marine environmental monitoring, and marine ecological restoration of serious accidents caused by marine pollution are costly, technically complex, and high-risk. Marine departments have professional advantages, practical experience, and convenient conditions, can implement marine pollution monitoring and early warning, find illegal marine ecological environment damage behavior, investigation and evidence collection, pollution emergency response, ecological damage restoration, and other aspects (Shi, 2017). At the same time, since pollution areas in the exclusive economic zone or near-shore waters will affect national maritime rights and interests, the State should authorize its government agencies to initiate proceedings on behalf of the State for compensation for damage to the marine ecosystem (Mei, 2020).

However, the marine administrative organs to initiate MEPIL still face many difficulties, which should be resolved promptly. First, there is a lack of explicit provisions on which administrative organ should initiate MEPIL, which causes the inaccurate definition of the subject of MEPIL and the low willingness to sue, seriously impacting the efficiency of the litigation and immediate relief for ecological damage to the marine environment. For example, the Zhuhai Bureau of Marine Agriculture and Water Affairs, as the plaintiff in the MEPIL was supported by Zhuhai Municipal People's Procuratorate to sue seven individuals as the defendants in the dispute over the responsibility for polluting and contaminating the marine environment by dumping toxic waste pollution. During the trial of the case, the plaintiff, Zhuhai Bureau of Marine Agriculture and Water Affairs was merged into Zhuhai Bureau of Natural Resources during the institutional reform. The institutional functions of the Zhuhai Bureau of Natural Resources and Zhuhai Bureau of Ecology and Environment could not be clarified at the time, resulting in the case being suspended by the Guangzhou Maritime Court for one year. It was finally determined that the Zhuhai Bureau of Ecology and Environment would continue to participate in the litigation as the plaintiff.

In addition, it lacks provisions for the scope and division of competencies for the marine environment administration in MEPIL. At the same time, the nature and legal provisions of the MEPIL are ambiguous, the provisions on bearing the costs of litigation are unspecified, and the litigation procedure is lengthy. Coupled with the lack of experience in litigation and legal professionals, the marine administrative authorities tend to prefer efficient dispute resolution methods, such as the consultative procedure on ecological damages, and thus causes the willingness to file lawsuits. The former State Oceanic Administration (SOA) was merged into the Ministry of Natural Resources of the PRC in the 2019 China institutional reform. The main responsibilities, such as administrative authorization for the use of maritime areas, were incorporated into the Ministry of Natural Resources, and the responsibilities for marine environmental protection were integrated into the Ministry of Ecology. However, the Marine Environmental Protection Law has not yet reclassified the powers and responsibilities. Article 5 of the Marine Environmental Protection Law is unable to cover the full scope of marine environmental supervision and management powers. For example, the supervision and protection of the marine environment of ship-breaking operations by the Maritime Safety Administration in the integrated port harbor area are not included in the above provision (Song, 2021).

Therefore, the provisions should be included to provide a clear division of responsibilities for the division of competence to clarify the relationship between different administrative organs in marine environmental public interest litigation.

4.2 Improvement of the legal system of MEPIL initiated by the procuratorial organs

As a representative of public interest, the procuratorate's standing in MEPIL, which is provided by Civil Procedure Law and Administrative Procedure Law, is also aimed at safeguarding the public interest in the marine ecological environment and is not in contradiction with its status as a legal supervisory organ (Xu, 2017). The procuratorate has the legal authority to represent the public interests and has the advantages of professional judicial personnel, effective legal means, and powerful coordination capabilities (Zhang, 2015a). From the point of view of judicial practice, procuratorial organs in MEPIL have a synergistic, and irreplaceable role in the preservation of marine natural resources and the ecological environment (Li, 2017).

MEPIL cases initiated by the procuratorial authorities can not only repair or compensate for damage to the marine ecosystem that has already been caused but can also play a preventive judicial role in preventing damage to the marine ecosystem from occurring or reoccurring (Li, 2020). In cases where "significant losses" have not yet been incurred or where preventive civil liability is required, the challenge of the relevant administrative authorities' inability to initiate the MEPIL procedure will be resolved. At the same time, the procuratorial authorities can investigate and handle the prosecution procedures for marine environmental pollution and ecological damage crimes, and civil compensation can be carried out simultaneously. For example, civil compensation for ecological damage to the marine ecosystem can be used as criminal sentencing scenarios to guarantee the performance of civil compensation, the investigation of criminal evidence can be used to judge the seriousness of the civil infringement, etc. (Sun and Tao, 2013). The procuratorial authorities have accumulated a relatively large number of experience, to avoid the administrative authorities' willingness to initiate public interest litigation (Luo, 2017). Through procuratorial recommendations or public notices, administrative organs or social organizations with standing should be urged to initiate the civil MEPIL.

Procuratorial authorities still face a series of problems in initiating the MEPIL. First, although criminal incidental civil public interest litigation is an effective remedy for marine ecological damage. However, a high proportion of CSCCP suits will bring about serious legal conflicts. CSCCP and civil MEPIL suits are very different in terms of the application of the law, jurisdiction, the status of the parties, the trial procedure, appeal, and other legal mechanisms. Civil proceedings are not independent, and there is excessive reliance on the procedures and results of criminal procedures. Until the facts of the criminal offense of damage to the marine environment are established by the courts, the issue of civil liability and compensation is put on hold, making it difficult to take preventive civil measures (Wu, 2021). The former is mainly based on Criminal Law and Criminal Procedure Law, while the latter is mainly based on Civil Procedure Law and Environmental Protection Law. In general, in civil litigation, a second instance can be brought, but the defendant's right to appeal in CSCCP may be limited, and if the amount of compensation proposed by the procuratorate is too high or too low, it may be difficult to rectify through the appeals procedure. In addition, the former is under the jurisdiction of the basic court in the place where the offense was committed or where the defendant resides, while the latter is under the jurisdiction of the maritime court in the place where the act of damage was committed, the result of the damage was caused, or the preventive measures were taken. There are also many differences in the legal system. The former proceedings are less than two months while the latter is usually six months. And the former lacks property preservation measures to guarantee enforcement. In the second, there is a shortage of legal provisions on the jurisdiction of prosecutorial public interest litigation, the second instance appeal system, the scope of administrative public interest litigation, and the criteria for determining whether an administrative organ has performed its duties by law. And there is also a lack of legal provisions relating to the possibility of the procuratorial authorities failing the cases, and the possibility of abuse of litigation rights arising from an excessively high rate of success in litigation (Yu, 2021).

Therefore, based on the construction of MEPIL, the specific mechanisms for the procuratorial authorities to participate should be stipulated. Firstly, procuratorial authorities, initiate the civil MEPIL cases independent of the criminal procedure under the exclusive jurisdiction of the maritime courts, thereby reducing the number of CSCCP cases and conflicts of jurisdiction. Secondly, it will improve the jurisdictional system and the appeal system at the second instance for the MEPIL cases, expand the scope of administrative public interest litigation, and clarify the criteria for determining whether administrative organs are performing their duties by the law. Thirdly, it is to improve the provisions relating to the failure of the procuratorial authorities to bring MEPIL cases and the evidence transfer, trial procedures, and jurisdiction of the CSCCP cases. Fourth is improving pre-litigation procedures. The pre-litigation procedure has the function of urging the administrative authorities of the marine environment to fulfill their statutory responsibilities and reinforcing the litigation capacity of social organizations (Liu, 2019). It should be prescribed that the procuratorial authorities shall have the power to investigate and obtain evidence in the proceedings and that specific systems such as the Public Notice Procedure and the interface between Pre-litigation and litigation procedures shall be improved (Hu, 2020).

The fifth is to enhance the prosecution support system of the procuratorial authorities. An important way for procuratorial authorities to participate in MEPIL is through a prosecution support system, which can be done through the provision of legal advice, the submission of written opinions, assistance in the investigation and evidence collection, and other means by the law to support social organizations or administrative authorities in civil MEPIL cases (Zhu and Liang, 2018). And this should be the appropriate way for the procuratorate to handle civil MEPIL cases (Lin, 2022). After the pre-litigation procedure, if the administrative departments or the relevant social organizations have not filed a lawsuit, or there are no suitable agencies to bring the MEPIL case, the procuratorial organs will directly file a civil MEPIL case (Zhang X. Q., 2019). This ensures that the procuratorial and administrative authorities fulfill their responsibilities

respectively and promptly, as well as working closely together in the litigation proceedings and subsequent processes such as the restoration of marine ecological and environmental damage remedy. Improvements to the procuratorial prosecution support system include: expanding the scope of prosecution support, clarifying the litigation status and functions, refining the modality and scope of authority and responsibility, and clarifying procedural provisions (Zhao, 2023). For example, the case of civil MEPIL between the plaintiff, Ledong Lizu Autonomous County Ecological and Environmental Protection Bureau of Hainan Province, and the defendants, some Fujian company and two individuals, was supported by the Second Branch of the Hainan Provincial People's Procuratorate. The procuratorate appointed staff to appear in court and participate in the investigation and debated procedures and expressed views on issues such as the assumption of legal responsibilities.

4.3 Expansion of the standing of the MEPIL

Public interests should be maintained through multiple means. The entities with standing to bring civil public interest litigation in the MEPIL should be pluralistic (Mei, 2017). Based on the theory of public trust and environmental rights, social organizations are important means for the public to participate in marine environmental public affairs. And expansion of the standing of social organizations is beneficial to the protection of the public interest (Zhang, 2015b). The first reason is the function of public interest integration. Social organizations can integrate the common interests of different citizens and groups because social organs have broader social bases and can directly contact the public, especially environmentally disadvantaged groups. The second is the function of supervision. Social organizations are non-profit organizations with relatively independent status which could balance the environmental decision-making authorities and citizens' environmental rights. And social organizations can supervise the behavior that destroys the marine environment and ecosystems, and the marine administrative organs through social forces effectively. The third is the relief function. If social organs could bring a lawsuit, while individuals can not bring MEPIL cases in China, to protect the marine resources, environment, and ecology which are crucial to human survival and sustainable development, and to maintain marine economic value and ecological value. Marine environmental and ecological legal disputes are very complicated and diversified, and the participation of social organizations can provide professional support in terms of technical and legal expertise.

Social organizations have professional advantages in the fields of law and marine science. At the same time, as MEPIL may involve certain sensitive marine areas, or the aggressors of marine pollution are foreign vessels or multinational enterprises, MEPIL suits initiated by neutral, non-governmental social organizations, and filed under the jurisdiction of the Chinese courts, can reduce the sensitivity of the incidents, international conflicts, and provide better protection for China's maritime rights and interests. (Chen and Bai, 2018). At the same time, social organizations can also bring their unique advantages by assisting in the commissioning of judicial appraisals, coordination and reconciliation between the plaintiff and defendant, and supervising the use of restoration funds as a third-party institution (Huang and Yu, 2021).

However, whether social organizations have standing has become a major concern in marine environmental law in China (Jin, 2021). Chinese environmental social organizations have been developing for a relatively short period facing challenges such as inadequate mechanisms, weak social support, and low degree of specialization. And there are fewer social organizations with expertise in marine environmental science and litigation capacity. Many of them are confronted with obstacles such as insufficient capacity to respond to lawsuits and financial constraints. As a result, some social organs are unable to undertake professional work such as investigating marine environmental pollution sources, assessing and collecting evidence, and initiating litigation. Some are unable to afford the high costs of investigation and evidence collection, damage appraisal, and litigation procedures. At the same time, social organizations face external dilemmas such as complicated registration and management procedures and the lack of incentive measures. As a consequence, the willingness of social organizations to initiate MEPIL has been relatively low, and the number of cases has shown a noticeable decline (Zhang et al., 2017).

The positive effects of social organization in MEPIL should be strengthened by enhancing their capacity while creating a stable external environment. Firstly, disputes over the standing in academic and judicial practice should be eliminated while the legal system should be improved. The procedural system for social organizations in MEPIL should be stipulated (Wu, 2014). The Civil Procedure Law is the basic law in the field of civil public interest litigation, while the Marine Environmental Protection Law is the specific law that applies to the protection of the marine environment which complements the Environmental Protection Law. The Environmental Protection Law and the Civil Procedure Law stipulate the standing of social organs in civil EPIL, which should also apply to the MEPIL cases. The Marine Environmental Protection Law does not prohibit social organizations from initiating MEPIL suits (Zhang and Zheng, 2021). Social organizations should notify the administrative organs before filing a lawsuit, and the administrative organs should respond within the period prescribed by law. If the administrative organs expressly indicate that they will not bring MEPIL, or do not respond within a reasonable period, the social organizations shall file MEPIL cases.

Secondly, it should establish an incentive system for environmental organizations' participation in MEPIL. Social organizations' registration and management procedures should be simplified, the standing should be appropriately lowered, and more social organizations should be motivated to participate. In addition, social organizations should be included in the list of exemptions or reduction of litigation fees to decrease the economic burden. A certain percentage of the ecological restoration fee can cover the cost of litigation for social organizations, such as investigations, appraisals, assessments, research, legal representations, and other necessary expenses (Huang and Du, 2018). The judges may

determine the bearing of the litigation costs according to the hearing. Part of the expenses undertaken may be covered by the defendants or included in the marine environment fund.

4.4 Improving the jurisdictional system

Whether all MEPIL cases belong to the exclusive jurisdiction of the Maritime Courts is highly debated, which affects the prompt hearing of these cases. According to the provisions of the Scope of Cases Accepted by the Maritime Courts, the exclusive jurisdiction of the Maritime Courts comprises 108 types of disputes in six categories, including lawsuits relating to the development, exploitation, and environmental protection of oceans and navigable waters, maritime administrative cases, and maritime special procedure cases. At present, there are 11 maritime courts in China, which have formed a relatively developed cross-administrative division of the trial mechanism. For example, the Qingdao Maritime Court, in which Qingdao is the main seat of the court, has jurisdiction over Yantai, Weihai, Rizhao, Dongying, and other major coastal cities which can cover the major maritime areas of Shandong Province.

The advantages of the exclusive jurisdiction of the maritime courts are reflected in the following: more comprehensive coverage, not subject to territorial jurisdiction, which is compatible with the cross-regional situation of marine environmental pollution. It is highly specialized, does not hear general cases, and has a unique advantage in handling maritime disputes. It has professional advantages in maritime trials, marine damage identification, the deployment of maritime areas, and the preservation of marine biological resources. The maritime court's exclusive jurisdiction ensures the trial standards' consistency, improves efficiency, enhances the strength of marine environmental conservation, and safeguards the rights and interests of the parties. The exclusive jurisdiction system should be gradually improved and harmonized with the civil, criminal, and administrative procedure laws.

First, the jurisdictional system for civil public interest litigation in the marine ecosystem should be clarified. According to Article 7 of the Law on Special Procedures in Maritime Litigation, civil MEPIL arising from damage caused by pollution of the sea area as a result of discharges, leaks, or dumping of oil or other harmful substances from ships, production or operation at sea, or breaking or ship-repairing operations shall be under the exclusive jurisdiction of the maritime court of the place where the pollution occurs, or where the damage is caused, or where the pollution-preventive measures have been taken. Therefore, civil MEPIL concerning damage caused by pollution of the maritime area as a result of sewage discharge from ships, production at sea, or vessel operations shall be brought before a maritime court. Some scholars believe that pollution of the marine environment caused by port operations, ship collisions, and discharges from land should be under the exclusive jurisdiction of the maritime courts (Wang and Xie, 2013).

However, since most inland provinces do not have maritime courts, to avoid cases being handled across geographical boundaries, to reduce the burden on the parties, and to save judicial resources, plaintiffs should be given the right to choose jurisdiction. Procuratorial authorities or environmental protection agencies may choose to file a MEPIL lawsuit in an ordinary court in the place where the pollution occurred, where the damage was caused, where the measures were taken to prevent the pollution, and where the defendant is domiciled, or they may choose the exclusive jurisdiction of a maritime court.

Second, according to the provisions of the Administrative Procedure Law, administrative cases shall be accepted by the People's Court, where the defendant's administrative organ is located. According to the Administrative Litigation Law provisions, the people's court where the defendant is located shall have jurisdiction over the case. However, supposing the administrative act involved developing and using oceans and navigable waters, fisheries, and protecting the environment and ecological resources. In that case, it shall be subject to the maritime court's jurisdiction. CSCCP cases are currently under the jurisdiction of the People's Court. With the Ningbo court, the Qingdao Maritime Court will also be authorized to hear criminal cases. Some scholars have argued that maritime courts, with their more excellent trial experience and expertise, should be unified in accepting maritime criminal cases in harmony with the provisions of the Criminal Procedure Law.

4.5 Improving public participation in the MEPIL

The public is the direct beneficiary of the maintenance of the marine public interest and sustainable development and is the main force for the protection of the marine ecological environment. The public has direct concerns about marine conservation. Under the increasingly serious situation of marine environmental pollution and damage, public awareness, participation, and support for the MEPIL is one of the key factors determining its effectiveness.

Firstly, various measures were taken to popularize the legal knowledge of the MEPIL, to raise public awareness, and to cultivate initiative in marine environmental protection. For example, in 2022, the Ningbo Maritime Court heard an MEPIL case on the illegal use of prohibited fishing gear to catch aquatic fish. Above 9,000 people, including residents living in coastal areas and marine practitioners, watched the live broadcast of the case. The public gained a deep understanding of the extinction threat and the continued decline of fishery resources posed by illegal fishing. The public awareness of the protection of marine ecological resources has been improved. At the same time, the public also expressed support for the court's judgment on the criminal liability of the perpetrators and the compensation for marine ecological damage. Secondly, the standing of social organizations should be stipulated. This has already been discussed in Part 4.3 of the paper and will not be further developed here. Thirdly, the possibility of establishing the legal system of the MEPIL initiated by the individuals should be considered in the future. Individuals who suffer from marine pollution should have the standing to bring the MEPIL suits.

5 Conclusion

The situation of marine environmental pollution and ecological resource destruction in China is still relatively serious (Zhang et al., 2019; Xu and Zhang, 2022) affecting sustainable economic and social development (Zhai and Chang, 2019). The basic structure of the marine environmental public interest litigation system has gradually formed, showing that the procuratorial organs are leading, social organizations actively initiate public interest litigation, civil cases account for the majority, the causes of action are diversified, etc. MEPIL has played an indispensable role in the preservation of marine resources and the environment. The MEPIL can effectively punish offenses, rehabilitate damaged marine ecosystems and improve public awareness of environmental protection.

For example, with the increase of coastal projects, some enterprises have illegally dumped construction waste into the sea to reduce costs, causing serious damage to the marine ecosystem. For instance, the Procuratorate of Haikou City, Hainan Province, filed a civil MEPIL case in 2019, which prevented and deterred illegal marine dumping and protected the marine ecosystem. Company C dumped 69,000 cubic meters of construction waste without obtaining permission. The construction waste was identified by a professional organization as containing toxic and hazardous substances, which would enter the marine biological chain and damage the marine ecosystem and resources. Through diffusion and dispersion, construction waste will have a lasting impact on the marine aquatic environment, and harmful heavy metals such as mercury, nickel, lead, arsenic, and copper will continue to affect the quality of seawater. At the same time, the dumped waste will directly change the original habitat of the benthic organisms in the involved marine area, and will completely change the geological environment of certain sea areas, with most of the benthic species being buried. After imposing administrative penalties on perpetrators of offenses, the local marine and fisheries department, after written advice and supervision by the procuratorate, did not bring a lawsuit for compensation and was therefore unable to hold the perpetrators liable for the damage caused to the marine ecosystem. The Haikou Municipal Procuratorate filed the civil MEPIL case, and the requests were supported by the Haikou Maritime Court. The court ultimately ruled that the three defendants including the company's real controller and commissioner of dumping, jointly liable for compensation for ecological damage totaling more than RMB 8.6 million for the restoration of the marine ecosystem, and made a public apology in the nationally distributed media.

However, China's MEPIL system still has many problems, restricting the implementation of the litigation goal. There are conflicting legal provisions on MEPIL, the number of cases is relatively low, and there are disputes on the eligible plaintiffs and the sequence. The position of the marine administrative authorities has not been fully reflected. The system of MEPIL initiated by procuratorial organs is not improved, and there are conflicts of jurisdiction and other problems. As part of environmental public interest litigation, marine environmental public interest litigation should comply with the basic provisions of the Civil Procedure Law and the Environmental Protection Law. It should be closely related to judicial practices and stipulate that the marine administrative authorities, social organizations, and procuratorial organs can initiate the MEPIL, and jointly safeguard the public interests of the marine ecological environment with their respective professional advantages. The marine administrative authorities have priority status, social organizations as complementary, and procuratorial organs as the ultimate protection of the public interest (Yu, 2021). China should gradually implement the exclusive jurisdiction system of the maritime court, to realize the advantages in maritime trials and the damage appraisal and other aspects. In the future, the institutional framework for MEPIL should be specified in the Basic Law of the Oceans, with detailed provisions on the function and nature of MEPIL, standing, litigation procedures, the scope of damages, rules of evidence, jurisdiction, adjudication and mediation, and the fund for compensation of damages.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

LY: Data curation, Funding acquisition, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was funded by China's National Social Sciences Foundation (No.22BKS165); Jinan 'New University 20 Items' Introduced Innovation Team Project (No. 2021GXRC075); China's Ministry of Education Special Research Programme for Teachers of Ideological and Political Theory Courses in Higher Education Institutions(No.22JDSZK055).

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Bayraktarov, E., Saunders, M. I., Abdullah, S., Mills, M., Beher, J., Possingham, H. P., et al. (2016). The cost and feasibility of marine coastal restoration. *Ecol. Appl.* 26 (4), 1055–1074. doi: 10.1890/15-1077

Brewer, J., and Libecap, G. D. (2010). Property rights and the public trust doctrine in environmental protection and natural resource conservation. *Aust. J. Agric. Res. Econ.* 53, 1–7. doi: 10.1111/j.1467-8489.2007.00423.x

Cao, X. G. (2017). Reform of jurisdiction of maritime criminal cases and perfection of maritime criminal legislation—based on the first judgment of criminal case in maritime court. *Chin. J. Maritime Law* 28 (04), 43–51.

Cao, X. Y. (2017). Selection of plaintiffs' Qualifications for environmental public interest litigation on marine pollution. *Gansu Soc. Sci.* 5, 173–178. doi: 10.15891/j.cnki.cn62-1093/c.2017.05.030

Chen, H. Z., and Bai, J. H. (2018). The Dilemma of Determining the Qualified Plaintiff in the Marine Environmental Civil Litigation for Public Interests under the New Situation and lts Solution. *J. South China Normal University (Soc.Sci.Edi.)* 2, 162–169.

Chen, S., Pearson, S., Wang, X. H., and Ma, Y. (2017). Public participation in coastal development applications: a comparison between Australia and China. *Ocean Coast. Manage.* 136, 19–28. doi: 10.1016/j.ocecoaman.2016.11.016

Chu, J. (2018). Vindicating public environmental interest: defining the role of environmental public interest litigation in China. *Ecol. Law Quarter.* 45 (3), 485–532. doi: 10.15779/Z38599Z22F

Chu, J. (2023). From peripheral actors to established players: environmental NGOs' Participation through public notice-and-comment procedures and environmental public interest litigation in China. *J. Contemp. China.* doi: 10.1080/10670564.2023.2204832

Chu, B. P., and Zhao, Y. L. (2023). System connection of environmental civil public interest litigation under the cross pollution of sea and land. *J. Dalian Maritime University(Soc. Sci. Edi.).* 22 (02), 1–7.

Deng, H. F. (2013). Study on the subjectivity and scope of State claims for marine oil pollution damage. *Law Review.* 31 (01), 71–77. doi: 10.13415/j.cnki.fxpl.2013.01.013

Duan, H. S. (2016). An initial exploration of four issues in marine environmental public interest litigation: pudong environmental protection bureau v. Midsum corporation and other ship pollution damage compensation cases. *Orient. Law.* 5, 37–44.

Gao, Q., and Gao, Q. (2018). "public interest litigation" in China: panacea or placebo for environmental protection? *China: Int. J.* 16 (4), 47–75.

Gao, Q., and Whittaker, S. (2019). Standing to sue beyond individual rights: who should Be eligible to bring environmental public interest litigation in China? *Transnational Environ. law.* 8 (2), 327–347. doi: 10.1017/S2047102519000141

Gong, G. (2019). Reflections on the positioning of the nature of environmental civil public interest litigation. *Chin. J. Law.* 41 (03), 127–147.

Han, F. (2018). A case commentary on the subjective competence of public interest organisations in marine environmental public interest litigation. *World Ship.* 41 (07), 54–56. doi: 10.16176/j.cnki.21-1284.2018.07.011

Hu, J. (2016). The function and position of public interest litigation initiated by environmental protection organisations-an appraisal of the judicial interpretation of environmental public interest litigation in China. *Law Rev.* 34 (04), 168–176. doi: 10.13415/j.cnki.fxpl.2016.04.018

Hu, W. L. (2020). The public interest litigation procuratorial system from the perspective of national governance. *J. Natl. Prosecutors Coll.* 28 (02), 3–20.

Huang, N., and Du, J. M. (2018). Optimized path about social organization participating in environmental public interest litigation. *Hebei Law Sci.* 36 (09), 191–200. doi: 10.16494/j.cnki.10023933.2018.09.014

Huang, X.-s., and Wang, Z.-z. (2020). Civil public interest litigation of marine environment: identification,difficulties and approaches -starting from Article 89 of Marine Environment Protection Law of the People's Republic of China. *Chin. J. Maritime Law* 31 (01), 28–35.

Huang, X. S., and Yu, X. L. (2021). Reconstruction of comprehensive incentive mechanism for social organizations to bring environmental public interest litigation. *Legal Forum.* 36 (01), 93–102.

Jia, X. (2022). On the sequence design and construction of the subject of environmental civil public interest litigation. *Modern Econ. Manage. Forum* 3 (2), 62–66. doi: 10.32629/memf.v3i2.765

Jiang, B. X. (2019). Practical development and institutional consummation of Chinese environmental public litigations. *J. Law Appl.* 1, 5–12.

Jiang, H., Blazey, P., Wang, Y., and Ashiabor, H. (2020). China's new approach to environmental governance and environmental public interest litigation. *Asia Pacific J. Environ. Law.* 23 (1), 39–73. doi: 10.4337/apjel.2020.01.02

Jiang, M., and Faure, M. (2022). The compensation system for marine ecological damage resulting from offshore drilling in China. *Mar. Policy* 143, 105132. doi: 10.1016/j.marpol.2022.105132

Jin, F. (2021). On the environmental civil public interest litigation system for the protection of the climate in China: Comments on two cases from a pragmatism perspective. *J. World Energy Law Business* 14 (1), 17–24. doi: 10.1093/jwelb/jwab006

Jin, H., and Xu, Z. H. (2022). A new analysis of ecological environmental damage compensation litigation system. *J. Hohai Univ. (Phil. Soc Sci.)* 24 (04), 107–115 + 137.

Landrigan, P. J., Stegeman, J. J., Fleming, L. E., Allemand, D., Anderson, D. M., Backer, L. C., et al. (2020). Human health and ocean pollution. *Ann. Global Health 86 (1)* 144, 1–64. doi: 10.5334/aogh.2831

Li, Y. (2017). The judicial practice and theoretical exploration of public lnterest litigation brought by the procuratorate. *J. Natl. Prosecutors Coll.* 25 (02), 3–18 + 170.

Li, L. (2020). On the readjustment of the subject qualification and rank of plaintiff in environmental civil public interest litigation. *Tribune Political Sci. Law.* 38 (01), 162–169.

Li, Y. (2022). The dilemma and countermeasures of public interest litigation of marine environmental pollution in China. *Sustainability* 14, 14415. doi: 10.3390/su142114415

Li, X. M. (2023). The basis of governmental litigation right in marine ecological environment damage: reflection and reconstruction. *J. Harbin Instit. Technology(Soc. Sci. Edi.)* 25 (03), 51–58. doi: 10.16822/j.cnki.hitskb.2023.03.008

Li, C., Zhao, Y. H., and Sun, P. Y. (2015). Study on the judicial authentication of marine environmental pollution damage and its evidentiary effect. *Mar. Environ. Sci.* 34 (01), 136–141. doi: 10.13634/j.cnki.mes.2015.01.024

Lin, L. H. (2022). A further analysis on the institutional space of civil public interest litigation initiated by the procuratorate - comparing with the scope of administrative public interest litigation. *Admin. Law Rev.* 2, 77–92.

Liu, J. L. (2019). The predicaments of the civil public lnterest litigation attached to criminal cases and their solutions. *Political Sci. Law.* 10, 84–94. doi: 10.15984/j.cnki.1005-9512.2019.10.008

Liu, Z. (2020). Study on the dynamic mechanism of environmental public interest litigation in China. *Fresenius Environ. Bulletin.* 19 (7), 5408–5414.

Liu, Y. (2020). The development and improvement of public interest litigation by procuratorate in China: An empirical analysis based on related data from 2017 to 2019. *J. Chongqing Univ. (Soci. Sci. Edi.)* 26 (04), 173–183.

Luo, L. (2017). The construction of Chinese environmental public interest litigation system and countermeasures. *China Legal Sci.* 03), 244–266.

Lv, Z. H. M., and Zhang, Z. M. (2017). Status of specialization of environmental justice and typology of environmental cases. *China J. Appl. Jurisprudence* 6, 87–112.

Mei, H. (2017). The New lssue and lts Theory Based On the lnterpretation Of Marine Environmental Damage.Legal Forum. *Legal Forum* 32 (03), 28–36.

Mei, H. (2020). The judicial protection subject of marine environment and its linkage mechanism. *J. Zhejiang Ocean University(Humanities Sci.)* 37 (01), 1–8.

Ministry of Ecology and Environment of the P.R.C. (2022). *Bulletin on the State of China's Marine Ecosystem in 2022.* Available at: https://www.mee.gov.cn/hjzl/sthjzk/jagb/202305/P020230529583634743092.pdf (Accessed 2023.7.25).

Ministry of Natural Resources of the P.R.C. (2022). *Statistical Bulletin on China's Marine Economy.* Available at: http://gi.mnr.gov.cn/202304/t20230413_2781419 (Accessed 2023.7.25).

Qin, T. B., and Wu, L. Z. (2020). Nature of lawsuit to damage compensation on marine ecological environment-investigation on relationship between related litigation types. *West. Law Review.* 2, 46–54.

Ruys, T. (2021). Legal standing and public interest litigation-are all erga omnes breaches equal? *Chin. J. Int. Law.* 20 (3), 457–498. doi: 10.1093/chinesejil/jmab030

Shi, C. L. (2017). Three issues of marine environmental public interest litigation: the interpretation of article 90(2) of marine environmental protection law. *J. South China Sea Stud.* 3 (02), 18–24.

Song, W. J. (2021). Study on the legal issues of judicial protection of marine environment in Bohai sea -taking Bohai sea pollution cases from 2011 to 2019 as the analysis object. *Tianjin Legal Sci.* 37 (01), 51–60.

Sun, S. Q., and Jin, Y. W. (2017). On the legal basis of civil public lnterest litigation for marine environment- focusing on the interpretative theory of article 89 (2) of Chinese marine environment protection law. *J. Zhejiang Ocean Univ. (Humanities Sci.)* 34 (04), 1–7.

Sun, H. K., and Tao, B. J. (2013). Double observations on procuratorial involvement in environmental public interest litigation–annotation on the improvement of article 55 of the civil procedure law. *Orient. Law.* 05, 115–124. doi: 10.19404/j.cnki.dffx.2013.05.012

Sun, H. T., and Zhang, Z. X. (2020). On the restraint and expansion of plaintiff's subject qualification in environmental public interest litigation. *J. Hohai University (Philosophy Soc Sci.)* 22 (04), 97–104 + 109.

The Supreme People's Prosecutor: The report on the implementation of public interest litigation (2019). Available at: https://www.12309.gov.Cn/llzw/yw/201910/t20191024_436143 (Accessed 2023.8.1).

Wang, W. H. (2018). Several issues on perfecting the system of procuratorial organ initiating administrative public interest litigation. *Law Science.* 39 (01), 96–108. doi: 10.16092/j.cnki.1001-618x.2018.01.010

Wang, X. G. (2018). Ecological and environmental damage actions from the perspective of public trust theory—A two-dimension theoretical framework of natural resources state ownership and public trust environmental rights and interests. *Legal Forum.* 33 (06), 32–38.

Wang, X. W. (2021). On the compensation of marine environmental damage. *J. East China Univ. Political Sci. Law* 24 (01), 76–86.

Wang, C. L., and Chang, Y.-C. (2021). A probe into legal issues of the civil public inte rest litigation on the marine ecological environment by procuratorial organs. *Chin. J. Maritime Law* 32 (02), 41–48.

Wang, C. L., and Chang, Y.-C. (2023). The Relationship betweena Community with Shared Future for Mankind and Development of International Law of the Sea -From the perspective of Establishing the BBNJ International Agreement. *J. Jiangsu Univ. (Soc. Sci. Edi.)* 25 (01), 73–85. doi: 10.13317/j.cnki.Jdskxb.2023.007

Wang, S. K., and Wu, Y. J. (2021). On the basis of governmental litigation right in eco-environment damage:Reflection and reconstruction. *J. Hohai Univ. (Soc. Sci. Edi.)* 23 (05), 34–47 + 67. doi: 10.13317/j.cnki.jdskxb.2021.46

Wang, Y., and Xia, Y. (2023). Judicializing environmental politics? China's procurator-led public interest litigation against the government. *China Quarterly.* 253, 90–106. doi: 10.1017/S0305741022001709

Wang, Q., and Xie, D. (2013). On the perfection of public interest litigation system of marine environmental pollution. *J. Anhui Agric. Univ. (soc.sci.)* 22 (01), 26–31. doi: 10.19747/j.cnki.1009-2463.2013.01.007

Wu, C. H. (2014). Study on the legal protection mechanism for the participation of social organisations in public interest litigation. *J. Capital normal Univ. (Soc.l Sci. Edi.).* 5, 64–70. doi: 10.3969/j.issn.1004-9142.2014.05.009

Wu, K. J. (2021). Nature and positioning of preventive procuratorate-filed environmental public interest litigation. *J. China Univ. geosci. (Soc. Sci. Edi.).* 21 (01), 30–44. doi: 10.16493/j.cnki.42-1627/c.2021.01.004

Wu, Y. Q., and Liu, X. C. (2019). Special jurisdiction of maritime criminal litigations. *People's Judicature.* 25, 46–50. doi: 10.19684/j.cnki.1002-4603.2019.25.011

Xiamen Maritime Court (2022). *First Case: Concluded the Marine Ecology Public Interest Litigation Case Filed by the Coast Guard Agency*. Available at: http://www.xmhsfy.gov.cn/xwzx/fydt/ 202203/ t202203 01_ 244210.htm.

Xie, L. (2021). Conflict and coordination between national claims for marine ecological damage and environmental public interest litigation. *Environ. Protect.* 49 (19), 50–55. doi: 10.14026/j.cnki.0253-9705.2021.19.008

Xie, L., and Xu, L. (2021). Environmental public interest litigation in china: a critical examination. *Transnational Environmental Law.* 10 (3), 441–465. doi: 10.1017/S2047102520000448

Xie, L., and Xu, L. (2022). Environmental public interest litigation in China: findings from 570 court cases brought by NGOs, public prosecutors and local government. *J. Environ. Law.* 34 (1), 53–81. doi: 10.1093/jel/eqab029

Xie, Y., and Yu, X. L. (2022). System positioning and perfection of marine environmental public interest litigation. *China popul Resour. Environ.* 32 (1), 168–176.

Xu, Q. B. (2017). Function orientation and system construction of procuratorial organ lnitiating administrative public interest litigation. *Admin. Law Review.* 5, 77–86.

Xu, W., and Zhang, Z. (2022). Impact of coastal urbanization on marine pollution : evidence from China. *Int. J. Environ. Res. Public Health* 19 (17), 10718. doi: 10.3390/ijerph191710718

Yang, Z. X. (2013). Study on the Basement of the Right and the Prosecute Sequence of Environmental Public Interest Litigation-Both on Theory points of real right to natural resources and environmental right. *Legal Forum* 28 (03), 102–112.

Yang, H. (2021). The main body of plaintiffs in marine environmental public interest litigation. *Stud. Law Business.* 38(03), 120–133. doi: 10.16390/j.cnki.issn.1672-0393.2021.03.010

Yu, M. H. (2021). Study on the path and procedure of procuratorial public interest litigation in marine environmental protection. *Chin. J. Maritime Law.* 32 (02), 33–40. doi: 10.3969/j.issn.1003-7659.2021.02.005

Zhai, T. C. (2018). Standing of environmental public-interest litigants in China: evolution, obstacles and solutions. *J. Environ. Law.* 30 (3), 369–397. doi: 10.1093/jel/eqy011

Zhai, T. T., and Chang, Y.-C. (2019). The contribution of China's civil law to sustainable development : progress and prospects. *Sustainability* 11 (1), 294. doi: 10.3390/su11010294

Zhang, F. (2015a). Construction of the subject qualification of procuratorial organs in environmental public interest litigation. *J. Political Sci. Law.* 1, 120–128. doi: 10.3969/j.issn.1002-6274.2015.01.015

Zhang, F. (2015b). Stimulation and restriction of ENGO's environmental public litigation qualification. *China Popul. Resour. Environ.* 25 (03), 169–176. doi: 10.3969/j.issn.1002-2104.2015.03.022

Zhang, J. F. (2019). The affirmation of accuser's subject ldentity in marine environmental nonprofit litigation-A case study of rong chengbo. *J. Zhejiang Ocean University(Humanities sci.).* 36 (6), 5–8.

Zhang, X. Q. (2019). Comparative study on public interest litigation filed by the procuratorate. *J. Natl. Prosecutors College.* 27 (01), 149–160.

Zhang, C. (2021). On the role of administrative acts on the effectiveness of legal acts–A systematic attempt from the theory of basic rights. *China Law Review.* 3, 80–91.

Zhang, Q., Lv, J. A., Ge, Y. W., Guo, C., Wang, Q., Hao, M. Y., et al. (2023). Evaluation on the achievements of environmental public interest litigation against the pollution in a typical lake in China. *Environ. Forensics*, 1527–5922. doi: 10.1080/15275922.2023.217209310

Zhang, J. P., Pan, Y., and Xu, W. G. (2017). Research on developmental obstacles of ENGO and countermeasures in China. *J. Shanghai Ocean University.* 26 (06), 933–938. doi: 10.12024/jsou.20170301995

Zhang, X. P., and Zheng, P. (2021). Confirming the qualified plaintiff in the civil public interest litigation on marine environment. *J. Hainan Univ. (Humanities Soc Sci.).* 39 (01), 122–128. doi: 10.15886/j.cnki.hnus.2021.01.016

Zhang, C. F., Zhou, H. H., Cui, Y. Z., Wang, C. S., Li, Y. H., and Zhang, D. D. (2019). Microplastics in offshore sediment in the Yellow Sea and East China Sea. *China. Environ. Pollution.* 244, 827–833. doi: 10.1016/j.envpol.2018.10.102

Zhao, X. H. (2023). On the Support for Prosecution by Procuratorial organs in civil public interest litigation of Marine environment. *J. Jiangsu Ocean Univ. (Humanities Soc Sci. Edi.)* 21 (3), 36–43.

Zhu, Z. X. (2015). Subordination of plaintiffs in marine environmental public interest litigation. *People's Judicature* 23, 25–28. doi: 10.19684/j.cnki.1002-4603.2015.23.008.

Zhu, X., and Liang, X. M. (2018). The subject status of procuratorate in marine litigation on public interests protection. *J. Zhejiang Gongshang Univ.* 05, 17–26. doi: 10.14134/j.cnki.cn33-1337/c.2018.05.002

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 11 December 2023
DOI 10.3389/fmars.2023.1305091

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
Dalian Maritime University, China

REVIEWED BY
Duminda Senevirathna,
Uva Wellassa University, Sri Lanka
Yi-Che Shih,
National Cheng Kung University, Taiwan

*CORRESPONDENCE
Sher Singh
hsher@ntnu.edu.tw
Ying-Fei Yang
f00622037@ntu.edu.tw

†These authors have contributed equally to this work

RECEIVED 30 September 2023
ACCEPTED 27 November 2023
PUBLISHED 11 December 2023

CITATION
Yu R-S, Yang Y-F and Singh S (2023) Global analysis of marine plastics and implications of control measure strategies.
Front. Mar. Sci. 10:1305091.
doi: 10.3389/fmars.2023.1305091

COPYRIGHT
© 2023 Yu, Yang and Singh. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Global analysis of marine plastics and implications of control measure strategies

Ren-Shou Yu[1], Ying-Fei Yang[2*†] and Sher Singh[3*†]

[1]Department of Tourism Management, Jimei University, Xiamen, China, [2]Department of Bioenvironmental Systems Engineering, National Taiwan University, Taipei, Taiwan, [3]Department of Life Science, School of Life Science, College of Science, National Taiwan Normal University, Taipei, Taiwan

Plastic pollution is a global environmental crisis that threatens marine ecosystems and human health. This study provides a comprehensive analysis of the current state of plastic pollution in oceans worldwide. We examined data on global plastic production, annual estimates of plastic emissions to oceans from different countries, surface plastic mass by ocean basin, the share of global plastic waste emitted to the ocean, the share of ocean plastics that come from the largest emitting rivers, microplastics in the surface ocean, and plastic mass and particles across the world surface ocean. Our analysis revealed alarming trends, such as the significant increase in plastic production since the 1950s and the projected estimate of up to 12,000 million metric tons of plastic waste in the natural environment by 2050. Additionally, we found that more than 1000 rivers account for 80% of global annual emissions, with Asia contributing the highest estimate of plastic emissions, followed by Africa, South America, North America, Europe, and Oceania. Furthermore, our findings showed that the largest contributors to ocean plastic waste are macroplastics, mesoplastics, and microplastics, with small microplastics dominating the percentage of surface ocean plastic by particle count. The recycling and reuse of waste plastics implement the concept of sustainable development of recycling and offsets the carbon emissions in the environment, potentially obtaining more carbon credits. Our findings highlight the urgent need for coordinated global efforts to reduce plastic waste and prevent further harm to our oceans, incorporating recycling and reuse strategies as key components of comprehensive control measures.

KEYWORDS

plastic pollution, marine ecosystems, control measures, carbon credit, recycling, sustainable development

1 Introduction

Plastic pollution has become a significant environmental and health challenge worldwide. The production and consumption of plastic have increased significantly over the past few decades, with global plastic production reaching 368 million metric tons in 2019 (Europe, 2020). While plastic has many benefits in various sectors, including food packaging, medical supplies, and construction, its indiscriminate disposal and lack of proper waste management have resulted in a pervasive environmental problem.

The impacts of plastic pollution on marine ecosystems and human well-being are severe and far-reaching. Plastic waste in the ocean harms marine species and their habitats, disrupts ecosystem functioning, and causes economic losses to fisheries and tourism (Beaumont et al., 2019). Plastic pollution also poses a threat to human health through the consumption of contaminated seafood and water, as well as through microplastic inhalation and ingestion (Smith et al., 2018). In addition, plastic pollution exacerbates climate change by contributing to greenhouse gas emissions from plastic production and disposal (Ford et al., 2022).

Given the magnitude and complexity of the plastic pollution problem, there is an urgent need for concerted efforts to reduce plastic production, consumption, and waste. Various measures have been proposed and implemented globally, including plastic bag bans, extended producer responsibility schemes, and the development of biodegradable and compostable plastics (Mallick et al., 2021). However, more comprehensive and collaborative solutions are necessary to tackle the plastic pollution problem effectively and sustainably. Control measure strategies, such as improving waste management, promoting sustainable consumption and production, increasing public awareness, and incentivizing industries to develop eco-friendly products, could play a critical role in mitigating plastic pollution (Abubakar et al., 2022). In order to awaken human attention to the marine environment, the United Nations designated June 8th as World Oceans Day starting in 2009, hoping that the world will use this to examine global issues such as marine pollution and excessive resource consumption. Given the far-reaching and devastating consequences of plastic pollution, it is essential to take swift and decisive action to address this crisis and safeguard our oceans' health and wellbeing.

Therefore, the objectives of this study are fourfold: (i) to analyze the current and future trends in global plastic production and its potential impact on the environment, particularly in the oceans, and identify measures to reduce plastic waste, (ii) to investigate the major contributors to plastic waste in the oceans, such as rivers, countries, and continents, and identify strategies to mitigate plastic emissions from these sources, (iii) to assess the magnitude and distribution of microplastics in the world's surface oceans, including their size and composition, and (iv) to propose methods and strategies to monitor and control proliferation of ocean plastics.

2 Materials and methods

To estimate the annual emissions of plastics to oceans, we adopted the platform of "Our World in Data" for data analysis. "Our World in Data" is a prominent online publication and data platform known for its credible and comprehensive approach to presenting global trends. By sourcing data from reputable international organizations, governments, and research institutions, it ensures the accuracy and reliability of its information. Through visually engaging charts, graphs, and interactive tools, the platform transforms complex data into easily understandable visualizations, aiding users in quickly grasping key insights. Its global perspective enables users to compare countries and regions across a wide range of topics, while its historical context feature allows for a deeper understanding of long-term trends. As an educational resource, "Our World in Data" is utilized by students, researchers, educators, and policymakers alike, offering open access to valuable knowledge. With its interdisciplinary insights, regular updates, and commitment to transparent information sharing, the platform stands as an invaluable tool for comprehending the complex dynamics that shape our world. (Ritchie and Roser, 2018).

The Our World in Data collected data on global plastic production from various sources, including industry reports and academic studies. Firstly, to analyze the current and future trends in global plastic production, the surface plastic mass by ocean basin shown on the Our World in Data platform were analyzed by using data from previous studies (Eriksen et al., 2014; Meijer et al., 2021). Secondly, to investigate the major contributors to plastic waste in the oceans, the share of global plastic waste emitted to ocean and the share of ocean plastics that come from the largest emitting rivers were evaluated by adopting data from Meijer et al. (2021). Thirdly, to assess the magnitude and distribution of microplastics in the world's surface oceans, microplastics in the surface ocean and plastic mass and particles across the world surface ocean were also investigated and visualized through Our World in Data (Eriksen et al., 2014; Lebreton et al., 2019). Finally, to propose methods and strategies to monitor and control proliferation of ocean plastics, global distribution of microplastics in the surface ocean in 2019 was estimated. We also used the NOAA, National Centers for Environmental Information (NCEI) and Microplastics Database (2022) for data analysis and visualization.

3 Results

3.1 Global plastic production

If assuming consistent use patterns with current global waste management trends to 2050, it was estimated that 9000 million metric tons of plastic waste will have been recycled, 12,000 million metric tons incinerated, and 12,000 million metric tons discarded in landfills or the natural environment (Geyer et al., 2017).

Based on the estimations, Figure 1 further projected the global plastic production from 1950 to 2019. The graph illustrates a significant increase in plastic production from 2 million metric tons in 1950 to 459.75 million metric tons in 2019 with 8300 million metric tons as of virgin plastics. Based on the estimation by Geyer et al. (Geyer et al., 2017), if current plastic production trends continue, approximately as much as 12,000 million metric tons of

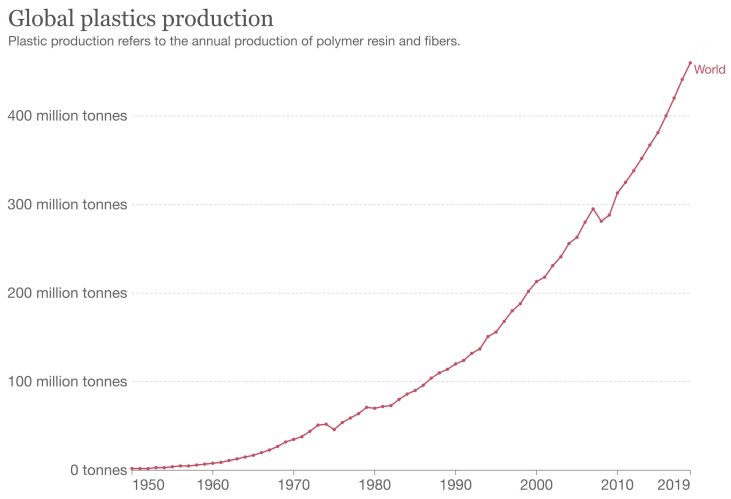


FIGURE 1
Annual global polymer and fiber creation. The data in this figure show the yearly accumulation of polymer resin and fibers. Analyzed by Our World in Data (Ritchie and Roser, 2018), the content relies on foundational work by (Geyer et al., 2017).

plastic waste will be in the natural environment by 2050 (Geyer et al., 2017).

3.2 Emitted plastics to oceans from different countries

It was estimated that more than 1000 rivers account for 80% of global annual emissions, ranging between 0.8 million to 2.7 million metric tons per year, with small urban rivers among the most polluting (Meijer et al., 2021). Based on the analyses of the previous study, Figure 2 visualizes the annual estimates of plastics with volume differences emitted to the oceans from various countries in 2019. Table 1 lists percentages of share of global plastic waste emitted to oceans from the first twenty countries and regions contribute most to plastic emissions (Meijer et al., 2021). The largest contributing country estimated was the Philippines with 4820 rivers emitting 356,371 million metric tons year^{-1}, followed by India with 126,513 million metric tons

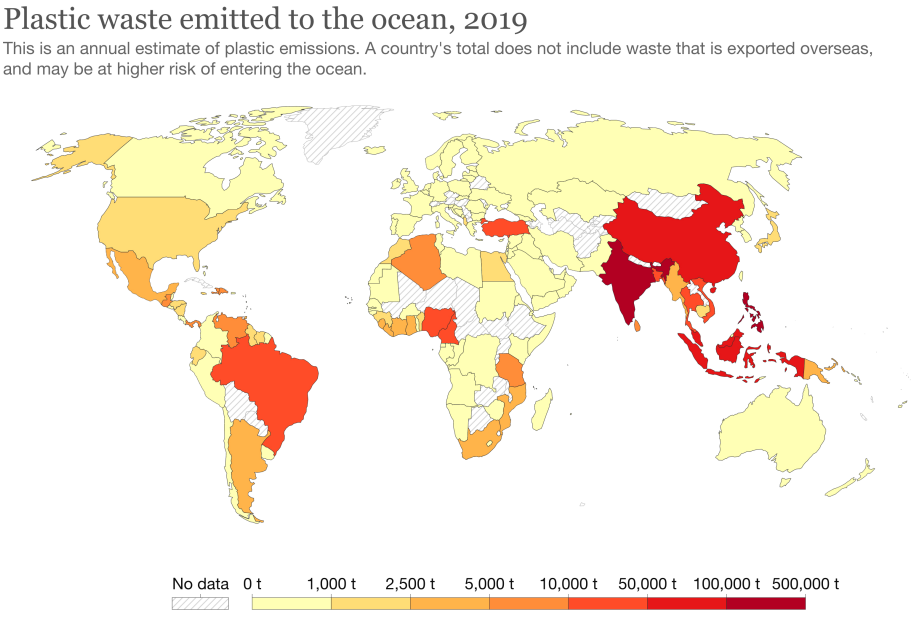


FIGURE 2
2019 Estimates of ocean-bound plastic. The figure indicates annual projections of plastic discharge into marine environments. Data for each country do not account for waste exported abroad, which may pose an elevated risk for ocean pollution. Analytics provided by Our World in Data (Ritchie and Roser, 2018), based on research by (Meijer et al., 2021). Notably, over 1000 rivers contribute to 80% of the global plastic inflow into oceans.

year^{-1}, Malaysia with 73,098 million metric tons year^{-1} through 1070 rivers, and China with 70,707 million metric tons year^{-1} through 1309 rivers (Meijer et al., 2021). We also included information of percentages of share of global plastic waste from100 countries orderly contributing to plastic emissions to oceans (Supplementary Table S1).

3.3 Emitted plastics to oceans from six continents

Figure 3 shows the share of global plastic waste emitted to the ocean. The data indicate that an estimated 8 million metric tons of plastic waste were emitted to oceans, with the majority coming from Asia. It was found that more than 1000 rivers account for 80% of global annual emissions, ranging from 0.8 million to 2.7 million metric tons per year. Among six continents, Asia accounts for the highest estimate of plastic emissions (80.99%), followed by Africa (7.99%), South America (5.51%), North America (4.5%), Europe (0.6%), and Oceania (0.37%) (Figure 3).

Figure 4 displays the surface plastic mass by ocean basin. The global ocean (total) surface plastic mass was 268,950 tonnes. The North Pacific had the highest surface plastic mass at 96,400 tonnes, followed by the Indian Ocean (59,130 and the North Atlantic. Based on the oceanographic model of floating debris dispersal, a minimum of 5.25 trillion particles weighing 268,940 tons were estimated (Figure 4).

TABLE 1 Plastic waste emitted to the ocean tonnes per year, 2019 (top 20 countries and 5 regions) (Ritchie and Roser, 2018; Meijer et al., 2021).

Country or region	Code	Share of global plastic waste emitted to the ocean (%)
Philippines	PHL	36.38
India	IND	12.92
Malaysia	MYS	7.46
China	CHN	7.22
Indonesia	IDN	5.75
Brazil	BRA	3.86
Vietnam	VNM	2.88
Bangladesh	BGD	2.52
Thailand	THA	2.33
Nigeria	NGA	1.90
Turkey	TUR	1.46
Cameroon	CMR	1.09
Sri Lanka	LKA	0.99
Guatemala	GTM	0.73
Haiti	HTI	0.71
Dominican Republic	DOM	0.64
Venezuela	VEN	0.61
Tanzania	TZA	0.59
Algeria	DZA	0.59
Panama	PAN	0.53
Asia		***80.99***
Africa		***7.99***
South America		***5.51***
North America		***4.50***
Europe		***0.60***

Texts in bold are region. Texts not in bold are countries.

3.4 Emitted plastics to oceans from different rivers

Figure 5 illustrates the share of ocean plastics that come from the largest emitting rivers. In accordance with the results in Figures 2, 3, The Pasig (Philippines) is the largest contributor, accounting for 6.43% of all plastic wastes, followed by the Klang (Malaysia) for 1.33% and the Ulhas (India) for 1.33%.

3.5 Prediction of microplastic in surface oceans

Figure 6 presents global accumulations of microplastics in the surface ocean under three plastic emissions scenarios. The mass of buoyant macroplastics on the global ocean surface and coastlines continue to increase with a relatively slower rate due to degradation of older objects into smaller particles if emissions of plastics into the oceans are kept constant from the year of 2020. If sources of buoyant macroplastics are stopped from the year of 2020, floating and stranded mass of macroplastics could decrease by 2050 to respectively 59% and 57% of their 2020 levels (Lebreton et al., 2019).

We further explored the distributions of microplastics with visualization in a global level (Figure 7). Consistent with Figures 2, 3, and 5, Philippines, India, and Malaysia have either very high (10 pieces/m^3 or greater) or high (1-10 pieces/m^3) concentrations of marine microplastics. Higher proportions of distributions of microplastics with 'very high' or 'high' concentrations were also observed in regions of Asia and Africa. There were also higher distributions of microplastics in high concentrations around Russia and the North Pacific Ocean (Figure 7).

3.6 Microplastics across world's surface oceans

Figure 8 displays the surface plastic by mass (tonnes) or by particle count across the world surface oceans. If counted by mass, macroplastics (>200 mm) dominate the per-centage of surface ocean plastic, followed by mesoplastics (4.76 mm-200 mm), large microplastics (1.01 mm-4.75mm), and small microplastics (0.33-1 mm) (Figure 8). If counted by particle count, small microplastics (0.33-1 mm) dominate the percentage of surface ocean plastic,

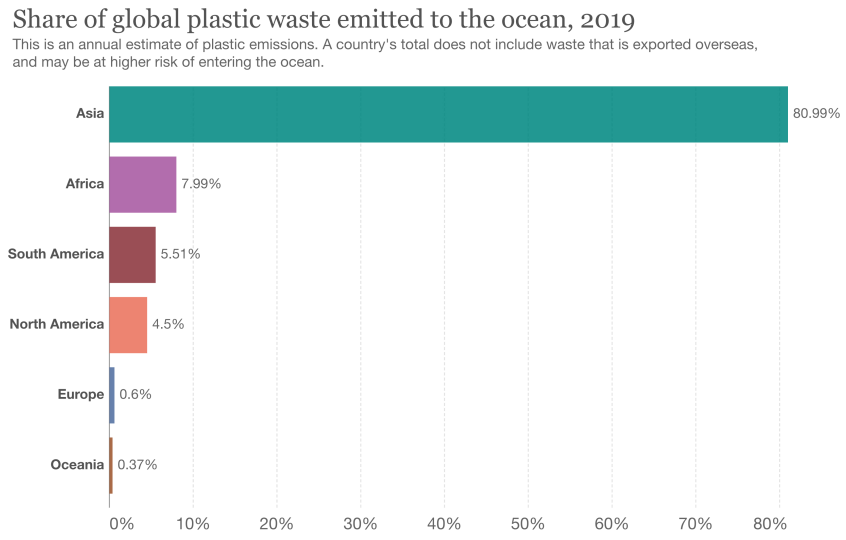


FIGURE 3
2019 Global oceanic plastic emission share. The figure presents yearly statistics of plastic waste entering marine ecosystems. The total for each country excludes waste for export, increasing the likelihood of oceanic contamination. Data were interpreted by Our World in Data (Ritchie and Roser, 2018), founded on the study by (Meijer et al., 2021). Notably, over 1000 rivers contribute to 80% of annual global plastic ocean entry.

followed by large microplastics (1.01 mm-4.75mm), and mesoplastics (4.76 mm-200 mm) (Figure 8).

4 Discussion

4.1 Plastic production and ocean pollution

Plastic production has reached an all-time high, with over 360 million tons of plastic produced globally in 2018. We also found that global plastic production was 459.75 million metric tons in 2019 (Geyer et al., 2017). This high production rate has led to an increase in plastic pollution, with millions of tons of plastic waste being dumped into the oceans each year. According to Jambeck et al. (2015), up to 13 million tons of plastic waste enters the oceans each year, threatening marine ecosystems and human health.

Plastic pollution in the oceans is a global issue, with plastic waste found in all ocean basins. A study estimated that Asia is the largest contributor to plastic pollution in the oceans, accounting for 81% of the total mass of plastic waste in the oceans (Schmidt et al.,

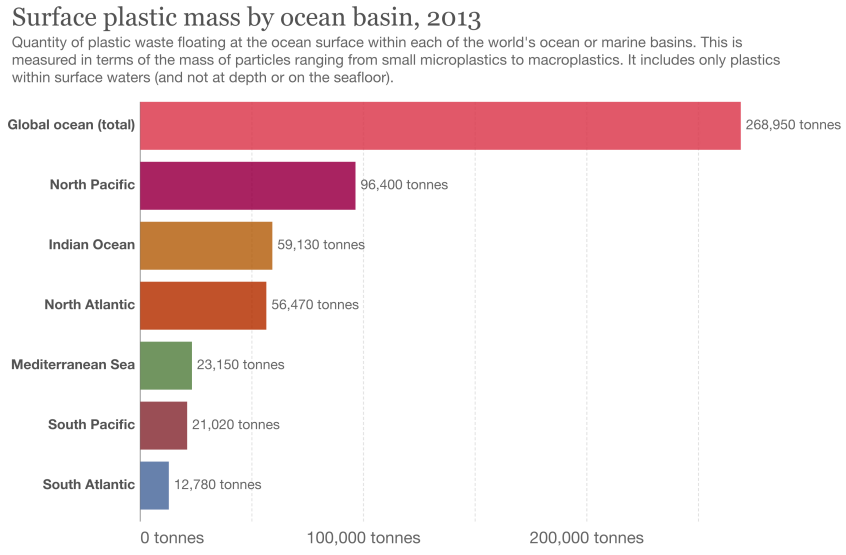


FIGURE 4
2013 Ocean basin surface plastic weights. The figure details the mass of floating plastic waste across global ocean basins, categorized from microplastics to larger particles. The focus is exclusively on surface-level plastics, disregarding those at greater depths or the ocean floor. Data were interpreted by Our World in Data (Ritchie and Roser, 2018), and are grounded in the study by (Eriksen et al., 2014). It's worth noting that over 1000 rivers are responsible for 80% of plastic entering global oceans.

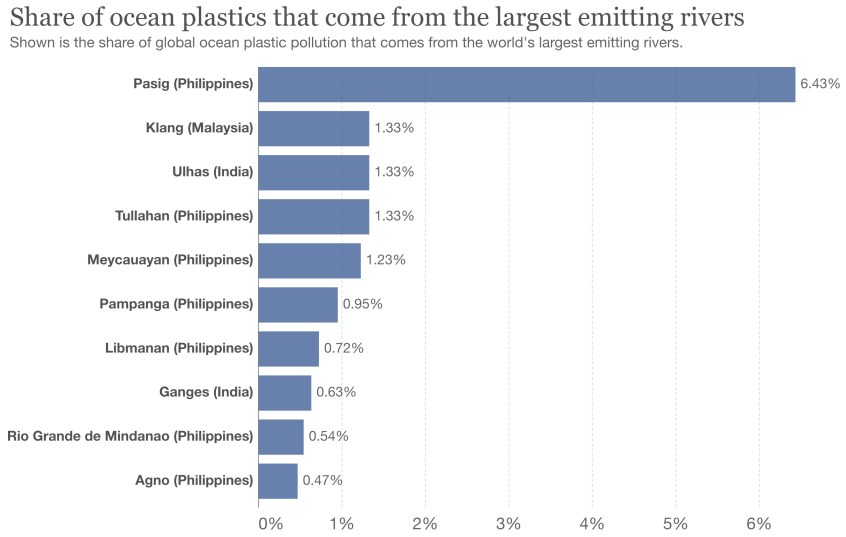


FIGURE 5
Major river contributors to ocean plastic. The figure delineates the percentage of oceanic plastic waste originating from the world's most significant river sources. Over 1000 rivers contribute to a substantial 80% of the plastic entering oceans globally. Data interpretation was conducted by Our World in Data (Ritchie and Roser, 2018), based on (Meijer et al., 2021).

2017). It was also found that the top 20 countries responsible for plastic waste in the oceans were located in Asia and Africa, with China being the largest contributor, followed by Indonesia and the Philippines.

The effects of plastic pollution on marine ecosystems are numerous and severe. Plastic waste in the oceans can harm marine organisms through ingestion, entanglement, and physical damage. A study found that over 800 species are affected by plastic debris, including sea turtles, whales, and seabirds (Gall and Thompson, 2015). Furthermore, plastic pollution can also have economic and social impacts, affecting industries such as fisheries and tourism.

Another issue that has been raising much concerns is the macroplastics, if counted by mass, macroplastics (>200 mm)

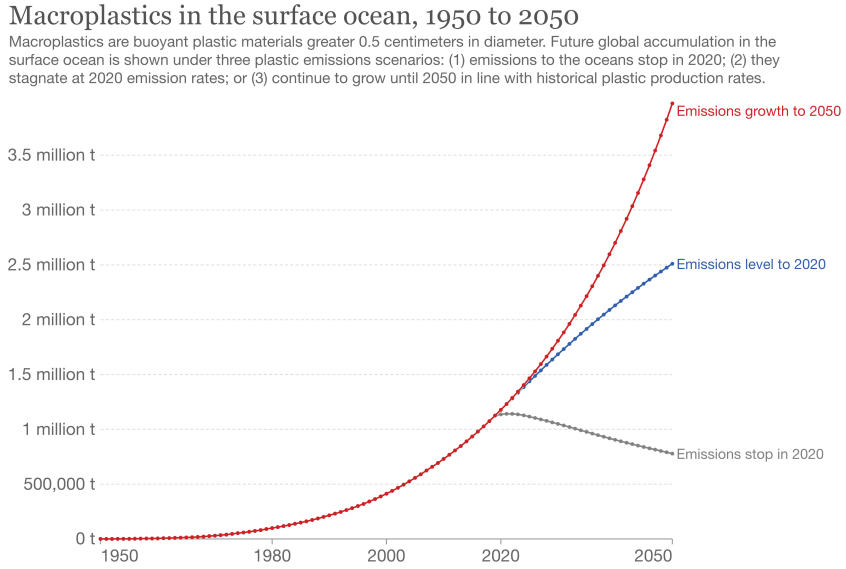


FIGURE 6
Oceanic macroplastic projections, 1950-2050. Macroplastics, defined as buoyant plastics larger than 0.5 cm in diameter, are the focus of this figure. It illustrates three future scenarios for macroplastic accumulation on ocean surfaces: (1) cessation of emissions after 2020; (2) maintenance of 2020 emission levels; and (3) continued growth aligned with past production rates until 2050. Data interpretation was done by Our World in Data (Ritchie and Roser, 2018), based on research by (Lebreton et al., 2019). It offers a global budget outlook for positively buoyant macroplastic waste in marine environments.

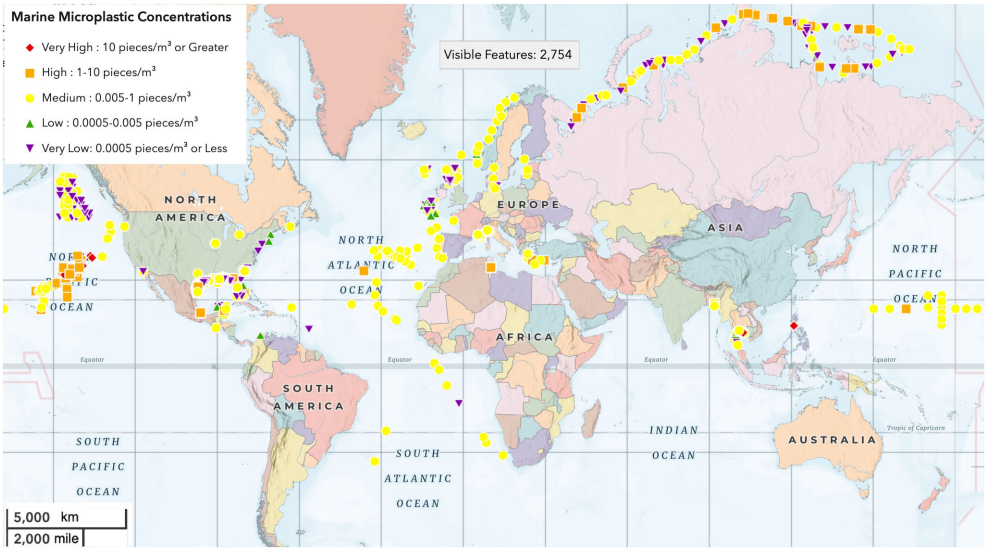


FIGURE 7
2019 Microplastic concentrations across global oceans. The figure utilizes varied shapes and hues to depict differing levels of surface ocean microplastic concentrations: red diamonds for very high levels (10 pieces/m^3 or more), orange squares for high levels (1-10 pieces/m^3), yellow circles for medium levels (0.005-1 pieces/m^3), green triangles for low levels (0.0005-0.005 pieces/m^3), and purple upside-down triangles for very low levels (0.0005 pieces/m^3 or less). Data were sourced from the NOAA/NCEI Microplastics Database (NOAA 2022).

dominate the percentage of surface ocean plastic, followed by mesoplastics (4.76 mm-200 mm), large microplastics (1.01 mm-4.75mm), and small microplastics (0.33-1 mm) (Figure 7). If counted by particle count, small microplastics (0.33-1 mm) dominate the percentage of surface ocean plastic, followed by large microplastics (1.01 mm-4.75mm), and mesoplastics (4.76 mm-200 mm).

Conclusively, plastic pollution in the oceans is a complex and urgent issue that requires global cooperation and action. It is essential to reduce plastic production, improve waste management, and promote sustainable alternatives to prevent further damage to marine ecosystems and human health. With the development of new technologies and increased awareness and education, there is hope for a cleaner and healthier future for our oceans.

4.2 Geographical distribution of plastic waste

Plastic waste is a global environmental challenge, with significant consequences for marine ecosystems and human health. The distribution of plastic waste in marine environments is influenced by a range of factors, including ocean currents, coastal

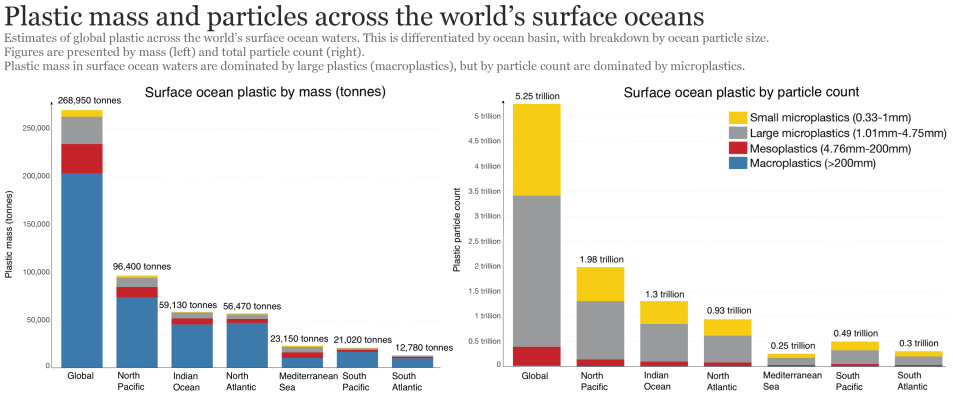


FIGURE 8
Plastic particles in the world's surface ocean. Estimates of global plastic across the world's surface ocean waters. This is differentiated by ocean basin, with breakdown by ocean particle size. Figures are presented by mass (left) and total particle count (right). Plastic mass in surface ocean waters are dominated by large plastics (macroplastics), but by particle count are dominated by microplastics. (Results were analyzed by Our World in Data (Ritchie and Roser, 2018), based on the original study of (Eriksen et al., 2014). Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at sea.).

populations, and waste management systems. We have found that the majority of plastic waste was coming from Asia, followed by Africa, South America, North America, Europe, and Oceania (Meijer et al., 2021). In addition, research has shown that plastic waste is distributed across all ocean basins, with varying concentrations depending on the location. Consistent with our results, Eriksen et al. (Eriksen et al., 2014) found that the North Pacific Ocean has the highest concentration of plastic waste, with an estimated 1.8 trillion plastic pieces weighing over 80,000 metric tons (Eriksen et al., 2014). The study also found that other ocean basins, such as the South Pacific and Indian Ocean, also have high concentrations of plastic waste. The Mediterranean Sea has the highest density of plastic waste in the world, with an estimated 1.25 million plastic particles per square kilometer (Suaria et al., 2016). The Bay of Bengal, the South China Sea, and the Gulf of Mexico have also been identified as regions with high densities of plastic waste (Cózar et al., 2014; Jambeck et al., 2015; Schmidt et al., 2017).

In the perspective of plastics emitted from rivers around the world, we also found that Pasig (Philippines) is the largest contributor, followed by the Klang (Malaysia) and the Ulhas (India). In addition, the concentration of microplastics in the Arctic Ocean has increased over the past decade due to the transport of plastic waste from other regions (Bergmann et al., 2022). The study also found that microplastics have the potential to accumulate in the Arctic marine food chain, posing a threat to wildlife and human health. Another study found that plastic pollution is impacting the Galapagos Islands, a UNESCO World Heritage site, with plastic debris found in the stomachs of various marine species (Jones et al., 2021). The study suggests that plastic waste is being transported from other regions and accumulating in the waters around the Galapagos Islands, highlighting the need for international cooperation to address this global issue.

4.3 Plastic threat to marine ecosystems

Plastic pollution is a major threat to marine ecosystems, and it is essential that we take action to address this issue. The impacts of plastic waste on marine life are well documented, with entanglement and ingestion being the most common causes of harm (Rochman et al., 2013; Gall and Thompson, 2015; Wilcox et al., 2015). Plastic waste can also leach harmful chemicals into marine environments, affecting the health of marine organisms and potentially entering the food chain (Teuten et al., 2009; Andrady, 2011; Geyer et al., 2017). The accumulation of plastic waste in the ocean is a global issue that requires urgent attention, and there is a need for more research into the distribution and impacts of plastic waste in marine environments.

The impacts of plastic waste on marine ecosystems are wide-ranging and significant. Plastic waste can entangle and kill marine organisms, and it can be ingested by marine animals, leading to internal injuries and death (Rochman et al., 2013; Gall and Thompson, 2015; Wilcox et al., 2015). Plastic waste can also leach harmful chemicals into marine environments, affecting the health of marine organisms and potentially entering the food chain (Teuten et al., 2009; Andrady, 2011; Geyer et al., 2017). Also, Plastic pollution can alter marine habitats, with impacts on ecosystem functioning. A study published in the journal Nature found that plastic pollution can increase the risk of disease transmission in coral reefs (Lamb et al., 2017). The study also found that plastic pollution can alter the microbial community in marine environments, with potential implications for nutrient cycling and carbon storage. The impacts of plastic waste on human health are less well understood, but there is evidence to suggest that microplastics, which are small plastic particles, can accumulate in seafood and other food sources, potentially posing a risk to human health (Rochman et al., 2013; Van Cauwenberghe and Janssen, 2014; Galloway et al., 2017).

Plastic pollution can have indirect effects on marine ecosystems, such as altering the physical properties of marine environments. It was found that plastic pollution can reduce the oxygen concentration in marine environments, leading to hypoxia and potentially harmful algal blooms (Breitburg et al., 2018). The study also revealed that plastic pollution can increase the acidity of marine environments, with potential impacts on marine organisms.

Efforts to address the issue of plastic waste in the ocean are ongoing, and there are many potential solutions that could help to reduce the amount of plastic that enters marine ecosystems. One approach is to improve waste management systems, particularly in countries where waste is often dumped or burned rather than being properly disposed of (Jambeck et al., 2015). This could involve investing in infrastructure to collect and recycle plastic waste, as well as educating the public about the importance of responsible waste disposal. Another approach is to develop sustainable alternatives to plastic, such as biodegradable materials or reusable containers (Yuan et al., 2021). This would require significant investment in research and development, as well as support from governments and industry.

There is also a need for greater public awareness and engagement on the issue of plastic pollution in marine ecosystems. This could involve campaigns to reduce the use of single-use plastics, as well as educational programs in schools and universities. It is important to engage people from all walks of life, from consumers to businesses, in order to create a widespread culture of responsible plastic use (Skoric et al., 2022). Ultimately, the key to addressing the plastic threat to marine ecosystems is a multifaceted approach that involves cooperation between governments, industry, and individuals.

4.4 Control measure strategies to mitigate marine plastics

This study highlights the alarming levels of plastic production, emissions, and microplastic pollution in the world's oceans. Control measures must be taken to mitigate the adverse impacts of plastic waste on the marine ecosystem. It is clear that reducing plastic production and managing plastic waste must be a priority. Efforts to reduce plastic use and increase recycling, reuse, and proper disposal should be implemented. It is also necessary to address the issue of plastic waste management in developing countries, particularly in Asia and Africa, which account for the largest share of plastic waste

emissions to the ocean. Solutions such as improving waste collection systems, implementing extended producer responsibility programs, and promoting public awareness and education about the impacts of plastic waste can be helpful.

To reduce the emissions of plastics from rivers to oceans, river clean-up campaigns and the installation of river-based waste collection systems can be effective measures. For instance, innovative and low-cost technologies such as floating booms and nets, and hydrodynamic separators can be deployed to capture plastic waste from rivers before they reach the ocean. Another effective measures is the reduction of plastic waste at its source, through the development of sustainable alternatives to plastic and the implementation of waste management systems (Figure 9). For example, the introduction of plastic bag bans has been found to be effective in reducing plastic waste in the ocean (CalRecycle, 2013), and the use of compostable bioplastics has been suggested as a potential alternative to conventional plastic (Moshood et al., 2022).

To address the problem of plastic waste in marine environments, a range of solutions are needed, including improved waste management systems, the development of sustainable alternatives to plastic, and greater public awareness and engagement. There is also a need for more research into the distribution and impacts of plastic waste in marine environments, as well as the development of innovative technologies and approaches to mitigate the problem. The United Nations has identified the reduction of marine litter, including plastic waste, as a key target in the Sustainable Development Goals (SDGs) (United Nations General Assembly, 2015), highlighting the urgent need for global action to address this pressing environmental challenge.

In addition, a study found that reducing plastic waste by 50% in the ten rivers that contribute the most plastic waste to the ocean could reduce global plastic pollution by 45% (Schmidt et al., 2017). The study highlights the importance of addressing the sources of plastic waste on land in order to reduce the amount of plastic that enters the ocean. Other efforts include the implementation of regulations and policies to reduce plastic waste, such as plastic bag bans and extended producer responsibility. A study conducted by CalRecycle, the agency responsible for enforcing waste management laws in California, found that in the six months following the implementation of a plastic bag ban, in 86 percent of transactions, customers brought their own bags and didn't purchase a paper or reusable bag. As a result, there was an 85 percent reduction in the number of plastic bags and a 61 percent reduction in the number of paper bags provided to customers (CalRecycle, 2013). However, the effectiveness of these measures may vary depending on the context and implementation.

Research and innovation are being carried out to develop new technologies that can help reduce plastic waste and clean up the oceans. For example, the Ocean Cleanup, a nonprofit organization, has developed a system to collect plastic waste from the oceans using a floating barrier and conveyor belt (https://theoceancleanup.com/; Eriksen et al., 2014). Another innovative solution is biodegradable plastic, which can break down naturally in the environment, reducing

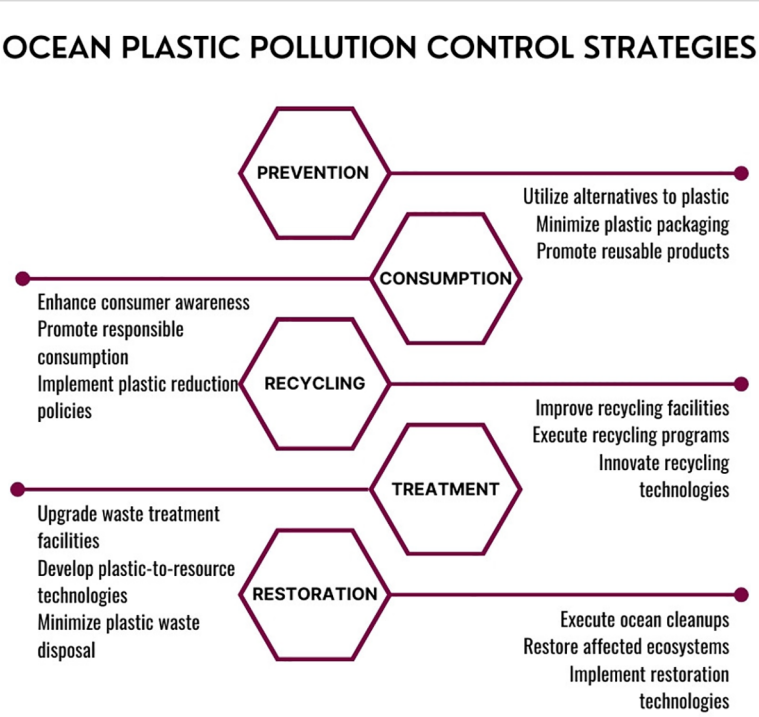


FIGURE 9
Ocean plastic pollution control strategies. The diagram outlines multi-tiered approaches ranging from prevention and consumption to recycling treatment and restoration. Strategies include but are not limited to utilizing alternatives to plastic, enhancing consumer awareness, improving recycling facilities, and executing ocean cleanups.

the amount of plastic waste that ends up in the oceans (Shen et al., 2020). In addition to technological innovations, education and awareness campaigns are essential in reducing plastic waste and preventing pollution. One study found that increasing environmental awareness and education can reduce the amount of plastic waste generated by individuals (Liu et al., 2023). Governments and organizations can also implement policies and regulations to reduce plastic production and promote sustainable alternatives, such as banning single-use plastics or implementing extended producer responsibility programs (Knoblauch and Mederake, 2021).

Innovative technologies are being proposed as a means to tackle the issue of plastic waste in the ocean. These include the use of artificial intelligence (AI) for monitoring and robotic technologies for waste removal (Figure 10). We proposed several mitigation measures with application of the AI tool, which includes (i) plastic sorting and recycling, (ii) plastic detection, (iii) supply chain optimization, (iv) predictive models, (v) bioplastics R&D, and (vi) public education and engagement. It is worthwhile to invest the AI tool to improve the efficiency of plastic sorting and recycling.

An example of such innovative strategy includes deploying unmanned surface vehicles fitted with cameras and sensors, designed to detect and extract plastic waste from marine environments (Yuan et al., 2023). Other technologies, such as booms and barriers, can also be used to capture plastic waste in rivers and other waterways before it enters the ocean (Schmidt et al., 2017).

Community engagement and awareness-raising campaigns are also important strategies for mitigating marine plastics. The involvement of local communities in beach clean-ups and recycling programs can help reduce the amount of plastic waste that enters the ocean (Callos, 2019). Educational programs and campaigns can also help raise awareness about the impact of marine plastics on the environment and encourage individuals to reduce their plastic consumption and properly dispose of plastic waste (Liu et al., 2023).

In summary, there are a variety of control measure strategies available to mitigate marine plastics, including reducing plastic waste at its source, developing sustainable alternatives to plastic, using innovative technologies to remove plastic waste from the ocean, and engaging communities through education and awareness-raising campaigns. However, a multi-faceted approach is needed to effectively address this global problem, and continued research and development in this area is necessary.

4.5 Urgent action for reducing plastic

Urgent action is needed to reduce plastic waste and prevent further damage to marine ecosystems and human health. The issue of plastic pollution has gained global attention in recent years, leading to increased awareness and efforts to address the problem. Reducing plastic waste requires a combination of strategies, including reducing plastic production, improving waste management systems, and promoting the use of sustainable alternatives to plastic (Geyer et al., 2017).

Governments and industry play a crucial role in reducing plastic waste. Many countries have implemented policies to ban or reduce the use of single-use plastics, such as plastic bags and straws. For example, in 2019, the European Union implemented a ban on single-use plastics, including straws, cutlery, and cotton buds (Commission, E, 2019). Similarly, many companies have made commitments to reduce their plastic waste, such as using more recycled materials and designing products for reusability. Individuals can also make a difference in reducing plastic waste. Simple actions, such as using a reusable water bottle, bringing a

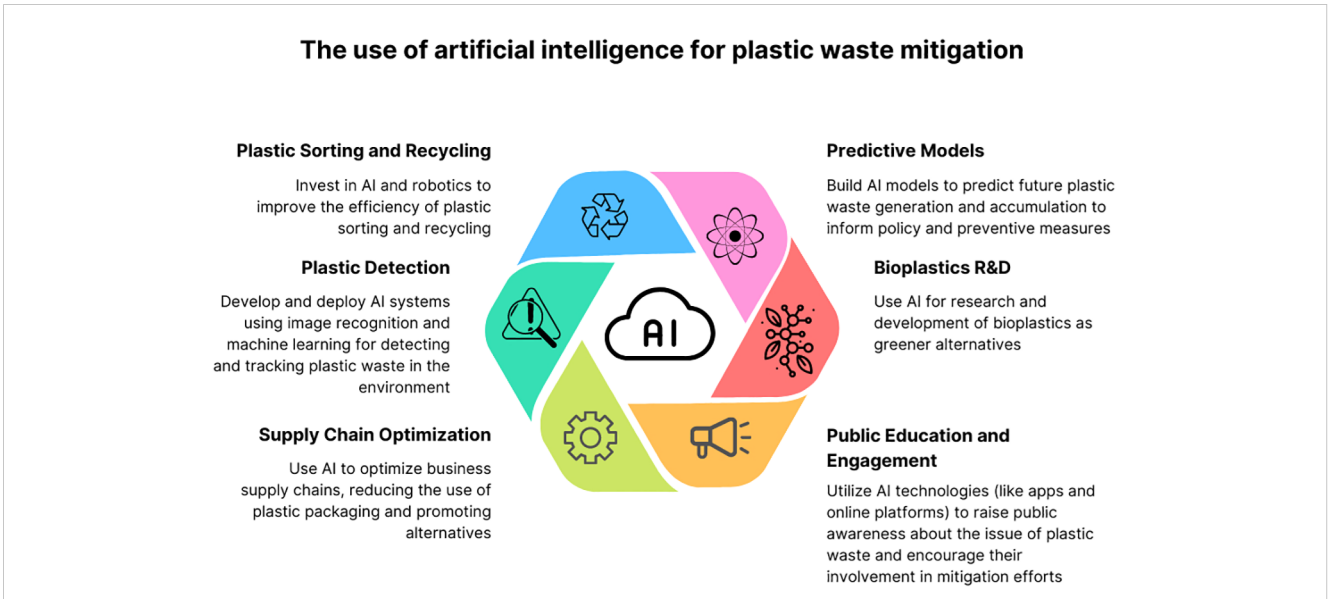


FIGURE 10
Potential applications of artificial intelligence (AI) for plastic waste mitigation. The diagram covers key areas such as plastic sorting and recycling, plastic detection, supply chain optimization, predictive modeling, bioplastics research & development, and public education & engagement. It showcases how AI and related technologies can enhance efficiency, track waste, and promote sustainable alternatives.

reusable bag to the grocery store, and avoiding single-use plastics, can have a significant impact on reducing plastic waste. Education and awareness campaigns can also help to encourage individuals to adopt more sustainable practices.

Bans on single-use plastics have been implemented in many countries and cities worldwide, and they have shown to be effective in reducing plastic waste. A study conducted in San Francisco found that the ban on plastic bags reduced the usage of plastic bags by 72% (Hoornweg et al., 2013). Product redesign is another strategy that can reduce plastic waste. For example, Coca-Cola has introduced a plant-based bottle made from sugarcane that can reduce the company's reliance on fossil fuel-based plastics (Coca-Cola, 2019). Recycling programs are also effective in reducing plastic waste. In Australia, the National Recycling Scheme has led to the collection and recycling of 2.7 million tonnes of plastic waste (National Plastics Plan, 2021).

In addition to these strategies, public awareness and education are crucial to reduce plastic pollution. Technological advancements in plastic recycling and biodegradable plastics can also help reduce plastic pollution. For instance, researchers have developed a biodegradable plastic made from cellulose and chitin that can be used in food packaging (Yu et al., 2020). These strategies and technologies have the potential to significantly reduce plastic waste and mitigate the negative impacts of plastic pollution on the environment and human health.

In conclusion, urgent action is needed to reduce plastic waste and prevent further damage to marine ecosystems and human health. This requires a global effort, with governments, industry, and individuals all playing a role in reducing plastic waste and promoting sustainable alternatives.

5 Conclusions

Our results highlight the urgent need for global action to reduce plastic waste and prevent further harm to our oceans. The high levels of plastic production and emissions, particularly from Asia, emphasize the importance of international cooperation to address this issue. Efforts to reduce plastic waste should focus on improving waste management and recycling systems, as well as encouraging the development of alternative materials to replace single-use plastics. The role of rivers as major contributors to plastic pollution underscores the need for riverine plastic management initiatives. Finally, the presence of microplastics in the surface ocean and plastic particles across the world surface ocean highlights the need for further research to understand the long-term impacts of plastic pollution on marine ecosystems and human health. We also provided several potential applications of A.I. technology in effective mitigation of plastic pollution in a global level.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://ourworldindata.org/plastic-pollution.

Author contributions

R-SY: Validation, Writing – review & editing. Y-FY: Conceptualization, Methodology, Writing – original draft. SS: Formal Analysis, Visualization, Writing – original draft.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was supported by the Scientific Research Foundation of Jimei University, China under Grant No. C622005/4411.

Acknowledgments

This investigation was supported in part by National Taiwan Normal University, School of Science (BISBE Lab) to SS.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2023.1305091/full#supplementary-material

References

Abubakar, I. R., Maniruzzaman, K. M., Dano, U. L., AlShihri, F. S., AlShammari, M. S., Ahmed, S. M. S., et al. (2022). Environmental sustainability impacts of solid waste management practices in the global south. *Int. J. Environ. Res. Public Health* 19 (19), 12717. doi: 10.3390/ijerph191912717

Andrady, A. L. (2011). Microplastics in the marine environment. *Mar. pollut. Bull.* 62 (8), 1596–1605. doi: 10.1016/j.marpolbul.2011.05.030

Beaumont, N. J., Aanesen, M., Austen, M. C., Börger, T., Clark, J. R., Cole, M., et al. (2019). Global ecological, social and economic impacts of marine plastic. *Mar. pollut. Bull.* 142, 189–195. doi: 10.1016/j.marpolbul.2019.03.022

Bergmann, M., Collard, F., Fabres, J., Gabrielsen, G. W., Provencher, J. F., Rochman, C. M., et al. (2022). Plastic pollution in the arctic. *Nat. Rev. Earth Environ.* 3 (5), 323–337. doi: 10.1038/s43017-022-00279-8

Breitburg, D., Levin, L. A., Oschlies, A., Grégoire, M., Chavez, F. P., Conley, D. J., et al. (2018). Declining oxygen in the global ocean and coastal waters. *Science* 359 (6371), eaam7240. doi: 10.1126/science.aam7240

Callos, N. (2019) *Stop plastic pollution: environment, beach, and ocean cleanup volunteering*. Available at: https://www.volunteerforever.com/article_post/stop-plastic-pollution-environment-beach-and-ocean-cleanup-volunteering/ (Accessed 27 June 2023).

CalRecycle (2013) *Plastic bag bans: analysis of economic and environmental impacts*. (Accessed 27 June 2023).

Coca-Cola (2019) *Introducing a world-first: A coke bottle made with plastic from the sea*. Available at: https://www.coca-colacompany.com/media-center/a-coke-bottle-made-with-plastic-from-the-sea (Accessed 27 June 2023).

Commission, E (2019) *European commission*. Available at: https://commission.europa.eu/index_en (Accessed 27 June 2023).

Cózar, A., Echevarría, F., González-Gordillo, J. I., Irigoien, X., Úbeda, B., Hernández-León, S., et al. (2014). Plastic debris in the open ocean. *Proc. Natl. Acad. Sci. U. S. A.* 111 (28), 10239–10244. doi: 10.1073/pnas.1314705111

Eriksen, M., Lebreton, L. C. M., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., et al. (2014). Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. *PloS One* 9 (12), e111913. doi: 10.1371/journal.pone.0111913

Europe, P. (2020) *Plastics – the facts 2020*. Available at: https://plasticseurope.org/wpcontent/uploads/2021/09/Plastics_the_facts-WEB-2020_versionJun21_final.pdf (Accessed 27 June 2023).

Ford, H. V., Jones, N. H., Davies, A. J., Godley, B. J., Jambeck, J. R., Napper, I. E., et al. (2022). The fundamental links between climate change and marine plastic pollution. *Sci. Total Environ.* 806 (Pt1), 150392. doi: 10.1016/j.scitotenv.2021.150392

Gall, S. C., and Thompson, R. C. (2015). The impact of debris on marine life. *Mar. pollut. Bull.* 92 (1), 170–179. doi: 10.1016/j.marpolbul.2014.12.041

Galloway, T. S., Cole, M., and Lewis, C. (2017). Interactions of microplastic debris throughout the marine ecosystem. *Nat. Ecol. Evol.* 1 (5), 116. doi: 10.1038/s41559-017-0116

Geyer, R., Jambeck, J. R., and Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Sci. Adv.* 3 (7), e1700782. doi: 10.1126/sciadv.1700782

Hoornweg, D., Bhada-Tata, P., and Kennedy, C. (2013). Environment: Waste production must peak this century. *Nature* 502 (7473), 615–617. doi: 10.1038/502615a

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., et al. (2015). Marine pollution. Plastic waste inputs from land into the ocean. *Science* 347 (6223), 768–771. doi: 10.1126/science.1260352

Jones, J. S., Porter, A., Muñoz-Pérez, J. P., Alarcón-Ruales, D., Galloway, T. S., Godley, B. J., et al. (2021). Plastic contamination of a Galapagos Island (Ecuador) and the relative risks to native marine species. *Sci. Total Environ.* 789, 147704. doi: 10.1016/j.scitotenv.2021.147704

Knoblauch, D., and Mederake, L. (2021). Government policies combatting plastic pollution. *Curr. Opin. Toxicol.* 28, 87–96. doi: 10.1016/j.cotox.2021.10.003

Lamb, J. B., van de Water, J. A., Bourne, D. G., Altier, C., Hein, M. Y., Fiorenza, E. A., et al. (2017). Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. *Science* 355 (6326), 731–733. doi: 10.1126/science.aal1956

Lebreton, L., Egger, M., and Slat, B. (2019). A global mass budget for positively buoyant macroplastic debris in the ocean. *Sci. Rep.* 9 (1), 12922. doi: 10.1038/s41598-019-49413-5

Liu, J., Hu, Z., Du, F., Tang, W., Zheng, S., Lu, S., et al. (2023). Environment education: A first step in solving plastic pollution. *Front. Environ. Sci.* 11. doi: 10.3389/fenvs.2023.1130463

Mallick, S. K., Pramanik, M., Maity, B., Das, P., and Sahana, M. (2021). Plastic waste footprint in the context of COVID-19: Reduction challenges and policy recommendations towards sustainable development goals. *Sci. Total Environ.* 796, 148951. doi: 10.1016/j.scitotenv.2021.148951

Meijer, L. J. J., van Emmerik, T., van der Ent, R., Schmidt, C., and Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. *Sci. Adv.* 7 (18), eaaz5803. doi: 10.1126/sciadv.aaz5803

Moshood, T. D., Nawanir, G., Mahmud, F., Mohamad, F., Ahmad, M. H., and AbdulGhani, A. (2022). Biodegradable plastic applications towards sustainability: A recent innovations in the green product. *Clean. Eng. Technol.* 6, 100404. doi: 10.1016/j.clet.2022.100404

National Plastics Plan (2021). Available at: https://www.agriculture.gov.au/sites/default/files/documents/national-plastics-plan-2021.pdf (Accessed 27 June 2023).

NOAA, National Centers for Environmental Information (NCEI) and Microplastics Database (2022) *Marine microplastic concentration map portal*. Available at: https://experience.arcgis.com/experience/b296879cc1984fda833a8acc93e31476 (Accessed 27 June 2023). Marine Microplastic Concentration Map Portal.

Ritchie, H., and Roser, M. (2018) *Plastic Pollution* (Our World in Data). Available at: https://ourworldindata.org/plastic-pollution (Accessed 27 June 2023).

Rochman, C. M., Browne, M. A., Halpern, B. S., Hentschel, B. T., Hoh, E., Karapanagioti, H. K., et al. (2013). Policy: Classify plastic waste as hazardous. *Nature* 494(7436), 169–171. doi: 10.1038/494169a

Schmidt, C., Krauth, T., and Wagner, S. (2017). Export of plastic debris by rivers into the sea. *Environ. Sci. Technol.* 51 (21), 12246–12253. doi: 10.1021/acs.est.7b02368

Shen, M., Song, B., Zeng, G., Zhang, Y., Huang, W., Wen, X., et al. (2020). Are biodegradable plastics a promising solution to solve the global plastic pollution? *Environ. pollut.* 263 (Pt A), 114469. doi: 10.1016/j.envpol.2020.114469

Skoric, M. M., Zhang, N., Kasadha, J., Tse, C. H., and Liu, J. (2022). Reducing the use of disposable plastics through public engagement campaigns: an experimental study of the effectiveness of message appeals, modalities, and sources. *Int. J. Environ. Res. Public Health* 19 (14), 8273. doi: 10.3390/ijerph19148273

Smith, M., Love, D. C., Rochman, C. M., and Neff, R. A. (2018). Microplastics in seafood and the implications for human health. *Curr. Environ. Health Rep.* 5 (3), 375–386. doi: 10.1007/s40572-018-0206-z

Suaria, G., Avio, C. G., Mineo, A., Lattin, G. L., Magaldi, M. G., Belmonte, G., et al. (2016). The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters. *Sci. Rep.* 6, 37551. doi: 10.1038/srep37551

Teuten, E. L., Saquing, J. M., Knappe, D. R., Barlaz, M. A., Jonsson, S., Björn, A., et al. (2009). Transport and release of chemicals from plastics to the environment and to wildlife. *Philos. Trans. R. Soc Lond. B. Biol. Sci.* 364 (1526), 2027–2045. doi: 10.1098/rstb.2008.0284

United Nations General Assembly. (2015). Transforming our world: the 2030 agenda for sustainable development. Available at: https://sdgs.un.org/2030agenda (Accessed 27 June 2023)

Van Cauwenberghe, L., and Janssen, C. R. (2014). Microplastics in bivalves cultured for human consumption. *Environ. pollut.* 193, 65–70. doi: 10.1016/j.envpol.2014.06.010

Wilcox, C., Van Sebille, E., and Hardesty, B. D. (2015). Threat of plastic pollution to seabirds is global, pervasive, and increasing. *Proc. Natl. Acad. Sci. U.S.A.* 112 (38), 11899–11904. doi: 10.1073/pnas.1502108112

Yu, Z., Ji, Y., Bourg, V., Bilgen, M., and Meredith, J. C. (2020). Chitin- and cellulose-based sustainable barrier materials: a review. *Emerg. Mater.* 3, 919–936. doi: 10.1007/s42247-020-00147-5

Yuan, L., Buzoglu Kurnaz, L., and Tang, C. (2021). Alternative plastics. *Nat. Sustain.* 4 (10), 837–838. doi: 10.1038/s41893-021-00750-2

Yuan, S., Li, Y., Bao, F., Xu, H., Yang, Y., Yan, Q., et al. (2023). Marine environmental monitoring with unmanned vehicle platforms: Present applications and future prospects. *Sci. Total Environ.* 858 (Pt 1), 159741. doi: 10.1016/j.scitotenv.2022.159741

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 29 December 2023
DOI 10.3389/fmars.2023.1323748

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Maruf M.,
Dalian Maritime University, China
M. Jahanzeb Butt,
Shandong University, China

*CORRESPONDENCE
Qi Xu
xuqi2019@jnu.edu.cn
Peng Guo
66973351@qq.com

RECEIVED 18 October 2023
ACCEPTED 12 December 2023
PUBLISHED 29 December 2023

CITATION
Xu Q, Zhang M and Guo P (2023) Reflections on Japan's participation in negotiations of the global plastic pollution instrument under international environmental law.
Front. Mar. Sci. 10:1323748.
doi: 10.3389/fmars.2023.1323748

COPYRIGHT
© 2023 Xu, Zhang and Guo. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Reflections on Japan's participation in negotiations of the global plastic pollution instrument under international environmental law

Qi Xu*, Mengxue Zhang and Peng Guo*

School of Law, Jinan University, Guangzhou, China

International negotiations towards a legally binding instrument on the global plastic pollution have obtained wide-ranging attention from international community. It is revealed that Japan has taken a conservative but proactive stance during negotiations. This study overviews Japan's current legal framework on the management of plastic pollution including land and the sea. On this basis, the paper then analyzes Japan's stance in the negotiations to examine the issues that are of most concern to Japan in international cooperation towards ending plastic pollution. It will further analyze Japan's views on the legally binding instrument's framework, operational mechanism and key components from the perspective of international environmental law. And it will also summarize Japan's specific claims and objectives in the negotiations, and provide an evaluation of Japan's stance.

KEYWORDS

international environmental law, plastic pollution, sustainable development, full lifecycle approach, environmental diplomacy

1 Introduction

The prevalence of plastic products has led to their extensive use, resulting in severe environmental pollution. From 2000 to 2019, the global amount of plastic waste increased from 156 million tons to 353 million tons globally, with just 9% recycled (OECD, 2022). More than 8 million tons of pandemic-associated plastic waste were generated during the COVID-19 outbreak, of which only 10% were recycled (Peng et al., 2021). In the same year, greenhouse gas emissions attributable to plastics amounted to 1.8 billion tons (UNEP, 2018) and are forecast to reach 6.5 billion tons by 2050, accounting for 15% of the worldwide carbon budget (Charlton-Howard et al., 2023). The global increase in plastic waste poses a significant environmental challenge that is exacerbated by its low recycling rate (Wright et al., 2013). This results in a

substantial quantity of plastics entering ecosystem and degrading into microplastics, causing persistent contamination of the environment. According to d'Ambrières' (2019) research, marine plastic pollution accounts for the greatest amount of damage, with approximately 4 to 12 million metric tons of plastics ending up in the oceans annually. There is evidence that marine plastic pollution has negatively compromised the safety of over 500 marine species (Gall and Thompson, 2015). It is also worth noting that plastics are extremely resistant to degradation and can persist in the environment for hundreds or even thousands of years (Zhang et al., 2021). With their transboundary nature (Oral, 2021) and long-lasting environmental implications, (Eriksen et al., 2014) plastics are likely to continue to permeate ecosystem for an extended period of time.

In the current international governance framework, a number of international agreements, such as the United Nations Convention on the Law of the Sea (UNCLOS), the Stockholm Convention, and the Basel Convention have addressed marine plastic pollution. Additionally, the United Nations Environment Assembly (UNEA) has held numerous meetings on this topic between 2014 and 2022. Whilst the G20, G7, and the European Union also enacted regulations and policies to govern plastic waste at the regional level (Nyka, 2019). Nonetheless, the previous governance system separated plastic pollution from the sea and land with frequent references to the concepts of marine litter, marine plastic and marine plastic pollution, while the plastic pollution from land-based sources has not received sufficient management and there is a significant lack of international hard law confronting this issue (Vince and Hardesty, 2018).

Several shortcomings have been identified in the existing international legal framework, including the prevalence of soft-law instruments and the fragmentation of the international governance framework (Ferraro and Failler, 2020). Moreover, attempts to achieve new rules by applying any procedural option for international law-making in isolation may be impractical (Chen and Xu, 2022a). Thus, the resumed 5th United Nations Environment Assembly (UNEA-5.2) concluded with a resolution geared towards ending plastic pollution and completing a legally binding international instrument (referred to as "the instrument") in 2022, making a turning point in the battle against plastic pollution (UNEP, 2022). In September 2023, the essential zero draft was launched with an alternative scenario for an overall target year-2040, which fits in with the "Osaka Blue Ocean Vision" that Japan has been advocating. Subsequently, states engaged in a more in-depth discussion of the zero draft with a view to providing the textual basis for the instrument at the third committee.

Limited to its location and scarce resources, Japan is quite sensitive to environmental problems and is one of the representative countries that has vigorously implemented the concept of sustainable development and has participated in environmental governance as an advocate. Specifically on the issue of plastic pollution, Japan has repeatedly introduced laws and plans related to plastic pollution, improved its administrative system and promoted the concept of recycling. For example, in view of the fact that marine plastic waste has been attracting international attention, Japan has set forth its policy on addressing this issue and agreed to the "Osaka Blue Ocean Vision". However, considering the influence of plastics on daily life and economy, it's not easy to reduce the use of plastics. Plastic Recycling Association (2021) finds that Japan's plastic pollution is still severe and its annual volume of plastic waste has exceeded eight million tons since 2000. And Japan's coastal waters contain up to 3.74 microplastics per cubic meter, approximately 27 times higher than the global average, (Asahi, 2019) lasting impact on the surrounding environment. Due to the transboundary nature of marine plastic pollution, it is also unrealistic for Japan to solve plastic pollution alone. Therefore, Japan has focused more on international cooperation, expecting to solve plastic pollution through the common actions of all countries.

Against the backdrop of the negotiations, this paper overviews Japan's domestic policies and actions in order to have a preliminary understanding of Japan's environmental governance. Following that, this paper investigates and evaluates Japan's claims for participation in the negotiations in light of international environmental law. It aims to identify Japan's top priorities for the negotiations. As a final point, a comparison is provided between Japan's claims and those of developed countries such as Europe and the United States, as well as China, a developing country and an importer of plastic waste from Japan until 2018, along with an assessment of Japan's potential role in future negotiations.

2 Overview of Japan's stance on plastic pollution before the negotiations

Given that the negotiations marked a turning point in the regulation of plastic pollution, it is necessary to analyze Japan's stance before and during the negotiations in order to identify its main concerns regarding the global plastic pollution instrument. Japan's stance on the governance of plastic pollution has been guided and shaped by a number of factors from the 1990s to now. Ultimately, it serves the national development strategy of building a resource-recycling society at the national level and increases its political influence through environmental diplomacy at the international level.

2.1 National guiding concepts and principles for plastic pollution governance

Constrained by its geographical location and the reality of resource scarcity, Japan has placed a high value on reducing and recycling resources and has gradually developed the concept of recycling and sustainable development with the 3Rs principle (Ministry of Economy, Trade and Industry, 2023), namely reduce, reuse and recycle, as its foundation.

2.1.1 National guiding concept for plastic pollution governance

A first point to note is the connection between environmental protection and economic development, and Japan's plastic pollution management framework is closely associated with and

mutually reinforces its economic development. Generally speaking, there is a pattern regarding environmental and technological innovations in Japan that is motivated by social concerns regarding environmental problems. Afterwards, the government implements regulations to meet these concerns (Yabar et al., 2013). Over the past century, Japan's economic boom has been accompanied by various environmental problems, especially the exposure of the Minamata disease (Ministry of Environment of Japan, 2005), which has brought Japan under international scrutiny. Consequently, Japan's economic prosperity has contributed to a greater awareness of environmental issues, and its waste management has evolved over the years from an end-of-pipe approach to a more proactive one that emphasizes quantity reduction and recycling (Hara and Yabar, 2012). In response to the persistent downturn in social conditions triggered by the economic crash in 1990s, Japan has shifted its focus towards sustainable development (Wang, 2020).

As part of Japan's commitment to sustainable development, the 3Rs principle is widely applied. It is generally recognized that 3R and waste management policies form the basis of developing a material cycles society (Sakai et al., 2011). And most of Japan's policies for plastic waste management are developed to address circular economy (Ono et al., 2023b). Through legislative activities, Japan has established a fundamental cognition of sustainable development as a pillar of the three significant areas of the economy, society and environment, and consequently formed two specific principles of plastic pollution governance: first, to clarify the priorities of plastic pollution management, emphasizing reduction and reuse instead of simple treatment. Specifically, Japanese industries are required to fully oversee the entire waste management process, thereby improving the efficiency of waste treatment. Second, applying extended producer responsibility(EPR) to the basic concepts for the development of 3Rs while establishing polluter pays principle (Cheng, 2019). The extended producer responsibility defined by OECD (2016) as an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle. By establishing ways in which consumers, municipalities and businesses are obliged to reduce plastic waste, (Plastic Waste Management Institute, 2019) Japan has covered the entire society in combating plastic pollution. As one of the central pillars for Japan's efforts leading towards a sustainable society, the Fundamental Law for Establishing a Sound Material-Cycle Society further emphasizes extended producer responsibility, which requires that municipalities, businesses and industrial associations to share responsibilities with other stakeholders (Kuan et al., 2022). In Japan, the EPR has two characteristics. It attempts to shift financial responsibility fully or partially from municipalities to producers and has incentivized producers to design products with environmental considerations in mind (Ono et al., 2023a).

There is also the concept of the polluter pays principle in Japan's waste management framework, which aims to manage plastic throughout its lifecycle. The Japanese Civil Code contains common tort provisions that entitle individuals to file actions to compel polluters to bear the responsibility of eliminating plastic waste (Bartsch, 1998). Meanwhile, Japan's environmental laws sets standards that permit third party to bring claims where damage has resulted from a breach of the polluter pays principle. By passing laws and enforcing strict rules on plastic waste, Japan has made consumers responsible for part of the costs associated with waste disposal. In parallel, Japan encourages and supports producers to independently develop technologies for the recycling of plastic waste in order to increase its recycling rate. With the help of product safelists and partnerships with companies, Japan has also strengthened the supervision of business activities (Okubo et al., 2022).

2.1.2 Specific national government actions

It is imperative that the legal system for controlling plastic pollution be improved so that political policy discourages and ultimately eliminates environmentally harmful disposal, while encouraging the use of recycled plastics and fostering innovations in plastics (Van Berkel, 2018). Legislations has been frequently used to promote pollution management in Japan, which has established a legal system based on two fundamental laws and a series of regulations. Japan adopted the Basic Law for the Environment in 1993, which laid the legal groundwork for environmental protection. Following the enactment of the Fundamental Law for Establishing a Sound Material-Cycle Society issued in 2000, Japan implemented it to consolidate the framework of plastic pollution governance. On this basis, Japan has successively issued comprehensive laws such as the Waste Management and Public Cleaning Law, as well as a series of special laws that regulate kinds of plastic products in a comprehensive manner. In 2019, Japan had specially formulated its National Action Plan for Marine Plastic Litter to curb indiscriminate disposal of plastic waste and its flow into the oceans and enhance innovation in substitute materials (Akenji et al., 2020). Meanwhile, Japan has accepted principles of international environmental law into its domestic law. There are provisions on the precautionary principle in the Basic Act on Ocean Policy (2007) and the purpose of principle 15 of the Rio Declaration is reflected in Japan's domestic legislation (Yotova, 2017).

An improved administrative system is necessary to ensure plastic pollution regulations are implemented effectively. In response to plastic pollution, Japan has restructured its administrative system and developed an appropriate institutional design. Two levels of government operate within the system, the central government and the local governments. Together, they ensure the implementation of environmental regulations across the country. As part of its pollution management strategy, the Japanese government collaborates actively with the private sectors through public-private partnerships (Ono et al., 2023b). Furthermore, the government ensures that strict source regulations are adhered to overseeing the business system (Ono et al., 2023a) and is deeply involved in the full lifecycle of plastic products.

What's more, recycling is vigorously promoted and social practices are encouraged in Japan. It is through the introduction of the Plastic Restriction Order that Japan has sought to reduce the use of plastic products. In the meantime, Japan is taking active steps to raise public awareness about recycling and environmental protection through publicity campaigns and practical initiatives.

Japan also strongly encourages private think tanks and non-governmental organizations to participate in the management of plastic pollution. Given that the recycling of plastics relies strongly on innovations in the area of technology, business and policy practices, (Fadeeva and Van Berkel, 2021) Japan has invested heavily in promoting technological advances, research and development of alternative products, as well as expanding the demand for renewable materials and bioplastics, resulting in the recycling of up to 80% of plastics in Japan (Keiichi, 2022).

2.2 Japan's stance and actions on international plastic pollution governance

Japan is not confined to its domestic plastic wastes but actively participates in international cooperation. The Japanese government has vigorously promoted its national policies in line with its international development strategy. Especially by spearheading the "Osaka Blue Ocean Vision" in the G20 (2019), Japan has made a unique move from being a "participant" to a "pioneer" in global plastic pollution governance.

2.2.1 Japan's stance on international plastic pollution governance

A prominent manifestation of Japan's approach to plastic pollution governance is its use of environmental policy as a diplomatic instrument, which is essentially a profit-making strategy (Sun, 2023). The fundamental intention is to accomplish Japan's political goal and to enhance its status in international community. As Wang (2020) stated, the Japanese government declared in the Basic Act on Ocean Policy that the Japanese international partnership was "aiming at bearing the leading role for the formation and development of the international order", setting the tone for its involvement in global ocean governance in 2017. Then, Japan set the ambitious goal of demonstrating its leadership through international contributions to the Fifth Basic Plan for the Environment within the following year (Ministry of the Environment, 2018). Japan's Third Phase of the Marine Basic Plan laid out its strategic foundation for ocean statehood in May of 2018 (Cabinet Office, 2018). In order to achieve its goals, Japan has played as a "participant" in international cooperation and has earned the appreciation of the international community. Then, Japan kept reiterating the gravity of plastic pollution in its 2019 New Year's address, at the WEF Forum and elsewhere, stating, "Japan will work with the world to address plastic pollution" (Tao, 2019). In May 2019, Japan launched the Plastic Resource Circulation Strategy, followed by the G20 Osaka Summit in June, where Japan made the marine plastic pollution a vital issue and contributed to the establishment of the "Osaka Blue Ocean Vision". This series of actions has made Japan a "pioneer" in plastic pollution management. It can be said that every step of Japan's environmental diplomacy has accounted for the "mainstream discourse" and "political correctness" in the international political arena (Cui, 2020) and has effectively elevated Japan's status in international environmental governance.

The fundamental spirit of Japan's stance is to maximize its national interests. As an isolated nation, Japan's survival and development are hampered by the quality of its resource acquisition and utilization. As early as the 1980s, Japan had already signed the Basel Convention banning the transboundary movement of waste. However, to ensure the cleanliness of its domestic environment and alleviate the burden of dealing with plastic waste, Japan still exported plastic waste to neighboring countries such as China and Vietnam. At the G7 Summit in 2018, considering the public's daily use of plastic products and the development of related industries, Japan ultimately refused to sign the "Ocean Plastics Charter", which was aimed at reducing the use of plastics as one main target. And the "Osaka Blue Ocean Vision" advocated by Japan did not impose plastic usage reduction targets, but committed to collecting plastic waste and promoting waste management. Moreover, as concerns over plastic pollution has grown both internationally and nationally, Japan gradually cut down on plastics through the reduction of packaging plastics and utilization rates. In general, based on the economic benefits and convenience of life that plastics have brought, Japan has attempted to deal with plastics through a promotion approach.

Japan's participation in international governance is contingent upon its promotion of the 3Rs principle. By vigorously promoting the 3Rs principle and circular economy, Japan has extensively cooperated with countries at the international and regional levels. At the international level, Japan and other nations reached a consensus on the "Osaka Blue Ocean Vision", which was proposed by Japan as a blueprint for reducing marine plastic pollution. At the end of 2022, the Ministry of the Environment (2022) issued the white paper, stating that Japan would take the 2023 G7 Summit in Hiroshima as an opportunity to publicize its experience and measures of pollution management to the world, with a particular focus on Japan's efforts to promote the international framework for ending plastic pollution based on the "Osaka Blue Ocean Vision". At the regional level, Japan had taken the lead in establishing regional cooperation platforms, such as the Regional 3R Forum in Asia, and has promoted the 3Rs as the basic principle of cooperation. Japan also demonstrated its leadership by launching ocean initiatives, which sought to improve the management of plastic waste and the recycling of marine waste (Atsushi, 2019). With the ratification of the "Bangkok 3R Declaration" in the Regional 3Rs Forum in Asia and the Pacific (2022), the 3Rs principle has gradually become the consensus of the countries concerned. In addition, Japan has made it possible for recipient countries to put the 3Rs principle into practice through its official development assistance.

2.2.2 Japanese actions on international cooperation

At the hard law level, Japan has participated in a number of international conventions and treaties. Japan has met its international obligations by adhering to the International Convention for the Prevention of Pollution from Ships in 1983 and amending its domestic Water Pollution Control Law twice to domesticate the Convention's contents and obligations.

Correspondingly, these obligations from international law can also be a lever for politicians to overcome domestic political resistance and populist challenges (Chen et al., 2023). While the Basel Convention does not explicitly codify the polluter pays principle, it does expressly support the general principles of international environmental law, which do include the polluter pays principle (Fidler, 2001). Again, international recognition of the polluter pays principle certainly encourages Japan to incorporate this principle into its domestic environmental law. Meanwhile, Japan has taken the initiative to partake in revising and implementing international agreements and has asserted its rights actively. In response to the severe marine plastic pollution, Japan and Norway have proposed a revision program for the amendment of the Basel Convention in 2019, calling for the inclusion of contaminated waste plastics on the list of prohibited import and export controls. In addition, Japan has paid close attention to the role of the United Nations in expanding Japan's presence and appeal in the international community through its programs and ideas.

At the level of soft law, Japan has taken an active lead in regional cooperation. On the one hand, Japan has engaged in extensive official cooperation with various countries or regions. At the ASEAN 10 + 3 Leaders' Meeting in 2018, Japan put forward an initiative, which provided ASEAN nations with a certain amount of government development assistance to improve their capacity of plastic waste treatment, and promoted the smooth progress of regional cooperation. In June 2019, Japan hosted the G20 Osaka Summit and pushed for a consensus on the "Osaka Blue Ocean Vision" and ratified the "G20 Implementation Framework for Actions on Marine Plastic Litter", a practical guide for plastic management. At the 21st ASEAN Plus Summit Meeting, Japan made the management of marine plastics debris one of the topics. On the other hand, Japan has engaged in cooperation and dialogue with many civil society organizations and research institutes and has supported Southeast Asian countries such as Vietnam and Laos in the form of "public-private initiatives" (Zhang and Jin, 2020). While promoting its own experience, Japan also assisted developing countries in improving their capacity to deal with plastic pollution. Through above actions, Japan has become an indispensable force in international cooperation in dealing with plastic pollution and has effectively promoted the pollution governance process.

3 Analysis of Japan's stance in the negotiations from the perspective of international environmental law

In the context of globalization, Japan, as a member of the international community, is integrated into the international community and regulated by the rules and principles of international law and customary international law. This chapter will analyze Japan's negotiating claims and considerations and discover the extent to which international environmental law and customary international law have influenced Japan's stance. Or in other words, this chapter will discuss whether Japan's negotiating stance comply with the principles of international environmental law and customary international law.

3.1 Sustainable development

Focusing on the relationship between the carrying capacity of the natural systems and economic and social development, (de Sadeleer, 2023) the principle of sustainable development was forged to reconcile development needs with environmental protection (Bosselmann, 2012). Sustainable development can be defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" by the World Commission on Environment and Development (1987), including substantive elements, such as the integration of environmental protection and economic development and the polluter pays principle, and procedural elements, such as public participation and environmental impact assessment. In general, it is accepted that the concept of sustainable development is based on three pillars: environmental protection, economic development and social concerns (Fitzmaurice et al., 2022). Japan has championed the concept of sustainable development, which is entirely reflected in its advocacy in the negotiations. As a mechanism for implementing sustainable development, science is necessary to legal decision-making processes (Sipiorski, 2023). In light of the pervasive use of plastics in everyday life and the high disposal rate, Japan suggests to increase the use of recycled materials and reduce the production of primary plastic products by constructing a scientific system. Since the production, manufacturing and disposal of plastics are commonly dispersed, (Tessnow-von Wysocki and Le Billon, 2019) Japan accordingly proposes establishing a full-lifecycle management framework for plastics (Japan, 2023c) and adopting appropriate measures at each stage to achieve quantitative control of plastics. In order to prevent harmful effects on future generations by plastic pollution, Japan (2023c) also notes that it is necessary to consider and implement measures to address them as the responsibility of current generation. In addition, Japan's proposal also includes the following requirements for the instrument's content.

3.1.1 Principle of public participation

Japan attaches great importance to public participation, views non-governmental organizations (NGOs), research institutions and the general public as important forces in the governance of plastic pollution, and assigns each of these groups with distinct responsibilities. As industry actors have played a key role in shaping the types of policies implemented worldwide, (Knoblauch et al., 2018) Japan firmly encourages non-governmental organizations to participate in the negotiations as stakeholders to ensure that the instrument maximizes its international interests. NGOs often reference Principle 10 of the Rio Declaration, asserting that this principle formally empowers them as public participants in environmental protection (Batt and Short, 1992). And the increasing involvement of NGOs in the environmental governance has played an equally pivotal role in encouraging and demanding the adoption of the principles of international environmental law, such as the polluter pays principle, as legal tools to combat plastic pollution in Japan. Japan also places a premium on the influence of science, such as research institutions and independent experts, and proposes the establishment of an expert group to ensure that the instrument's

content is linked to scientific knowledge and technology. Due to science can catalyze cooperation at the international level among states, (Koppelman et al., 2010) Japan, therefore, asserts to promote the implementation mechanism of the instrument by developing international scientific standards for plastics. As for the public, Japan sees it as one of the central forces in the fight against plastic pollution. Besides, Japan advocates education and awareness-raising as one of the instrument's core obligations (Japan, 2022b). In conclusion, Japan believes that the global objective of ending plastic pollution is inextricably related to the participation of a wide range of stakeholders.

3.1.2 Polluter pays principle

The polluter pays principle first appeared in a legal context prepared by the OECD (1972). In 1992, it was included in the Rio Declaration as an "instrument of international jurisprudence that articulates policies and prescriptions directed at the achievement of worldwide sustainable development" (Batt and Short, 1992). This principle is founded on a sensible approach to mitigating environmental degradation, (Bell et al., 2013) and enforced by internalizing environmental costs through the use of economic instruments, which are implemented through economic incentives, combined with market and non-market mechanisms and private sector pollution and environmental cost-spreading investments (Fitzmaurice et al., 2022). It means that when public authorities take measures to prevent potential and actual environmental damage, those responsible for the pollution should bear the expenses incurred (Smets, 1994). Since plastic pollution stems from the production-consumption pattern of societies and the manner in which countries dispose of their waste, (Chen, 2015) the role of manufacturers and consumers in ending plastic pollution must be addressed. As mentioned previously, the polluter pays principle has developed a parallel trend with the producer pays principle in Japan, which requires producers to be responsible for resolving plastic pollution and is increasingly used to maintain fairness and equity in economic and social development. In general, Japan not only requires polluters to bear pollution management costs, but has also gradually increased the categories of post-cleanup costs, remedial costs, etc. Likewise, as Popp (2006) points that regulations can trigger technological innovation, Japan attempts to stimulate producers to design alternative products by increasing prices. Japan puts emphasis on the implementation of the polluter pays principle throughout the full-lifecycle of plastics by making a series of claims during negotiations, such as improving production technology, bolstering collection and recycling capacity, prohibiting illegal dumping and so on (Japan, 2023b). Japan also urges that measures should be taken prior to the damage occurs to ensure that enterprises and individuals shoulder responsibility for preventing, reducing and eliminating pollution as early as possible.

3.2 The principle of common but differentiated responsibilities

In international environmental law, the principle of common but differentiated responsibilities underpins the international obligations of states and encompasses both common responsibilities and differentiated responsibilities. Based on various socio-economic considerations, the applying of this principle results in different kinds of responsibilities. Generally speaking, this principle requires developed countries to shoulder a greater share of the burden than developing countries (Stone, 2004). Specifically, it is beneficial for countries to take action by discussing policy coherence in more general terms at the level of policy objectives, instruments and implementation practices (Nilsson et al., 2012). Most industrialized countries believe that this principle applies only in the context of global environmental problems, while developing countries accept responsibility in the context of the pressures their societies place on the global environment and the technologies and financial resources they possess (Fitzmaurice et al., 2022). In the negotiations, Japan prefers to emphasize the shared responsibilities that all states must undertake and to downplay the differentiated responsibilities. First, with regard to the objectives of the instrument, Japan (2023c) claims that plastic pollution is occurring throughout the global chain, and plastic leakage into the environment is not only from developed countries but also from developing countries, which means that plastic pollution is an issue that all states should address. Accordingly, Japan is in favor of setting global goals and timeframes to guarantee that countries effectively fulfill their common responsibilities, but this ignores the disparities between developed and developing countries' abilities to address pollution and places a disproportionate amount of international responsibility on developing nations which produce less plastic pollution. Second, concerning the implementation mechanism, Japan calls for national action plans to be formulated by countries on their own, underscoring that any measures should reflect national capacities and actual circumstances. Japan's argument seems to endorse differentiated responsibility. However, it is more of a defense of national discretion and blurs the differentiated responsibility between developed and developing countries, allowing developed countries that produce more plastic pollution to escape a greater proportion of responsibility. Moreover, given that the reporting mechanism of the existing international agreements has not yet been effectively implemented, Japan's claim diminishes the instrument's influence and binding force. In short, Japan's contention was more about defending national interests and avoiding the assumption of common but differentiated international responsibilities.

3.3 The precautionary principle

The Rio Declaration (1992) provides a typical definition of precautionary principle: where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used to postpone cost-effective measures to prevent environmental degradation. Then the precautionary principle has been confirmed by international judicial practice (Ma et al., 2023). The application of this principle requires two prerequisites: the scientific uncertainty of the risk posed by the activity and the risk threshold for its application (Gao and Sun, 2007). However, as its core factor is

scientific uncertainty, there is no explicit standard for the application of the precautionary principle in practice. In the Southern Bluefin Tuna case, the Tribunal makes clear that there was scientific uncertainty about the conservation measures for Bluefin tuna and that it was unable to assess whether the available evidence could prove that Japan's fishing practices posed a threat to the Bluefin tuna population (ITLOS, 1999). But the Tribunal also states that nations are under the due diligence to apply the precautionary approach, which requires them to take all appropriate measures to prevent damage. In the MOX Plant case (2001; The MOX Plant Case (Ireland v. United Kingdom), Provisional Measures, NO.10 (ITLOS 2001)), the Court more directly points out that the duty to cooperate is a fundamental principle in the prevention of pollution. The precautionary principle also states to take measures to protect the natural environment (Anton et al., 1993). For Japan, "take all measures necessary" means that it must, within its best capabilities, exhaust all possible measures to "prevent, reduce and control pollution" rather than using such rhetoric as a shield from international legal obligations (Chen and Xu, 2022b). Therefore, Japan has already formulated an environmental impact assessment system that conforms to the concept of the precautionary principle in its Environmental Impact Assessment Law in 1997, which requires that environmental impact assessment procedures should be adopted for businesses that may cause environmental impact (Ma et al., 2023). However, Japan also uses the term "precautionary approach" in practice to avoid overuse of the precautionary principle (Tadashi, 2010) and prefers to advocate that environmental protection should be carried out "to prevent a hindrance to the environmental conservation based on broad scientific knowledge" in its Basic Environment Law (1993). In other words, although Japan has taken some preventive measures, this does not mean that Japan has fully fulfilled its obligation to achieve the precautionary principle (Ma et al., 2023). To prevent plastic pollution, Japan recommends taking necessary steps at the lifecycle of plastics in the negotiations, but Japan sets a lot of limitation before taking these steps through placing high priorities on scientific research and knowledge application. By recommending the adoption of science, such as expert groups and the timely introduction of scientific knowledge and technology, Japan holds the idea that the effectiveness of plastic pollution control can only be confirmed based on science. Generally speaking, Japan (2023c) recognizes the value of the precautionary principle (ICJ, 2015), but it further notes that this term lacks an internationally agreed definition and should not be used as a pre-set justification for restricting plastic products without solid scientific evidence.

3.4 Sovereignty over national environmental resources and the non-harm principle

The principle of national sovereignty over environmental resources materializes the national sovereignty theory (Zou, 2009) and is also one of the core principles of international environmental law. And Japan has been very protective of its sovereign rights. As early as the Whaling in the Antarctic case, Japan (2013) has made clear that the Court cannot substitute its own appreciation for that of the contracting government. In other words, the Court shall show deference to the state's appreciation of the factual and legal conditions in environmental practice. By authorizing a "bottom-up" approach in negotiations, Japan demonstrates its high regard for the sovereignty of states before the negotiations (Planet Commons, 2023). Japan has also repeatedly stated that the instrument's content should be determined by the parties' own national plans in accordance with their national conditions. While global decision-making could potentially direct national incentives, national-level policy actions are the mechanisms for steering action (Vince and Hardesty, 2018). Japan believes that only by distinguishing between mandatory and voluntary measures in the instrument can it have faith that the states will actively implement the instrument's content at the national level.

Based on the concept of harmonization of rights and obligations, the principle of national sovereignty over environmental resources corresponds to the no-harm principle, which can be traced to the Trail Smelter arbitration that the tribunal provided an articulation of the requirement on states to prevent the infliction of transboundary environmental harm on neighboring states (Fitzmaurice et al., 2022). After a long period of practice with international subjects, the no-harm principle has developed over the course of the 20th century from an idea grounded in'good neighborliness' into a general requirement of prevention of environmental harm. Boyle and Redgwell (2021) believe that the no-harm principle has been generally acknowledged as portion of customary international law. The no-harm principle illustrates that states exercise due diligence in controlling and regulating all private activities on their territory to prevent transboundary pollution (Koivurova, 2008) and is generally applicable to areas within and beyond the national jurisdiction (Boyle and Redgwell, 2021). According to the principle 2、18 and 19 of Rio Declaration (1992), the no-harm principle compels states to prevent, reduce and control environmental pollution and damage, as well as the obligations of notification, consultation and environmental impact assessment. During the negotiations, Japan stands for a stringent and transparent monitoring system and a listing system to make certain that states adhere to the non-harm principle.

3.4.1 Monitoring system

From the perspective of sustainable development, it is more important to prevent than cure in environmental protection. Just like the Certain Activities Carried Out by Nicaragua in the Border Area Case (Certain Activities Carried Out by Nicaragua in the Border Area (Costa Rica v. Nicaragua) and Construction of a Road in Costa Rica along the San Juan River (Nicaragua v. Costa Rica)), the ICJ clams that to fulfil its obligation to exercise due diligence in preventing significant transboundary environmental harm, a state must, before embarking on an activity having the potential adversely to affect the environment of another State, ascertain if there is a risk of significant transboundary harm. (Judgment, 1995) As an obligation of conduct, the no-harm principle requires states to act with due diligence (Koivurova, 2008). Accordingly, Japan has put forward several approaches during negotiations for ensuring

that countries will perform their obligations in good faith. The International Law Commission (2001) has stated: what would be considered a reasonable standard of care or due diligence may change with time. Hence, this due diligence requires a state to keep abreast of technological changes and scientific developments. At the international level, while encouraging countries to formulate national action plans independently, Japan also fosters evaluating and comparing the progress states have made in ending plastic pollution. And Japan proposes establishing a transparent and robust Plan-Do-Check-Act (PDCA) mechanism to evaluate countries' concrete actions to guarantee that they comply with due diligence. Therefore, countries need to make their actions visible through objective data and measures in national reports, (Japan, 2023c) which the instrument's Committee should review in a timely and consistent manner. Japan thinks that only through concrete data and measures, such as quantities and rates of waste generation, collection and recycling, as well as policy targets, can it be guaranteed that the global goals and international obligations outlined in the instrument are effectively implemented. At the state level, as private individuals are the primary actors involved in producing and discharging plastics, (Finska, 2021) Japan advocates a waste management system based on appropriate priorities for the classification, collection and recycling of plastics. On this basis, plastic waste should be handled sector-by-sector according to the phases of the lifecycle of plastics and measures should be taken accordingly, thus realizing a comprehensive and orderly process of plastic management in each country.

3.4.2 Inventory system

As establishing an effective compliance mechanism is a critical aspect of the instrument, (Stöfen-O'Brien, 2022) Japan considers national action plans to be a central element in assessing countries' implementation. In particular, Japan tends to utilize national targets, action plans and long-term strategies to motivate parties to meet their commitments, as these documents represent a high-level of political commitment that can penetrate and drive all policy sectors (Chen, 2015). Japan also notes that the content of national plans should cover certain common elements and requests the Committee to provide a standard template for countries. Meanwhile, due diligence does not mandate all states apply a same standard (Koivurova, 2008). As well as the effectiveness of international instrument on plastic pollution is mediated by national implementation, which is intertwined with different levels of extant national policies and organizations of waste management infrastructures (Dauvergne, 2018). Japan is of the opinion that the instrument should provide a list of practicable measures for parties to choose from, including both voluntary and mandatory measures, thereby facilitating the selection of appropriate measures by countries within their national capacities.

3.5 Principles of international cooperation

The principle of international environmental cooperation stipulates that when confronting environmental problems, all states should act cooperatively as opposed to aggressively. The obligation to cooperate has been incorporated into a number of international instrument s, with varying provisions depending on agreements (Wolfrum, 2021). Given practical constraints such as the absence of policy coordination and interstate dialogue in international plastic governance, (Raubenheimer and McIlgorm, 2018) Japan asserts that the duty to cooperation should be strengthened. The key step is to conduct environmental impact assessments (EIAs) in each nation, a procedure to detect environmental risks and integrate environmental concerns into the decision-making process, (Boyle and Redgwell, 2021) which leads to the sharing of information, such as product materials, pollution treatment etc., among countries and increases cooperation with stakeholders. EIAs are closely associated with the no-harm principle and the duty to cooperate with other states, including obligations to notify and consult prior to decisions being taken (Craik, 2008). Specifically speaking, EIAs endeavor to detect signs of future environmental risks of a proposed project (Tanaka, 2021). It is conducive to assisting countries determine the phases of plastic pollution governance and make appropriate adjustments so that plastic pollution can be adequately controlled. Another key step is to establish globalized standards and guidelines and to share information and technology for dealing with plastic pollution, thus contributing to the implementation of the instrument's project at all levels. Japan holds the belief that wide-ranging information exchange and harmonized standards of practice would both improve the level of comprehensive international governance and promote effective and high-quality action.

During the negotiations, Japan supports the implementation of principles of international environmental law in a flexible manner based on its national concerns. Emphasizing that plastic pollution is an issue that all countries should address, Japan advocates the principles of cooperation and sustainable development to address them in the present and prevent harmful effects on future generations. While recognizing that plastic pollution occurs throughout the global value chain, Japan also proposes the implementation of extended producer responsibility, the polluter pays principle, and public participation to ensure that relevant stakeholders share their roles and responsibilities at each stage of the plastic life cycle. However, Japan also applies some principles flexibly to safeguard its economic interests and national development. In order to protect its plastics industry, Japan opposes the direct application of the precautionary principle to control the production of plastic products and seeks to apply the principle of common but differentiated responsibilities by emphasizing common responsibilities at the expense of differentiated responsibilities, thereby reducing its international responsibilities. Through its flexible assertion, Japan selectively enforces environmental principles and customary international law in negotiations.

4 Comparative study of the stances of Japan and other major negotiating parties

During the negotiations, the proposals of states differed due to disparities in the environmental policies and national interests of

each country. This chapter compares Japan's stance with that of the European Union and the United States, as well as China, in terms of the scope of the instrument, objectives, core obligations, and control measures, in order to better grasp the characteristics of Japan's negotiating position. Through the comparisons, this paper evaluates Japan's stance and predicts its future negotiating position on this basis.

4.1 Comparison of negotiating stances with Europe and the United States

About the instrument's scope, countries presently holds divergent opinions regarding which segment should be given priority as the complete lifecycle of plastics involves several segments. (UNEP, 2023) For the EU, it is the key that priority should be given to the upstream parts, and that unnecessary, avoidable, and problematic plastics should be reduced, eliminated or banned (IISD, 2022a). Japan, however, contends that the instrument should focus on end-of-pipe waste management to develop circular economy (Japan, 2022b). As a major oil-exporting nation, the United States tends to take a conservative stance considering the instrument's impact on the petrochemical industry chain may affect it to a greater extent. So the United States (2023) has mainly called for a country-driven instrument with reservations on global prohibitions and import/export controls related to plastic products, with an emphasis on a voluntary basis. In the third session, the United States further calls for a possible need for exemptions for national security and public health (U.S, 2023a, p. 3).

Concerning the objectives of the instrument, the EU has proposed an "open mandate" resolution before the negotiations (IISD, 2022c), which would enable countries to work on a broad range of issues related to plastic pollution. In its proposal of zero draft, The EU (2023a) considers that the instrument should cover all forms of plastic pollution, including but not limited to the marine environment. Since Japan's resolution explicitly addresses "marine plastic pollution", it is primarily focusing on the management of marine plastic debris (Japan, 2022a). At the same time, Japan has repeatedly recommended that the objectives should include a timeline for achieving zero marine plastic debris by 2040 (Matsuzaki and Sato, 2018). The United States desires to avoid setting a time-bound target in the objective and has reservations about global targets on plastic products at first. However, it turned to support Japan's 2040 target in the third session (U.S, 2023b). And it prefers that countries retain the discretion to determine specific policies and measures for promoting sustainable production of plastics. In short, Japan assumes that established time targets could facilitate the implementation of the instrument, whilst the United States opposes overburdening states with excessive restrictions.

In the domain of control measures, which international law framework that the instrument should adopt is one of the focal points of the negotiations. As the European Union accentuates the obligatory nature of the instrument's control measures, Japan and the United States appeal to a compromise on control measures. Specifically speaking, the EU plays a leading role in sustainable development and recycling (Seay and Ternes, 2022). As a consequence, it takes a relatively radical position in negotiations, expressly favoring a "top-down" hard law framework of binding force. Several EU members have stated a "preference for the instrument to be based on mandatory global measures" (Valerie Volcovici, 2022) In contrast to the EU, Japan's environmental policy relies more on a voluntary approach (Arimura et al., 2019) accomplished through negotiations with polluters. This model has also been applied to the negotiations by Japan, which supports a bottom-up soft law framework that permits states to develop their national plans based on national circumstances. Japan (2023d) advocates that consideration should be given on national circumstances and existing domestic measures rather than applying direct and uniform control measures at international level. The United States is the second largest exporter of plastic waste in the world (Law et al., 2020). The U.S. Environmental Protection Agency (2020) has reported that the whole country generated roughly 4.2 million tons of plastic waste in 2018, of which only 10 percent was recycled. Moreover, the U.S. federal government has largely been absent from the plastic management (Hannah, 2020). And the regulation of plastic pollution in the United States can be described as chaotic, incomplete and uncoordinated (Nagtzaam and Kourabas, 2022). Taking into account these domestic factors, the U.S. similarly supports the soft law framework in negotiations, which parties could implement their obligations through nationally determined policies and measures.

On core obligations, most states support the notion of considering national action plans as one of the instrument's core obligations. However, there are nuances regarding components among nations. According to IISD's news(2022c), the EU demands a mandatory monitoring and reporting framework, including at the stages of production, trade and waste leakage of plastic products, and emphasizes the importance of a joint monitoring framework to strengthen the binding nature of the instruments. Believing in a binding decision can impose a binding obligation upon disputing parties (Qi, 2023), the EU (2023b) stresses the need for a common framework of indicators and methods, not only at the national, but also at the regional and global level. While Japan suggests a standard template for countries and a set of mandatory and voluntary measures, which would weaken the mandatory force of the instrument accordingly. As Japan (2023e) suggests in its proposal, the choice of appropriate policies such as charging for plastics, taxation, and EPR systems should all be left to the countries, as it would be more effective to be tailored to the actual situation in each country. And parties could at any time adjust national action plans with a view to enhancing its level of ambition (Japan, 2023f). The United States takes a different view that states should enjoy greater discretion in determining the measures and policies of national action plans. In other words, the United States would like the instrument's content and structure to be more voluntary than mandatory.

For the instrument's potential elements, national claims have also highlighted different points. The principle of extended producer responsibility is a common legislative practice in Europe (Sachs, 2006) and promoted by the EU during negotiations. The EU

(2023b) recommends the establishment of a technical review committee in its submission of zero draft, which could be responsible of the assessment of the sustainability of alternatives and substitutes before authorizing the placement of any new product on the market. With the EU and Japan both prefer not including a separate article on principles, Japan notes that the precautionary principle is not appropriate for plastics regulations and the scope of EPR is a national consideration, that are the most appropriate to a specific region or country, taking into consideration national capabilities (Japan, 2023a). As for Japan, it supports common but differentiated responsibilities in some aspects of the instrument, but has weakened the differentiated responsibilities between developed and developing countries. In contrast, the United States argues for the same obligations for all parties and strongly opposes the application of common but differentiated responsibilities to technical assistance. Moreover, The United States objects developing globally agreed lists and universal standards advocated by Japan, and instead proposes the establishment of a voluntary certification scheme for plastic products at the global level. What's more, the United States (2023) posts a suggestion in its submission that the instrument should include a withdrawal provision that once a Party has decided to withdraw, it should be permitted to do so.

In summary, the EU is the most radical in its advocacy and urges to strengthen the binding effect of the instrument on states; whereas the United States' stance is more lenient and it opposes the inclusion of too many mandatory measures in the instrument. Japan takes a position in the middle and suggests that the instrument can play the role in urging and supervising the fulfillment of states' obligations, while also hoping that states can enjoy a certain degree of discretionary power.

4.2 Comparison with China's negotiating stance

Japan and China have some differences in core obligations, control measures and means of implementation of this global convention (Gao, 2022). While both of them support the concept of the full lifecycle of plastics, China focuses on the leakage of plastic wastes, with explicit references to the development of a timetable for the controlling measures on transboundary pollution, especially from the developed to developing countries (Ecology and Environment, 2021) whereas Japan concentrates on waste management and lacks attention to transboundary movements of wastes between countries as emphasized by China. Second, China (2022b) clarifies that the principle of common but differentiated responsibilities should be fully incorporated into the instrument, contending that the negotiations should take into account the differentiated national circumstances and economic capabilities of developed and developing countries. In particular, developed countries should provide additional, sufficient and predictable financial support and technical assistance to developing countries in international plastic management (China, 2022a). Although Japan also claims assistance measures in technology and financing, it mainly targets countries in greatest need and does not make clearly distinguish between developed and developing countries. What's more, China (2023) declares that principles are fundamental to negotiations that will provide guidance to the negotiations and suggests to prioritize the discussions of principles in the zero draft. Instead, Japan holds the opinion that principles can be included in the relevant articles, which indicates that articles on "principles" are not necessarily required in the zero draft (Japan, 2023d).

Considering the core commitments, China maintains that there is no one-size-fits-all approach (IISD, 2022b) and that the instrument's mechanism should fully account for the capacity and resource constraints of developing countries. Due to the significance of plastics as fundamental materials to industries, constructions, agriculture and other areas, limiting the production of plastic polymers is not a straight solution to plastic pollution and goes beyond the mandate of the instrument (China, 2023). In comparison, Japan puts more emphasis on autonomous decisions based on each country's national capacity. In the same time, Japan (2023c) considers it highly important to have an explicit reference to an overall target year "2040" in the instrument so as to share common commitments to address plastic pollution in a speedy manner.

As can be seen from the above comparisons, Japan opposes the EU's approach of demanding uniform measures at international level and favors greater national autonomy. In this respect, Japan's position may not be conducive to the implementation of the instrument, as it may weaken the instrument's unity and binding force. However, Japan has provided an appropriate explanation that it is difficult to set a uniform global standard for all plastic products due to differences in national circumstances and domestic measures among countries. Similarly, Japan does not agree with China's proposal to offer more flexibility and assistance to developing countries, but rather advocates the common responsibilities, thus reducing its responsibilities as a developed country. In short, Japan's position reflects its intention to eliminate plastic pollution without compromising its national interests. Given its narrow geography and limited resources, Japan's proposals are indeed constrained by the realities of its national development. This provides an example for the subsequent negotiations, which must take into account not only the efficiency of dealing with plastic pollution, but also the actual capacity of each country, thereby ensuring the instrument can be accepted by as many states as possible.

5 Conclusion

The negotiations are still ongoing. This paper provides an overview of the general characteristics of Japan's plastic pollution policies. Based on its domestic environmental planning, Japan has integrated the management of plastic pollution into its "recycling society" structure and organically combined it with other environmental policies to form a relatively complete environmental protection system in Japan and ensure the cleanliness of its domestic environment. Simultaneously, Japan has promoted its environmental philosophy to the international community with an "eco-friendly country" image, using environmental diplomacy to greatly enhance its international influence and political status. It can be said that Japan's domestic and international pollution policies share the common goal of safeguarding Japan's national interests, thus contributing to its clean domestic environment and

international reputation. It's the same in negotiations: while Japan has brought many constructive ideas to the negotiations in support of an expeditious solution to the global plastic pollution problem, Japan also sought to minimize the international responsibilities it would bear so as not to unduly compromise its national interests due to the realities of its geography and resource limitations.

By summarizing Japan's main points in the negotiations and comparing its stance with that of other countries, this paper provides an apt analogy of Japan's negotiating stance. It can be characterized as two sides of the same coin, spanning from a progressive position to promote international coordination on plastic governance to a comparatively conservative position to safeguard its national interests. In the negotiations, Japan has maintained its consistent environmental strategy and endeavored to expand its international influence by extending its domestic concepts to international cooperation. To achieve its objective of steering the direction of the negotiations, Japan has also adjusted its advocacy compatible with the mainstream viewpoint through dynamic adjustments. In other words, without unduly jeopardizing its national interests, Japan would be willing to make some compromises in order to conform to the prevailing viewpoints in the negotiations and advance the negotiating process of the instrument. Hence, Japan's advocacy is more flexible than that of other countries. It is expected that Japan will play an active role in future negotiations, allowing its advocacy to permeate some aspects of the instrument and binding Japan to international plastics governance, thereby bolstering its positive international image. As certain aspects of the instrument diverge from Japan's current practices, it would be prudent for Japan to take greater thoughtfulness towards aligning its domestic approach on plastic pollution with international governance, thus reinforcing its ability to tackle this issue. For the mandatory binding framework of national action plans, Japan needs to implement its duties under the instrument to ensure that the instrument's mechanism system can effectively perform its role in terminating plastic pollution. Regarding the partial common but differentiated principles advocated by Japan during the negotiations, it's necessary for Japan to modify its strategy and embrace its international responsibilities, so that Japan could use the power of international cooperation to deal with its domestic plastic pollution problems. What's more, implementing the principles of international environmental law, such as the precautionary principle, in Japan's domestic legal system would also help Japan to address plastic pollution in a practical manner and improve the efficiency of its governance.

Furthermore, Japan's negotiating stance reflects an aspect of the negotiations that cannot be ignored, namely, the impact of practical factors at the national level on international cooperation. Since the ambitious goal of the instrument to eliminate plastic pollution requires effective implementation by states at the national level, the feasibility of the instrument and the national capacity to implement it should be the focus of further negotiations. The more appropriate way to advance the instrument process is for all parties to view the negotiations from a comprehensive perspective and to strengthen cooperation in the context of shared international interests. In order to address global marine environmental concerns, China is endeavoring to advocate that the international society builds a maritime community with a shared future, in which combating marine plastic pollution is an important part of China's initiative (Xu and Tan, 2023). Therefore, if Japan and China to forge more consensus in the negotiations on a global convention on plastic pollution, strengthening cooperation in building a maritime community with a shared future can play a positive role.

Author contributions

QX: Conceptualization, Methodology, Supervision, Writing – review & editing. MZ: Writing – original draft. PG: Funding acquisition, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. Fundamental Research Funds for the Central Universities Project No. 23JNQN04 National Social Science Foundation Project No. 21&ZD226.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

(1993). *The Basic Environment Law, 91 § Article 4*. Available at: https://www.env.go.jp/en/laws/policy/basic/index.html.

(2007). *Basic Act on Ocean Policy*. Available at: https://www8.cao.go.jp/ocean/english/act/pdf/law_e.pdf.

Akenji, L., Bengtsson, M., Hotta, Y., Kato, M., and Hengesbaugh, M. (2020). Policy responses to plastic pollution in Asia: Summary of a regional gap analysis. *Plast. Waste Recycling* 2020, 531–567. doi: 10.1016/b978-0-12-817880-5.00021-9

Anton, D. K., Kohout, J., and Pain, N. (1993). Nationalizing environmental protection in Australia: The international dimensions. *Envtl.L* 23, 763. Available at: http://www.lclark.edu/lawlaw_reviews/environmental_law/.

Arimura, T. H., Kaneko, S., Managi, S., Shinkuma, T., Yamamoto, M., and Yoshida, Y. (2019). Political economy of voluntary approaches: A lesson from environmental policies in Japan. *Economic Anal. Policy* 64, 41–53. doi: 10.1016/j.eap.2019.07.003

Asahi, S. (2019). *Japan offshore, micro 7 no kibu and kibu river office outflow*. Available at: https://www.asahi.com/articles/ASM2100N3M10ULBJ029.html (Accessed 6/18/2023).

Atsushi, S. (2019). *A vision for protecting the world's oceans* (Japan Times). Available at: https://www.Japantimes.co.jp/opinion/2019/07/16/commentary/Japan-commentary/vision-protecting-worlds-oceans/ (Accessed 6/18/2023).

Bartsch, E. (1998). Liability for environmental damages: Incentives for precaution and risk allocation. (Mohr Siebeck, Tübingen), 14. Available at: https://api.semanticscholar.org/CorpusID:166756225.

Batt, J., and Short, D. C. (1992). The Jurisprudence of the 1992 Rio Declaration on environment and development: A law, science, and policy explication of certain aspects of the united nations conference on environment and development. *J. Nat. Resour. Envtl. L* 8, 229.

Bell, S., McGillivray, D., and Pedersen, O. (2013). *Environmental law* (USA: Oxford University Press).

Bosselmann, K. (2012). "Sustainable development and international environmental law," in *Routledge Handbook of International Environmental Law* (New York: Routledge), 697–710. doi: 10.4324/9781003137825-4

Boyle, A. E., and Redgwell, C. (2021). *Birnie, Boyle, and Redgwell's international Law and the environment* (New York: Oxford University Press). doi: 10.1093/he/9780199594016.001.0001

Cabinet Office of Japan. (2018). *The Third Basic Plan on Ocean Policy*. Available at: https://www8.cao.go.jp/ocean/policies/plan/plan03/pdf/plan03.pdf.

Certain Activities Carried Out by Nicaragua in the Border Area. (Costa Rica v. Nicaragua) and Construction of a Road in Costa Rica along the San Juan River (Nicaragua v. Costa Rica), I.C.J. Reports 2015 (ICJ 1995).

Charlton-Howard, H. S., Bond, A. L., Rivers-Auty, J., and Lavers, J. L. (2023). 'Plasticosis': Characterising macro-and microplastic-associated fibrosis in seabird tissues. *J. Hazardous Materials* 450, 131–190. doi: 10.1016/j.jhazmat.2023.131090

Chen, C.-L. (2015). Regulation and management of marine litter. *Mar. Anthropogenic Litter* (Switzerland: Springer Cham), 395–428. doi: 10.1007/978-3-319-16510-3_15

Chen, X., and Xu, Q. (2022a). Mitigating effects of sea-level rise on maritime features through the international law-making process in the Law of the Sea. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.1072390

Chen, X., and Xu, Q. (2022b). Reflections on international dispute settlement mechanisms for the Fukushima contaminated water discharge. *Ocean Coast. Manage.* 226. doi: 10.1016/j.ocecoaman.2022.106278

Chen, X., Xu, Q., and Li, L. (2023). Illegal, unreported, and unregulated fishing governance in disputed maritime areas: reflections on the international legal obligations of states. *Fishes* 8 (1), 36. doi: 10.3390/fishes8010036

Cheng, X. (2019). The reasons and impacts of Japan's "Plastic resource recycling strategy". *JAPANESE Res.* 33 (6), 29–41. doi: 10.14156/j.cnki.rbwtyj.2019.06.004

China. (2022a). *Call for written submissions—Proposed response template on the potential options for elements towards an international legally binding instrument, Proposed response template on the potential options for elements towards an international legally binding instrument*. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/41768/Chinasubmission.pdf?sequence=1&isAllowed=y (Accessed 5/1/2023).

China. (2022b). *General statement of the Chinese delegation at the first session of the Intergovernmental Negotiating Committee for an International Instrument on Plastic Pollution*. Available at: https://apps1.unep.org/resolutions/uploads/China_inc-1_statements_0_0.pdf (Accessed 5/1/2023).

China. (2023). *Proposed response template on written submissions prior to INC-3 (part a)*. Available at: https://resolutions.unep.org/resolutions/uploads/China_13092023_a.pdf (Accessed 9/24/2023).

Craik, N. (2008). *The international law of environmental impact assessment: Process, substance and integration* (New York: Cambridge University Press). doi: 10.1017/CBO9780511494611

Cui, Y. (2020). Global marine plastic litter governance: progress, predicament and China's participation. *Pacific J.* 28 (12), 79–90. doi: 10.14015/j.cnki.1004-8049.2023.03.007

d'Ambrières, W. (2019). Plastics recycling worldwide: Current overview and desirable changes. *Field Actions Science Reports. The Journal of Field Actions. Special Issue* 19, 12–21. Available at: https://www.oneplanetnetwork.org/sites/default/files/from-crm/factsreports-5102.pdf.

Dauvergne, P. (2018). Why is the global governance of plastic failing the oceans? *Global Environ. Change* 51, 22–31. doi: 10.1016/j.gloenvcha.2018.05.002

de Sadeleer, N. (2023). "Environmental law in the EU: A pathway toward the green transition," in *Blue Planet Law: The Ecology of our Economic and Technological World* (Swiss: Springer International Publishing Cham), 21–33. doi: 10.1007/978-3-031-24888-7_2

Ecology and Environment (2021). *Notice on action plan for plastic pollution control*. Available at: https://www.env.go.jp/recycle/3Rs/en/outline.html.

Eriksen, M., Lebreton, L. C., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., et al. (2014). Plastic pollution in the world's oceans: More than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PloS One* 9 (12). doi: 10.1371/journal.pone.0111913

EU. (2023a). *Proposed response template on written submissions prior to INC-3 (part a)*. Available at: https://resolutions.unep.org/resolutions/uploads/eums_14092023_a.pdf.

EU. (2023b). *Proposed response template on written submissions prior to INC-3 (part b) Potential Areas Identified by the Contact Groups*. Available at: https://resolutions.unep.org/resolutions/uploads/eums_14092023_b.pdf.

Fadeeva, Z., and Van Berkel, R. (2021). Unlocking circular economy for prevention of marine plastic pollution: An exploration of G20 policy and initiatives. *J. Environ. Manage.* 277. doi: 10.1016/j.jenvman.2020.111457

Ferraro, G., and Failler, P. (2020). Governing plastic pollution in the oceans: Institutional challenges and areas for action. *Environ. Sci. Policy* 112, 453–460. doi: 10.1016/j.envsci.2020.06.015

Fidler, D. P. (2001). Challenges to humanity's health: The contributions of international environmental law to national and global public health. *Envtl. L. Rep. News Anal.* 31. Available at: https://www.elr.info/articles/elr-articles/challengeshumanitys-health-contributions-international-environmental-law.

Finska, L. (2021). *Confronting the Global Plastics Problem Threatening the Marine Environment–A Framework and Elements of an International Legal Response* (Norway: Doctoral dissertation, Faculty of Law, The Arctic University of Norway). Available at: https://munin.uit.no/handle/10037/23741.

Fitzmaurice, M., Wong, M. S., and Crampin, J. (2022). *International Environmental Law: Text, Cases and Materials* (Cheltenham: Edward Elgar Publishing).

G20. (2019). *G20 Implementation Framework for Actions on Marine Plastic Litter*. Available at: http://www.g20.utoronto.ca/2019/2019-G20-Implementation-Framework-for-Actions-on-Marine-Plastic-Litter.html (Accessed 5/10/2023).

Gall, S. C., and Thompson, R. C. (2015). The impact of debris on marine life. *Mar. pollut. Bull.* 92 (1–2), 170–179. doi: 10.1016/j.marpolbul.2014.12.041

Gao. (2022). *Global negotiations on plastic pollution are in full swing, with countries taking different positions*. Available at: https://mp.weixin.qq.com/s/AXnDadUWW74GXkB0OmjbUQ (Accessed 6/18/2023).

Gao, X., and Sun, J. (2007). On the applicable requirements of the risk prevention principle-with the background of international environmental law. *Contemp. Law* 2, 114–118. Available at: https://caod.oriprobe.com/articles/21137620/On_the_Applicable_Conditions_of_the_Precautionary_.htm.

Hannah, S. (2020). "The U.S. falls behind most of the world in plastic pollution regulation," in *Env't Health News*. Available at: https://www.ehn.org/plastic-pollution-2655191194.html.

Hara, K., and Yabar, H. (2012). Historical evolution and development of waste management and recycling systems—Analysis of Japan's experiences. *J. Environ. Stud. Sci.* 2, 296–307. doi: 10.1007/s13412-012-0094-8

IISD. (2022a). *Daily Report for November 28*. Available at: https://enb.iisd.org/plastic-pollution-marine-environment-negotiating-committee-inc1-daily-report-28nov2022 (Accessed 6/10/2023).

IISD. (2022b). *Daily Report for November 30*. Available at: https://enb.iisd.org/plastic-pollution-marine-environment-negotiating-committee-inc1-daily-report-30nov2022 (Accessed 6/10/2023).

IISD. (2022c). *Daily Report for December 1, 2022*. Available at: https://enb.iisd.org/plastic-pollution-marine-environment-negotiating-committee-inc1-daily-report-1dec2022 (Accessed 6/18/2023).

ILC. (2001). *Draft Articles on Prevention of Transboundary Harm from Hazardous Activities with Commentaries*. Available at: https://legal.un.org/ilc/texts/instruments/english/commentaries/9_7_2001.pdf.

ITLOS. (1999). *Southern Bluefin Tuna* (New Zealand v. Japan: Australia v. Japan), Provisional Measures of August 27, 1999.

Japan. (2013). *Written Observations of Japan on the written observations submitted by New Zealand*. Available at: https://www.icj-cij.org/index.php/node/104913.

Japan. (2022a). *Draft Resolution on an international legally binding instrument on marine plastic pollution Proposed by: JAPAN*. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/37625/Draft%20Resolution%20on%20an%20international%20legally%20binding%20instrument%20on%20marine%20plastic%20pollution_Japan.pdf?sequence=1&isAllowed=y.

Japan. (2022b). *Japan's July 15, 2022 submission to the Intergovernmental Negotiating Committee for an International Legally Binding Instrument on Plastic Pollution, including Plastic Pollution in the Marine Environment*. Available at: https://apps1.unep.org/resolutions/uploads/Japan.pdf (Accessed 5/1/2023).

Japan. (2023a). *CG1: Japan's text Proposal on core obligations (Part II, Item 7 to 13)*. Available at: https://resolutions.unep.org/resolutions/uploads/Japan_16112023_core_obligations_part_ii_item_7_to_13.pdf (Accessed 25/11/2023).

Japan. (2023b). *Japan's February 13, 2023 submission on potential options for elements of an international legally binding instrument to be developed*. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/41794/Japansubmission.pdf?sequence=1&isAllowed=y (Accessed 7/1/2023).

Japan. (2023c). *Japan's written submission of May 29*. Available at: https://resolutions.unep.org/resolutions/uploads/Japanstatement.pdf (Accessed 7/1/2023).

Japan. (2023d). *TEMPLATE FOR SUBMISSIONS (part b)*. Available at: https://resolutions.unep.org/resolutions/uploads/Japan_15092023_b.pdf (Accessed 9/25/2023).

Japan. (2023e). *TEMPLATE FOR SUBMISSIONS (part b)*. Available at: https://resolutions.unep.org/resolutions/uploads/Japan_15092023_b.pdf.

Japan. (2023F). *CG1: Japan's text Proposal on Problematic and avoidable plastic products, and Exemption (Part II 3 and 4 of Zero Draft)*. Available at: https://resolutions.unep.org/resolutions/uploads/Japan_problematicandavoidableplasticproducts.pdf (Accessed 25/11/2023).

Keiichi, T. (2022). Legal and Policy Developments Concerning Plastics. *J. "Japan Assoc. Environ. Law Policy,"* 2022 (25), 28–38. doi: 10.57382/kkhs.2022.25_28

Knoblauch, D., Mederake, L., and Stein, U. (2018). Developing countries in the lead—What drives the diffusion of plastic bag policies? *Sustainability* 10 (6), 1994. doi: 10.3390/su10061994

Koivurova, T. (2008). "Due diligence," in *The Max Planck Encyclopedia of Public International Law (MPEPIL)* (New York: Oxford University Press).

Koppelman, B., Day, N., Davison, N., Elliott, T., and Wilsdon, J. (2010). *New frontiers in science diplomacy: Navigating the changing balance of power* (London: The Royal Society). doi: 10.3390/su10061994

Kuan, S. H., Low, F. S., and Chieng, S. (2022). Towards regional cooperation on sustainable plastic recycling: Comparative analysis of plastic waste recycling policies and legislations in Japan and Malaysia. *Clean Technol. Environ. Policy* 24 (3), 761–777. doi: 10.1007/s10098-021-02263-0

Law, K. L., Starr, N., Siegler, T. R., Jambeck, J. R., Mallos, N. J., and Leonard, G. H. (2020). The United States' contribution of plastic waste to land and ocean. *Sci. Adv.* 6 (44). doi: 10.1126/sciadv.abd0288

Ma, D., Xu, Q., and Zhou, J. (2023). The application of the precautionary principle in the decision of releasing Fukushima radioactive contaminated water into the sea. *Mar. Policy* 156. doi: 10.1016/j.marpol.2023.105803

Matsuzaki, Y., and Sato, K. (2018). Efforts to combat marine litter in Japan and future tasks. *Mater Cycles Waste Manage Res.* 29 (4), 278–285. doi: 10.3985/mcwmr.29.278

Ministry of Economy, Trade and Industry (2023). *3R Policies*. Available at: https://www.meti.go.jp/english/policy/energy_environment/3r/index.html.

Ministry of Environment of Japan (2005). *Japan's experience in the promotion of the 3Rs*. Available at: https://www.env.go.jp/recycle/3Rs/en/approach/02.pdf.

Ministry of the Environment of Japan (2018). *Fifth Environmental Basic Plan*. Available at: https://www.env.go.jp/policy/kihon_keikaku/plan/plan_5/attach/ref01-2.pdf.

Ministry of the Environment of Japan (2022). *Annual Focused Policy 2023*. Available at: https://www.env.go.jp/content/000098819.pdf.

Nagtzaam, G., and Kourabas, S. (2022). Failing the future: the complex road to effective plastic regulation in the US. *Ariz. J. Env't L. Pol'y* 13 (2), 224–260. Available at: https://static1.squarespace.com/static/6307d452a995602a1c242475/t/6452c2821a3434520a9b70e6/1683145346846/Failing+the+Future+-+Effective+Plastic+Regulation+in+the+US.pdf.

Nilsson, M., Zamparutti, T., Petersen, J. E., Nykvist, B., Rudberg, P., and McGuinn, J. (2012). Understanding policy coherence: Analytical framework and examples of sector–environment policy interactions in the EU. *Environ. Policy Governance* 22 (6), 395–423. doi: 10.1002/eet.1589

Nyka, M. (2019). Legal approaches to the problem of pollution of marine environment with plastic. *Zeszyty Naukowe Akademii Morskiej w Szczecinie* 59 (131), 162–167. doi: 10.17402/364

OECD. (1972). *Environment and Economics: Guiding Principles Concerning International Economic Aspects of Environmental Policies. Cf. C/M(72)15(Final), Item 129(a), (b) and (c) - Doc. No. C(72)128* (Paris: OECD Publishing).

OECD. (2016). *Extended Producer Responsibility*. Available at: https://www.oecd.org/environment/extended-producer-responsibility.htm.

OECD. (2022). *Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options* (Paris: OECD Publishing). doi: 10.1787/de747aef-en

Okuho, N., Shunichi, H., Kenichi, O., Tadashi, O., Tomoko, S., Teishu, H., et al. (2022). Part 2: panel discussion 3R law and resource recycling. *J. "Japan Assoc. Environ. Law Policy* 25, 69–105. Available at: https://jaelp.smoosy.atlas.jp/ja/journal_epub25v.

Ono, S., Govindarajan, G., and Visvanathan, C. (2023a). Situational analysis of plastic waste management in India and Japan: Cross-country learnings to increase plastic circularity. *J. Material Cycles Waste Manage.* 25 (5), 3033–3047. doi: 10.1007/s10163-023-01737-1

Ono, S., Hewage, H. T. S. A., and Visvanathan, C. (2023b). Towards plastic circularity: current practices in plastic waste management in Japan and Sri Lanka. *Sustainability* 15 (9), 7550. doi: 10.3390/su15097550

Oral, N. (2021). "From the plastics revolution to the marine plastics crisis: A patchwork of international law," in *Frontiers in International Environmental Law: Oceans and Climate Challenges*, 281–315. doi: 10.1163/9789004372887_012

Peng, Y., Wu, P., Schartup, A. T., and Zhang, Y. (2021). Plastic waste release caused by COVID-19 and its fate in the global ocean. *Proc. Natl. Acad. Sci.* 118 (47). doi: 10.1073/pnas.2111530118

Planet Commons (2023). *Plastic Reduction Now-Summary and Outlook of the First Intergovernmental Negotiations on Plastic Pollution*. Available at: https://mp.weixin.qq.com/s/m4nbJwHGiMagi4GNJb3-FQ.

Plastic Recycling Association (2021). *Plastic Products Production, Disposal, Recycling, and Disposal Status in 2021*. Available at: https://www.pwmi.or.jp/pdf/panf1.pdf.

Plastic Waste Management Institute (2019). *Introduction to plastic recycling*. Available at: pwmi.or.jp/ei/plastic_recycling_2019.pdf.

Popp, D. (2006). International innovation and diffusion of air pollution control technologies: The effects of NOX and SO2 regulation in the US, Japan, and Germany. *J. Environ. Economics Manage.* 51 (1), 46–71. doi: 10.1016/j.jeem.2005.04.006

Qi, X. (2023). Reviving the monetary gold principle? A case note on the judgment of preliminary objections in the Mauritius/Maldives case. *Ocean Dev. Int. Law* 54 (1), 1–25. doi: 10.1080/00908320.2023.2175751

Raubenheimer, K., and McIlgorm, A. (2018). Can the Basel and Stockholm Conventions provide a global framework to reduce the impact of marine plastic litter? *Mar. Policy* 96, 285–290. doi: 10.1016/j.marpol.2018.01.013

Rio Declaration. (1992). *UN Doc. A/CONF.151/26/Rev.1 (Vol. I), Annex I*. Available at: https://www.un.org/esa/dsd/agenda21/Agenda%2021.pdf.

Sachs, N. M. (2006). Planning the Funeral at the Birth: Extended Producer Responsibility in the European Union and the United States. *Harvard Environmental Law Review* 30, 51.

Sakai, S., Yoshida, H., Hirai, Y., Asari, M., Takigami, M. H., Takahashi, S., et al. (2011). International comparative study of 3R and waste management policy developments. *J. Material Cycles Waste Manage.* 13 (2), 86–102. doi: 10.1007/s10163-011-0009-x

Seay, J., and Ternes, M. E. (2022). A review of current challenges and legal advances in the global management of plastic waste. *Clean Technol. Environ. Policy* 24 (3), 731–738. doi: 10.1007/s10098-022-02289-y

Sipiorski, E. (2023). "Scientific knowledge: its impacts on judicial decision-making and international law in the era of sustainability," in *Blue Planet Law: The Ecology of our Economic and Technological World* (Swiss: Springer International Publishing Cham), 59–69. doi: 10.1007/978-3-031-24888-7_5

Smets, H. (1994). The polluter pays principle in the early 1990s. *Environ. after Rio: Int. Law Economics* 131, 137–141. Available at: https://api.semanticscholar.org/CorpusID:128051357.

Stöfen-O'Brien, A. (2022). The Prospects of an international treaty on plastic pollution. *Int. J. Mar. Coast. Law* 37 (4), 727–740. doi: 10.1163/15718085-bja10108

Stone, C. D. (2004). Common but differentiated responsibilities in international law. *Am. J. Int. Law* 98 (2), 276–301. doi: 10.2307/3176729

Sun, C. (2023). Japan's environmental diplomacy to southeastern asia in the context of the "Indo-pacific strategy". *Forum World Economics & Politics* 3, 92–115. Available at: https://kns.cnki.net/kcms/detail/detail.aspx?FileName=SJJT202303005&DbName=CJFQ2023.

Tadashi, O. (2010). The precautionary principle in environmental law. *Annu. Rev. Philosophy Law*, 54–71.

Tanaka, Y. (2021). Obligation to conduct an environmental impact assessment (eia) in international adjudication: interaction between law and time. *Nordic J. Int. Law* 90 (1), 86–121. doi: 10.1163/15718107-bja10022

Tao, X. (2019). *Why Japan listed marine plastic waste and microplastics governance as an important issue at the G20 Summit in Osaka* (China Ocean Development Research Center). Available at: https://aoc.ouc.edu.cn/2019/0712/c9824a253493/page.htm (Accessed 6/18/2023).

Tessnow-von Wysocki, I., and Le Billon, P. (2019). Plastics at sea: Treaty design for a global solution to marine plastic pollution. *Environ. Sci. Policy* 100, 94–104. doi: 10.1016/j.envsci.2019.06.005

The MOX Plant Case (Ireland v. United Kingdom), Provisional Measures, NO.10 (ITLOS 2001). Available at: https://www.itlos.org/fileadmin/itlos/documents/cases/case_no_10/published/C10-O-3_dec_01.pdf.

UNEP (2018). *Governing the Global Programme of Action*. Available at: https://www.unep.org/explore-topics/oceans-seas/what-we-do/addressing-land-based-pollution/governing-global-programme?_ga=2.267685133.2008218181.1673248060-509981857.1669890540 (Accessed 6/18/2023).

UNEP (2022). *UNEP/EA.5/L.23/Rev.1*. Available at: https://www.unep.org/environmentassembly/unea-5.2.

UNEP (2023). *Life Circle Initiative*. Available at: https://www.lifecycleinitiative.org/life-cycle-approach-to-plastic-pollution/.

United States (2023). *U.S. interventions at INC-2 Contact Group 1 on (a) Objective and (b) Core obligations, control measures, and voluntary approaches*. Available at: https://resolutions.unep.org/resolutions/uploads/23062023_us_cg1.pdf.

U.S (2023a). *Submission by the United States of America at INC-3 Contact Group 3*. Available at: https://resolutions.unep.org/resolutions/uploads/usa_nationalsecurity.pdf.

U.S (2023b). *U.S. Submission on Elements Not Discussed at INC-2*. Available at: https://resolutions.unep.org/resolutions/uploads/united_states_of_america_15092023_a.pdf.

U.S. Environmental Protection Agency (2020). *Advancing Sustainable Materials Management: 2018 Tables and Figures*. Available at: https://www.epa.gov/sites/default/files/2021-01/documents/2018_tables_and_figures_dec_2020_fnl_508.pdf.

Valerie Volcovici, V. (2022). *Countries split on plastics treaty focus as UN talks close. Reuter*. Available at: https://www.reuters.com/business/environment/countries-split-plastics-treaty-focus-un-talks-close-2022-12-03/#:~:text=WASHINGTON%2C%20Dec%202%20%28Reuters%29%20-%20The%20first%20round,be%20global%20and%20mandatory%2C%20or%20voluntary%20and%20country-led.

Van Berkel, R. (2018). Materials recycling for circular economy. International Conference on Sustainable Growth through Material Recycling—Policy Prescriptions. 115-265. Available at: https://legiscan.com/US/text/SB3508/id/1821744/US_Congress-2017-SB3508-Enrolled.pdf.

Vince, J., and Hardesty, B. D. (2018). Governance solutions to the tragedy of the commons that marine plastics have become. *Front. Mar. Sci.* 5. doi: 10.3389/fmars.2018.00214

Wang, X. (2020). The concept, policy and practice of Japan's participation in global ocean governance. *J. Boundary Ocean Stud.* 01, 57–71. Available at: https://kns.cnki.net/kcms/detail/detail.aspx?FileName=BJYH202001005&DbName=CJFQ2020.

Wolfrum, R. (2021). "Solidarity and community interests: Driving forces for the interpretation and development of international law," in *Solidarity and Community Interests*. Ed. B Nijhoff (Leiden, Boston: Brill Nijhoff).

World Commission on Environment and Development (1987). *Our Common Future* (New York: World Commission on Environment and Development), 65. Available at: https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf.

Wright, S. L., Thompson, R. C., and Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: A review. *Environ. pollut.* 178, 483–492. doi: 10.1016/j.envpol.2013.02.031

Xu, Q., and Tan, Z. (2023). Building a maritime community with a shared future: Scholarly reflections on China's new ocean vision. *Mar. Policy* 9. doi: 10.1016/j.marpol.2023.105508

Yabar, H., Uwasu, M., and Hara, K. (2013). Tracking environmental innovations and policy regulations in Japan: Case studies on dioxin emissions and electric home appliances recycling. *J. Cleaner Production* 44, 152–158. doi: 10.1016/j.jclepro.2012.10.045

Yotova, R. (2017). Challenges in the identification of the general principles of law recognized by civilized nations: the approach of the international court. *Can. J. Comp. Contemp. L.* 3, 269.

Zhang, K., Hamidian, A. H., Tubić, A., Zhang, Y., Fang, J. K., Wu, C., et al. (2021). Understanding plastic degradation and microplastic formation in the environment: A review. *Environ. pollut.* 274. doi: 10.1016/j.envpol.2021.116554

Zhang, F., and Jin, Z. (2020). Marine plastic litter pollution and its management: foreign experience and enlightenment. *Observation Reflection* 12, 92–100. Available at: https://kns.cnki.net/kcms/detail/detail.aspx?FileName=GCYS202212010&DbName=CJFQ2022.

Zou, H. (2009). On the basic principles of international environmental law. *Environ. Prot.* 4, 81–83. Available at: https://kns.cnki.net/kcms/detail/detail.aspx?FileName=HJBU200904033&DbName=CJFQ2009.

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 08 February 2024
DOI 10.3389/fmars.2024.1343710

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Oran Young,
University of California, Santa Barbara, United States
Muhammad Tamoor,
Chinese Academy of Sciences (CAS), China
Gabriela Oanta,
University of A Coruña, Spain

*CORRESPONDENCE
Qi Xu
xuqi2019@jnu.edu.cn

RECEIVED 24 November 2023
ACCEPTED 08 January 2024
PUBLISHED 08 February 2024

CITATION
Chen X and Xu Q (2024) The implementation of the environmental impact assessment in Fukushima contaminated water discharge: an analysis of the international legal framework. *Front. Mar. Sci.* 11:1343710. doi: 10.3389/fmars.2024.1343710

COPYRIGHT
© 2024 Chen and Xu. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

The implementation of the environmental impact assessment in Fukushima contaminated water discharge: an analysis of the international legal framework

Xidi Chen[1] and Qi Xu[2]*

[1]Tsinghua University School of Law, Beijing, China, [2]Jinan University School of Law, Guangzhou, China

Japan is discharging nuclear contaminated water from the 2011 Fukushima incident into the sea after treatment with the Advanced Liquid Processing System (ALPS). This process is expected to continue for decades, as planned by the Japanese government. This decision sparks opposition from many countries and international organizations, as well as constant protests from people in Japan and neighboring countries. Although there are no international documents specifically addressing the discharge of contaminants from a nuclear accident, it is found that the LOS Convention, treaties on nuclear safety, and international environmental laws provide the basis and legal framework for requiring Japan to implement environmental impact assessments throughout the entire process of Fukushima contaminated water discharge. First, this paper evaluates the consistency between the measures taken before Japan's decision to discharge contaminated water into the sea and the requirements under international laws. Second, this paper further examines the substantive and procedural requirements under international law for the entire process of Fukushima contaminated water discharge. It identifies substantive criteria to be applied in assessing the environmental impact of Fukushima contaminated water discharge based on international documents and explores the procedural requirements to assure transparency, prudence, and accountability of the assessment. Finally, given the potential transboundary damage caused by the discharge of nuclear-contaminated water into the sea, this paper proposes that a new multi-stakeholder cooperative mechanism is necessary to achieve effective and credible monitoring and respond to the claims of potentially affected parties. In addition to providing a legal framework for the environmental impact assessment in the Fukushima case, this paper may also contribute to the proper disposal of nuclear contaminants in future nuclear accidents.

KEYWORDS

environmental impact assessment, Fukushima nuclear accident, nuclear contamination, transboundary damage, precautionary principles

1 Introduction

On August 24, 2023, the Japanese government officially launched the discharge of nuclear contaminated water from the 2011 Fukushima nuclear accident that has been treated through its "Advanced Liquid Processing System (ALPS)" into the Pacific Ocean (IAEA, 2023; Reuters, 2023). On March 11, 2011, an earthquake with an epicenter 130 kilometers east of Sendai and a magnitude of 9.0 struck Japan, triggering a tsunami that exceeded 14 meters above the site of the Fukushima Daiichi nuclear power plant (World Nuclear Association, 2022). The 2011 Fukushima nuclear accident resulted in a massive release of radioactive materials, exposing more than 2,000 workers to dangerous doses of radiation, and radioactive elements from the accident soon spread worldwide (Anzai et al., 2011). The Fukushima nuclear accident was finally recognized as a "Level 7" nuclear accident (the highest level) by the Nuclear and Industrial Safety Agency (NISA) of Japan, the same level as that of the Chernobyl nuclear accident in 1986 (IAEA, 2011).

As a result of the tsunami, the cores of Units 1 to 3 of the Fukushima Daiichi nuclear power plant melted. To avoid more explosions and the further spread of radioactive contamination, the Tokyo Electric Power Company (TEPCO) decided to continuously inject water into the units to cool the cores and recycle the water. TEPCO stored contaminated water in storage tanks near the nuclear plant (IAEA, 2022a). Simultaneously, a large amount of groundwater flowing below the surface of the Fukushima Daiichi nuclear power plant, as well as infiltrated rainwater, which comes into contact with highly radioactive substances in the case of damaged buildings and pipes of the units, constitutes another source of nuclear contaminated water (Prime Minister of Japan and His Cabinet, 2021b). As of March 2021, more than 1.25 million tons of nuclear effluent had been stored in these tanks, with 140 tons added daily. TEPCO has repeatedly complained that there is so much nuclear-contaminated water constantly generated that long-term storage is unsustainable and economically unaffordable (Yamaguchi, 2017).

Therefore, since 2013, the Japanese government has evaluated five options for the disposal of nuclear-contaminated water, including geosphere injection, vapor release, discharge into the ocean, and underground burial, and the evaluation report issued by the ALPS Subcommittee concluded that directly releasing Fukushima's water into the Pacific Ocean is the most convenient and least costly, which drove the Japanese government's decision to discharge Fukushima nuclear-contaminated water into the ocean (Prime Minister of Japan and His Cabinet, 2021b). Recently, the Japanese government stepped up the implementation of its discharge plan. However, the decision has aroused strong concern and opposition at home and abroad. Among the criticisms from various countries, international organizations, and citizen groups, an important point was that Japan's action was considered irresponsible and found not in conformity with international law, because it rushed to the decision before conducting adequate environmental impact assessments (EIAs) (Ministry of Foreign Affairs of the PRC, 2021).[1] There are concerns that the discharge of Fukushima nuclear-contaminated water may cause unknown ecological and environmental impacts. In other words, Fukushima water discharge, from their perspective, may become another radioactive disaster after the 2011 Fukushima nuclear accident.

In fact, such concern is proving to be valid. In 2011, Japan discharged a portion of the contaminated water into the sea without conducting proper EIAs or informing relevant countries and international organizations, which led to widespread international condemnation (CNN, 2011). There are numerous studies and reports stating that the treatment system that Japan relies on cannot guarantee the harmlessness of Fukushima nuclear-contaminated water and that the reliability of the storage and treatment facilities for Fukushima water has been questioned due to repeated problems (Men, 2021). Even TEPCO and the Japanese government have admitted that the relevant indicators of radioactivity have fluctuated and exceeded standard values on several occasions, but have not provided a reasonable explanation and have continued to promote the discharge plan under these circumstances (NHK, 2021). It is noted that claims about the safety of nuclear-contaminated water have not been scientifically supported by available information and data (Greenpeace East Asia, 2021).

It has been commonly accepted, since the beginning of the twenty-first century, that states bear the legal obligation to conduct EIAs on activities that can potentially impact the environment, as determined by multiple treaties, customary international law, and general principles of law (Preiss, 1999; Yang, 2018; Rajamani and Peel, 2021). As international lawyers have pointed out, the EIA is considered the first and perhaps the most significant barrier in international law to protect ecology and the environment from possible transboundary damage (Kersten, 2009). However, from the perspective of potentially affected states, the requirements of international law for the EIA seem to have failed to play an appropriate role in achieving the goal of regulating the actions of the state. The Japanese government is still fast-tracking the implementation of its discharge plan without the necessary EIA, while rebutting that its conduct is in conformity with EIA obligations. It should be noted that Fukushima nuclear contaminated water discharge is the first attempt in human history to discharge pollutants from a nuclear accident into the sea, where the fragmentation of international law norms makes it challenging for states, international organizations, and international law scholars to apply and interpret the relevant rules. In this context, a systematic review of the international law rules and requirements for the EIA and achieving their concretization in specific circumstances would contribute to reducing the arbitrariness of Japan's decisions and actions in the Fukushima

1 Environmental impact assessment (EIA) is generally defined as a systematic process that identifies, predicts, evaluate, and mitigating the biophysical, social and other relevant effects of development actions, in advance. The emphasis, compared with many other mechanisms for environmental protection, is on prevention. See Glasson, J.; Therivel, R.; Chadwick, A. Introduction to Environmental Impact Assessment, New York: Routledge, 5.

incident; it could also contribute to the proper disposal of post-accident nuclear contaminants in the future.

This paper aims to provide an analysis of the international legal framework for the implementation of Fukushima contaminated water discharge. Part 2 examines the compatibility of Japan's discharge, taking into account the conducted testing of ALPS water at the current stage, with its international legal obligations for EIAs. It is found that the Japanese government bears the duty to further conduct the assessment to determine the environmental safety of its discharge plan. Part 3 systematically analyses the procedural and substantive EIA requirements in the Fukushima incident under treaties, customary international, as well as general principles of law, and discusses the full-process approach to advancing the implementation of EIAs in the Fukushima incident in accordance with international law. In Part 4, to address the disposal of nuclear contaminants from the Fukushima incident and future occasions, we propose a feasible EIA mechanism initiative based on established international legal rules.

2 Japan's discharge and the EIA obligations in international law

Before discussing how the EIA of the disposal of Fukushima nuclear-contaminated water can be improved through international law, it is necessary to identify the consistency between Japan's discharge plan and activities at the current stage and obligations under international conventions, customary international law, and general legal principles. This section analyzes whether the Japanese government's discharge plan conforms with international law on nuclear safety, the law of the sea, and international environmental law. Particularly noteworthy is the fact that the EIA obligation in international law contains comprehensive requirements, and the mere detection or monitoring of the content of some radioactive elements in nuclear contaminated water may not be sufficient.

2.1 Japan's discharge and the EIA obligations under the law of the sea

The United Nations Convention on the Law of the Sea (UNCLOS), adopted in 1982 and referred to by some authors as the "Constitution of the Oceans," is a legal document with comprehensive provisions on marine environmental protection (Koh, 1982). Part XII of the Convention provides the concerned systematic rules, including EIA obligations for all contracting states. As a contracting party, Japan is obliged to act in accordance with UNCLOS and relevant rules of international law.

2.1.1 Obligations to implement EIA under the UNCLOS

At the beginning of Part XII of the UNCLOS, Article 192 as "the leading principle for a reasonable and careful maintenance of the sea" generally prescribes the obligation for states to "protect and preserve the marine environment" and the following terms specify the content of such obligation (Proelss, 2017). Article 194 of the UNCLOS further states that

"States shall take … all measures … that are necessary to prevent, reduce, and control pollution of the marine environment from any source, using … the best practicable means at their disposal and in accordance with their capabilities, and they shall endeavor to harmonize their policies in this connection."[2]

Although there is no direct reference to the EIA, this paragraph imposes the requirement of due diligence, which requires Japan and any other parties to take all possible measures to "prevent, reduce, and control pollution of the marine environment" within their best capabilities, which, as the "general provisions," must be read together with the specific provisions that follow (Gold, 2006).

Meanwhile, the language of the Convention makes it clear that the requirement of due diligence applies not only to marine pollution within a state's jurisdiction, but also to transboundary marine pollution, where the state shall ensure that activities under their jurisdiction not cause transboundary damage to other states, and that "pollution arising from incidents or activities under their jurisdiction or control does not spread beyond the areas."[3] In a word, Japan is required, under the UNCLOS, to minimize polluting the marine environment from their activities "to the fullest possible extent."[4]

It may be argued that these "general" provisions are not sufficient to determine Japan's EIA obligations in international law, but the existence of Articles 204-206 of the Convention responds well to this viewpoint. Article 204 is entitled "monitoring of the risks or effects of pollution" and provides that States shall "observe, measure, evaluate, and analyze, by recognized scientific methods, the risks or effects of pollution," and Article 205 requires the State to make the data and reports obtained from monitoring available to all States Parties.[5] Furthermore, According to Article 206,

"[w]hen States have reasonable grounds for believing that planned activities under their jurisdiction or control may cause substantial pollution of or significant and harmful changes to the marine environment, they shall, as far as practicable, assess the potential effects … and shall communicate reports…"[6]

The purpose of these provisions is to ensure that planned activities can be effectively controlled, and that potentially affected states are informed of the potential risks and impacts of these activities. As such, it is an essential component of a State's environmental obligations and a specific application of the obligation declared in Article 194.2, to adopt all necessary measures to ensure that activities under their jurisdiction or

2 UNCLOS, Montego Bay, 10 December 1982, United Nations Treaty Series, Vol.1833, No. 31363, p. 3, Art. 194.1. Available at https://treaties.un.org/doc/Publication/UNTS/Volume%201833/volume-1833-A-31363-English.pdf.

3 UNCLOS, Art. 194.2.

4 UNCLOS, Art. 194.3.

5 UNCLOS, Art. 204.1 & 205.

6 UNCLOS, Art. 206.

control are carried out without causing damage to other States and their environment by pollution (Nandan and Rosenne, 1995). Specifically, in understanding Article 206, it should be noted that it imposes two kinds of different, but related EIA obligations: the first is a preliminary assessment of "planned activities" to determine whether there are "reasonable grounds for believing" that there will be significant environmental damage, and the second is the obligation to assess the potential effects of such activities on the marine environment "as far as practicable." (Proelss, 2017)

Therefore, only if Japan performs a "preliminary EIA" and properly concludes that there is no significant environmental risk associated with the discharge plan, or if, after conducting both EIAs, it is ultimately determined that no such risk exists or that the potential environmental harm is proportional, can its obligations under Article 206 and relevant provisions of the UNCLOS of the EIA be properly discharged.

2.1.2 The "preliminary EIA"

With respect to the "preliminary EIA" defined above, publicly available information indicates that Japan seems to have already conducted such an assessment to initially determine whether its discharge plan would "cause substantial pollution of or significant and harmful changes to the marine environment." (TEPCO, 2020) Currently, Japan has repeatedly emphasized in its public reports and statements that the radioactive impact of the discharge of Fukushima contaminated water is extremely low (Prime Minister of Japan and His Cabinet, 2021a). Assuming that this is the conclusion of Japan's "preliminary assessment," it seems to imply that it believes that the planned discharge activities will not cause substantial pollution or changes to the environment, and therefore, there is no need to initiate a formal EIA. The language of Article 206 requires the State to provide "reasonable grounds" for its conclusion, but does not offer specific criteria for the existence of "substantial pollution" or "significant and harmful changes to the marine environment."

Nevertheless, the content of this obligation has been affirmed in international adjudications. It was observed that a preliminary assessment must be implemented based on an objective assessment of all relevant factors, which means that all impacts that can be reasonably assumed to occur should be examined objectively.[7] Meanwhile, it was observed that only "transitory" pollution or the less significant outcome should be considered without the risks of causing "substantial pollution" as prescribed (Proelss, 2017). In this regard, it is noted that the claim by a considerable number of countries that Japan should assess radioactive elements other than tritium in the Fukushima nuclear contaminated water and the possible cumulative effect of the discharge that can cause permanent, rather than "transitory" pollution to the oceans has not been responded to by the Japanese government.

A series of facts indicate that the environmental safety of Fukushima nuclear effluent is of concern. On September 16, 2021, TEPCO reported that the purification unit had stopped operating and the reason for the phase stoppage was unknown (KFB, 2021). A few months later, according to the Japanese Ministry of Health, Labor, and Welfare, on February 8, 2022, the radioactive cesium activity of catches caught off the coast of Fukushima Prefecture reached 1,400 becquerels per kilogram, far exceeding the Japanese food hygiene standard of 100 becquerels per kilogram. It is noteworthy that the catches offshore from Fukushima Prefecture exceeded the radioactivity limit in February and April 2021 and were once suspended from sale until December 2021, when the suspension was lifted (Ryall, 2022). Under these circumstances, it seems difficult to assert that Japan has duly fulfilled its obligations of the preliminary assessment.

Furthermore, in the 2016 South China Sea case, the arbitral tribunal issued an opinion on the state's EIA obligations, although China challenged the facts upon which it relied. For the purposes of the preliminary assessment, the judgment found that "the scale and impact" of the relevant activities alone would leave the state no choice but to believe that they "may cause significant and harmful changes."[8] Applying this jurisprudence, given the scale of the nuclear-contaminated water being discharged, the significance of the environmental damage, and the geographic area potentially affected, it seems that any state "could not reasonably have held any belief" other than that the discharge plan could "cause significant and harmful changes." Therefore, proceeding to the "substantive EIA" stage is of necessity.

2.1.3 The "substantive EIA"

In terms of the "substantive EIA," the detailed analysis of the State's domestic law in the South China Sea case seems to imply that the arbitral tribunal believes that EIA obligations under the UNCLOS are not a mere ambiguous statement, but must be fulfilled in accordance with some standards.[9] Although the 2016 judgement did not elaborate further on this point and has been criticized for its excessive harshness and lack of evidence to support its jurisprudence, there is value in the idea of limiting the state's discretion in the "substantive EIA." It is useful to recall the "general provisions" mentioned earlier in this context.

As the Vienna Convention on the Law of Treaties (VCLT) points out, a specific provision should be read together with the context to achieve a correct interpretation of the law.[10] When considering EIA obligations under the UNCLOS, the requirements of due diligence that have been emphasized several times in its context should be applied. In previous reports, the International Law Commission (ILC) emphasized the need for EIAs to be commensurate with the nature and magnitude of the planned

7 ICJ, Certain Activities Carried Out by Nicaragua in the Border Area (Costa Rica v. Nicaragua), Judgment of 16 December 2015, para. 153-156.

8 PCA, The South China Sea Arbitration (The Republic of Philippines v. The People's Republic of China), Award of 12 July 2016, para. 987-988.

9 PCA, The South China Sea Arbitration (The Republic of Philippines v. The People's Republic of China), Award of 12 July 2016, para. 990.

10 VCLT, Vienna, 23 May 1969, United Nations Treaty Series, Vol.1155, No. 18232, p. 331, Art. 31. Available at https://treaties.un.org/doc/Publication/UNTS/Volume%201155/volume-1155-I-18232-English.pdf.

activity and to avoid underestimating the potential for adverse environmental impacts.[11]

Moreover, the use of the term "as far as practicable" should not be construed as a derogation of EIA obligations for Japan, one of the most developed countries, since the provision was included in the provision of the UNCLOS only to relieve the undue burden on developing countries that lack the necessary capacity.[12] This means that in the Fukushima incident, the Japanese government is not only obligated to conduct an EIA of the discharge plan, but also all measures "that are necessary to prevent, reduce, and control pollution" to the best of its capacities for the EIA. Hence, the threshold of the test is clearly much higher than that of the "preliminary assessment." As what has been discussed above, it is even doubtful that Japan has met the requirement of "preliminary assessment," let alone met this higher threshold, which makes it convincing that Japan has not fulfilled its EIA obligations and therefore breached Article 206 of the Convention.

Last but not least, it is important to note that, while the international standards referred to in Article 197 may be used in the EIA process, they are comprehensive, integrated standards and do not merely include "the international standards" already established by the IAEA or World Health Organization (WHO). In fact, the incomplete standards are provided only for specific radiation sources, which cannot be applied unchanged to the disposal of nuclear contaminated water after a major accident. (Chen and Xu, 2022) Even if the discharge by Japan meets the IAEA standards, it does not mean that Japan has fulfilled its obligation to implement the EIA under the Convention. In addition to this, IAEA's comprehensive report has made it clear that many of the technical topics reviewed and evaluated by the Working Group will need to be revisited with the discharges in order to assess whether the activities during the treated water discharge operations are in compliance with the relevant international safety standards. (IAEA, 2023) This issue will be further clarified in Part 3.

2.2 Japan's discharge and the EIA obligations under international laws on nuclear safety

Compared to the elaborate rules concerning the EIA and transboundary EIA under the law of the sea regime, international law on nuclear safety fails to provide sound regulations regarding the disposal of nuclear waste and contaminants. This is mostly due to the fact that nuclear regulation and restraint, even merely on civilian nuclear facilities or technology, is often regarded by most states as a sensitive topic directly related to their national interests, making it exceptionally difficult to construct international law rules in this area (Elbaradei et al., 1995). Nevertheless, the requirement for states to conduct proper EIAs can still be established under the international nuclear safety regime. In this section, we consider the consistency between Japan's discharge and the Convention on Nuclear Safety (CNS) as well as the Convention on Early Notification of a Nuclear Accident (CENNA), respectively.

2.2.1 The CNS

The 1994 Convention on Nuclear Safety, in its preamble, reaffirms the responsibility for "the State having jurisdiction over a nuclear installation" to assure nuclear safety, and it specially notes that "accidents at nuclear installations have the potential for transboundary impacts."[13] In light of this, the CNS requires contracting states to take the appropriate steps to "give due priority to nuclear safety" and ensure adequate financial resources available for that safety.[14] More importantly, Art.16 of CNS provides rules on emergency preparedness that the appropriate steps shall be taken to ensure that "its own population and the competent authorities of the States in the vicinity of the nuclear installation arc provided with appropriate information for emergency planning and response," when there is a radiological emergency.[15]

Nonetheless, the question we need to consider is whether the Convention for Nuclear Facilities is applicable in the case of Fukushima water discharge. The CNS provides that "[t]his Convention shall apply to the safety of nuclear installations," and nuclear installations are defined as "any land-based civil nuclear power plant."[16] The Fukushima Daiichi nuclear power plant is obviously a civilian nuclear power plant, but whether the Fukushima nuclear-contaminated water discharge falls within the scope of the safety of nuclear installations requires further clarification. It should be noted that the discharge of Fukushima water was not an isolated incident, but rather a follow-up to the Fukushima nuclear accident in 2011. This means that discharge should be considered together with the Fukushima nuclear accident in this regard. Looking back at the CNS description of the "radiological emergency," it is clear that an accident of the installation that results in a nuclear release is within the scope of application of this legal document; only then do the provisions for radiological emergencies make sense. Therefore, the discharge of water from Fukushima is directly related to the nuclear safety of the Fukushima Daiichi nuclear power plant, and CNS is the applicable rule.

Although the CNS does not directly stipulate that state parties shall undertake EIA measures before the disposal of the

11 ILC, Report of the International Law Commission: Draft Articles on the Prevention of Transboundary Harm from Hazardous Activities with Commentaries, UN Doc. A/56/10 (2001), 404-405.

12 ITLOS Seabed Dispute Chamber, Responsibilities and Obligations of States Sponsoring Persons and Entities With Respect to Activities in the Area, Advisory Opinion of 1 February 2011, ITLOS Report (2011) - 10, para. 160.

13 CNS, Vienna, 20 September 1994 , United Nations Treaty Series, Vol. 1963, No. 33545, p. 293, preamble. Available at https://treaties.un.org/doc/Publication/UNTS/Volume%201963/v1963.pdf.

14 CNS, Art. 10-11.

15 CNS, Art. 16.2.

16 CNS, Art. 2-3.

contaminant after a nuclear accident, without appropriate EIAs, it is not convincing to claim that "appropriate information" has been provided or that nuclear safety has been prioritized. Simultaneously, VCLT indicates that the provisions of treaties should be interpreted in accordance with the purpose for which the parties entered into the treaty, whereas in the CNS we can see that the treaty is intended to mitigate the "radiological consequences" in the event of the nuclear accident.[17] In the absence of proper EIA, it implies that the relevant countries are not clear about the consequences, and therefore, it is impossible to achieve the so-called "mitigation of radiological consequences."

However, as previously noted, Japan's EIAs of the discharge plan were inadequate. Greenpeace notes that Japan's current EIA report fails to apply the basic principle of radiation protection, which requires that low-level increases in radiation risk are justified and that the net benefit to society is demonstrated as well. Simultaneously, Japan's EIAs ignore the cumulative effects of radioactive elements and the long-term impacts on marine ecology, species, and food chains. The basic consensus is that Japan's assessments on the discharge of Fukushima nuclear contaminated water into the sea are "extremely limited," not considering long-term environmental risks, including impacts on the larger region of Japan's east coast or the Pacific Ocean (Greenpeace East Asia, 2021). In this case, it is difficult to convince that the EIA conducted by Japan conforms to the requirements under the CNS, since it neither qualifies as the appropriate step, nor provides for "its own population and the competent authorities of the States in the vicinity" with appropriate information for emergency planning and response.

2.2.2 The CENNA

Additionally, the 1986 Convention on the Early Notification of a Nuclear Accident (CENNA) also constitutes a source of the EIA obligation. The CENNA applies to the activity that may result in an international transboundary release that could be of radiological safety significance for another state, where the discharge of the Fukushima water obviously falls.[18] Indeed, the definition of the scope of application implies that the state conducting such activities should bear the burden of determining whether they are likely to cause significant transboundary effects.

Furthermore, according to Article 5 of CENNA, Japan is required to provide information when deciding to release nuclear-contaminated water, which at least includes " the foreseeable development … relevant to the transboundary release" and "the general characteristics of the radioactive release, including … the nature, probable physical and chemical form and the quantity, composition and effective height of the radioactive release."[19] Unfortunately, the apparent failure of the Japanese government or TEPCO to provide all of the above information constitutes a breach of its treaty obligations and violates the treaty's purpose of minimizing transboundary radiological consequences.[20]

2.3 EIA obligations under the international environmental law

The Stockholm Declaration of 1972 is commonly accepted as the foundation of international environmental law, and Principle 21 accurately summarizes the environmental obligations of sovereign states under international law (Pallemaerts, 2014). Principle 21, on the one hand, affirms that states have "the sovereign right to exploit their own resources," and on the other hand, it prescribes their "responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction." With the recognition of Principle 21 as customary international law, or more precisely as the core of international environmental law, the international legal obligations of States to prevent, reduce, and control transboundary environmental damage are established.[21]

Subsequently, the state's obligations of transboundary environmental protection have been continuously crystallized in different areas through the path of treaties or customary international law (Knox, 2002). Among others, the requirement for transboundary EIA is widely recognized and accepted, and its practice has become *custom* in international law.

The Pulp Mills case, which was decided by the ICJ in 2010 is a landmark case in the development of the transboundary EIA rule. The court stated in paragraph 204 of its judgment that if a State's proposed activity carries a risk of causing significant adverse environmental effects across a border, general international law requires the State to carry out an EIA.[22] It found that the state practice of transboundary EIA had been accepted by states for some years prior to the case and could be considered a rule of general international law.[23] Although Argentina brought the Pulp Mills case under the Statute of the River Uruguay, the Court's determination of the obligation of transboundary EIA was established based on customary international law. Since then, international adjudications, including the International Seabed Development Advisory Opinion, have repeatedly confirmed the

17 CNS, Art. 1.

18 CENNA, Helsinki, 17 March 1992, United Nations Treaty Series, Vol. 2105, No. 36605, p. 457, Art. 1. Available at https://treaties.un.org/doc/Publication/UNTS/Volume%202105/v2105.pdf.

19 CENNA, Art. 5.

20 CENNA, preamble.

21 Rio Declaration on Environment and Development, Principle 21.

22 ICJ, Pulp Mills on the River Uruguay (Argentina v. Uruguay), Judgment of 20 April 2010, para. 204.

23 ICJ, Pulp Mills on the River Uruguay (Argentina v. Uruguay), Judgment of 20 April 2010, para. 204.

customary international law status of transboundary EIAs.[24] Simultaneously, from the perspective of state practice, transboundary EIA has been increasingly applied since the 1980s to activities that may cause transboundary harm "in many parts of the world," and developing countries have gradually accepted this rule (Chen and Xu, 2022).

Concerning the Fukushima incident, the next question that needs to be answered is regarding the specifics of a transboundary EIA as an obligation of international law. In this regard, the Costa Rica/Nicaragua case before the ICJ is useful for understanding cross-border EIA. In that case, it is broadly agreed that under general international law, a state has an obligation to conduct a transboundary EIA for activities within its jurisdiction that present the risk of causing significant damage to other states.[25] Furthermore, it is observed that transboundary EIA should reasonably include all potential impacts, and perhaps more importantly, if the state claims that its activity does not have a significant environmental impact, and the potentially affected state believes that it may have such impacts, according to the ICJ, the party that decides to conduct the activity is obliged, according to the ICJ, to carry out the EIA and thus present evidence to prove the non-existence of the impact, not by the potentially affected state.[26]

Moreover, in the Costa Rica/Nicaragua case, Nicaragua asserted that Costa Rica had an obligation under the CIL to notify and negotiate with Nicaragua. In considering this Nicaraguan claim, the tribunal confirmed that if the EIA determines that there is a risk of substantial environmental damage, a State planning such a risky activity should notify and negotiate in good faith with the potentially affected state on the appropriate measures to prevent and mitigate such risk.[27] In this regard, although the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention) does not bind Japan, China or Korea, it may be used as an appropriate reference. The Espoo Convention requires countries to implement planned activities that may have significant transboundary impacts to actively include potentially affected countries and their citizens in the assessment process by providing early notification and proper negotiation at the time the EIA is conducted.[28]

Overall, the EIA obligation under international law, which has been elaborated by international adjudications, reminds us once again that in the Fukushima incident, Japan has the duty to reasonably assess all the possible environmental impacts on other countries of such a worrisome activity as the discharge of Fukushima nuclear-contaminated water. Obviously, the questions and comments raised by China, Korea, and the Pacific Islands are potentially valid; however, in the absence of scientific certainty regarding the environmental safety of the discharge plan, Japan insists on proceeding with the plan rather than doing so after a proper transboundary EIA. Such recklessness *per se* constitutes a violation of the requirement of transboundary EIA and counters the precautionary principle and due diligence requirements in international environmental law. In addition, Japan has no intention of including potentially affected countries and their citizens when conducting EIAs, which is one of the major reasons for protests and criticisms.

3 Advancing proper EIAs in the Fukushima contaminated water discharge through international law

After considering the gap between the Japanese government's discharge activities and its EIA obligations under international law, we can conclude that Japan's discharge has raised concerns about its compliance with the UNCLOS, nuclear safety treaties, and international environmental laws. Although the international community has urged Japan to suspend the discharge plan until the environmental risks of Fukushima nuclear contaminated water discharge have been properly assessed, it seems unlikely that the Japanese government or TEPCO will revisit their decisions considering the current situation. In this context, this section systematically discusses the procedural and substantive requirements of international law for EIA implementation throughout the full process of discharge, and provides pathways and guidelines to be followed for possible discharge activities to reduce the risk of Fukushima water discharge from a realistic perspective.

3.1 Comprehensive assessments and information transparency of the discharge

In terms of Japan's EIA obligations concerning the discharge of the Fukushima contaminated water, treaties, customary international law, and general principles of law provide procedural and substantive requirements applicable in this incident. Simultaneously, it is equally necessary to ensure the transparency of the assessment and insert the principle of proportionality. It should be noted that this is not the same as what Japan is doing now, which is only measuring the content of some radioactive substances in the ALPS water to be discharged, but is a comprehensive assessment of the environmental impact.

24 ITLOS, Responsibilities and obligations of States sponsoring persons and entities with respect to activities in the Area, Advisory Opinion of 1 February 2011, para. 147.

25 ICJ, Certain Activities Carried Out by Nicaragua in the Border Area (Costa Rica v. Nicaragua), Judgment of 16 December 2015, para. 101.

26 ICJ, Certain Activities Carried Out by Nicaragua in the Border Area (Costa Rica v. Nicaragua), Judgment of 16 December 2015, para. 154-155.

27 ICJ, Certain Activities Carried Out by Nicaragua in the Border Area (Costa Rica v. Nicaragua), Judgment of 16 December 2015, para. 168.

28 Espoo Convention, Espoo, 25 February 1991, United Nations Treaty Series, Vol. 1989, No. 34028, p. 309, Art. 3 & 5. Available at https://treaties.un.org/doc/Publication/UNTS/Volume%201989/v1989.pdf.

3.1.1 Procedural and substantive requirements of the EIA

As discussed above, before each batch of the Fukushima nuclear contaminated water is discharged into the sea, Japan may have to adopt two types of EIAs for different purposes, according to international law.[29] The first type, or the "preliminary assessment," is designed to determine whether there is a risk of substantial pollution or significant environmental damage from the planned discharge activities that would necessitate a formal EIA process.

Even though the first type of EIA is referred to as the "preliminary assessment," it does not mean that no applicable criteria exist or that there is a very low bar that would allow Japan to easily claim that its planned discharge of the Fukushima water does not pose sufficient environmental risks to warrant a formal assessment. In terms of procedural requirements, there is no specific rule in international law that explicitly states that the "preliminary assessment' needs to follow one step or the other; therefore, Japan can decide this with a certain degree of flexibility.

In terms of substantive requirements, Japan is obligated under international law to include all possible environmental impacts of its discharge plan within the scope of the assessment and to set up appropriate steps to adequately examine whether these possible impacts will constitute a significant environmental risk, as defined in international documents (Popiel, 1994). In this process, Japan does have some freedom to decide what is a "possible" impact and what is not, and the latter does not need to be assessed. To prevent states from abusing this freedom, and prevent the slightest possibility of being exaggerated, the ICJ requires that such impacts be "reasonable." (Dong, 2022) Considering the general meaning of the term in the interpretation of international law, this means that speculation about the existence of certain impacts should be considered "reasonable" if it is consistent with logic and scientific common sense (Corten, 1999).

With this in mind, as we look at the challenges and criticisms raised by potentially affected states and international organizations, it is rather difficult to deny that their concerns about the potential environmental risks of Japan's discharge are "reasonable." For example, some opponents have argued that it is irresponsible for the Japanese government to claim that all radioactive elements in the Fukushima water other than tritium are at safe levels without adequate assessment, and the Fukushima nuclear-contaminated water may also contain large amounts of components that are harmful to humans (The Government of the PRC, 2021). Given the severity of the 2011 Fukushima nuclear accident and the limited design of Japan's ALPS systems, it is necessary for Japan to test all nuclear-contaminated water to be discharged to assess whether it may contain other radioactive elements that exceed this limit. In addition, the possible cumulative effects of nuclear-contaminated water containing radioactive elements that meet the discharge criteria should also be considered by the Japanese government.

As for formal EIA, the legal requirements to be observed by the Japanese government in this process are expected to be more stringent. First, the scope of the assessment includes, but is not limited to, the factors identified in the preliminary assessment. It should be noted that all factors identified in the preliminary assessment that possibly pose significant environmental risks should be further assessed at this stage to determine the "possible impacts" of the environmental damage from the discharge of Fukushima nuclear-contaminated water.[30] Neither international treaties nor international adjudication has emphasized the scope of implementation of the formal EIA, but the context has suggested that ignoring any risk identified in the "preliminary assessment" would be illogical and inconsistent with the purpose of preventing, mitigating, and controlling marine pollution in international treaties, customary international law, and general principles of law. Rather, as stipulated in the UNCLOS, Japan should conduct EIAs on all potential impact factors, "as far as practicable," which further suggests that the scope of the formal assessment should remain open to including all possibilities and not be limited to the scope of the "preliminary assessment."[31] Meanwhile, the expression "as far as practicable" mainly considers the special needs and limited capacity of developing countries, which cannot be used as an excuse to avoid or reduce the obligations of EIA for developed countries with greater capacity (Proelss, 2017). In contrast, Japan, as a developed country, is subject to higher requirements than developing countries.

It is also necessary to clarify the substantive criteria for the implementation of the EIA in the Fukushima accident. In the Mox Plant case, Ireland alleged that the United Kingdom's 1993 Environmental Statement was not a qualified EIA in violation of Article 206 of the UNCLOS.[32] In its separate opinion, Judge *ad hoc* Székely of the International Tribunal for the Law of the Sea (ITLOS), in dealing with Ireland's request for provisional measures, specifically considered the Environmental Statement as a superficial environmental impact statement that is wholly incompetent by any criteria: the document contains only the unilateral claims of the proponents establishing the nuclear fuel plant, without the most basic appropriate scientific or technical support; none of these claims have been independently verified; the document does not provide a specific assessment of the impact on the marine environment, the release or transport of radioactive material, etc.[33]

In addition, some authors note that the document should also include details of methods for dealing with radioactive discharges

29 According to the plan of the Government of Japan, each batch of ALPS treated water is different in terms of radioactivity equivalence and discharge arrangements, and therefore their environmental impacts may differ. This makes it necessary to properly fulfill the EIA obligations prior to each discharge.

30 UNCLOS, Art. 204.

31 UNCLOS, Art. 206.

32 ITLOS, The MOX Plant Case (Ireland v. United Kingdom), Provisional Measures, Order of 3 December 2001.

33 ITLOS, The MOX Plant Case (Ireland v. United Kingdom), Provisional Measures, Separate opinion of Judge *ad hoc* Székely.

and their alternatives, possible mitigation measures, data for assessing radioactive doses to key populations, a discussion of the radiological effects on marine life and ecosystems in Ireland, and special attention to gaps or uncertainties in the knowledge of marine biology (Tanaka, 2003). In other cases, the ICJ has also observed that the state should conduct the EIA with due diligence and tailor it to specific circumstances.[34]

3.1.2 Assuring information transparency and sufficient negotiation

Ensuring information transparency and sufficient negotiation with potentially affected states are also part of EIA's obligations under international law. According to UNCLOS Article 206, once a country has implemented an EIA, it is obligated to submit a report regardless of the outcome. In terms of how EIA reports are delivered, countries have two options: one is to publish the EIA report themselves or make it available to all countries individually; the other is to provide the report to a competent international organization, which in turn makes it available to all countries.[35]

As far as the content of the report is concerned, Japan should provide all the information produced in the EIA to the extent possible, although this should not constitute an undue adverse impact on its industrial and commercial secrets or national security. In this regard, given that the Convention does not provide a specific list of the content, relevant international documents can provide some assistance for the Fukushima incident. Annex II of the Espoo Convention provides a detailed list of information that should be provided in an EIA report at a minimum, including but not limited to (1) a description of the proposed activity and its purpose, (2) a description of reasonable alternatives to the proposed activity, as appropriate, (3) a description of the potential environmental impacts of the proposed activity and its alternatives, and (4) measures to reduce adverse environmental impacts.[36]

Furthermore, although Article 206 does not provide for interstate consultation, it is a by-product of the obligation to submit reports. Specifically, Japan is required to publish an EIA report not only to simply make the relevant information known to other countries, which is hardly meaningful, but also to enable other countries to express their opinions based on such information to monitor and promote the proper implementation of the EIA.

3.1.3 Applying the principle of proportionality

Finally, the principle of proportionality has become significant in international law. Countries worldwide not only agree that the principle of proportionality is a necessary limitation on the exercise of executive power by governments, but also accept it as an important constraint on the behavior of states under international law (Cottier et al., 2012). The EIA is not just a procedural requirement; its results should be fully considered in the decision-making process for the disposal of Fukushima nuclear-contaminated water in conjunction with the principle of proportionality. Given the critical and unshakable position of environmental health, biodiversity, and human rights in our international community, the environmental damage and risks identified by the assessment of the discharge plan must be prioritized under the "proportionality test" by the Japanese government as a basis for decision-making, along with other factors such as feasibility, economics, and reputational impacts.

3.2 Ensuring continuous monitoring and openness to adjustments during the discharge

Considering the Japanese government's recent positions and policies, it seems unlikely that suspending the implementation of its planned discharge of Fukushima water would be an option (Yamaguchi, 2023). From the perspective of legality in international law, this would be a violation of international law, assuming that Japan would hastily move forward with the implementation process without meeting its obligations. International law differs from domestic legal regimes, as there is no centralized authority that could force Japan to abandon its discharge plan, should it insist on doing so (Koskenniemi, 2017). Nevertheless, this does not mean that international law has failed. As noted, it can still contribute to regulating the discharge of Fukushima nuclear contaminated water and minimizing environmental risks by providing substantive and procedural rules.

In the Fukushima incident, the Japanese government's EIA for the discharge plan as well as for its implementation cannot be a one-time event; continuous monitoring, assessments, and timely adjustment to its policy on this ground are essential for marine environmental safety. Maintaining continuous monitoring of Fukushima's water discharge constitutes Japan's obligation under pertinent international treaties and customary laws. Regarding "monitoring of the risks or effects of pollution," the UNCLOS prescribes that "[i]n particular, States shall keep under surveillance the effects of any activities which they permit or in which they engage in order to determine whether these activities are likely to pollute the marine environment."[37]

Moreover, reports of the results obtained from such surveillance, according to Article 205, should be published or provided to "the competent international organizations, which should make them available to all States." The two articles, when read together, reveal that if the risks to the marine environment from the discharge of Fukushima nuclear-contaminated water into the sea remain, Japan is obligated not only to maintain continuous monitoring of factors that potentially cause damage but also to make the results public or report them to contracting states through international organizations. The monitoring and reporting obligations should, of course, be observed by Japan for the

34 ICJ, Pulp Mills on the River Uruguay (Argentina v. Uruguay), Judgment of 20 April 2010, para. 204.

35 UNCLOS, Art.205.

36 Espoo Convention, ANNEX 2.

37 UNCLOS, Art.204.

duration of the discharge - from 2023 to 2041 or 2051 as estimated - and even after the Fukushima water is fully discharged because the radioactive elements contained may still pose threats to the oceans. Considering the possible effects of ocean currents on the transport of radioactive elements in Fukushima water, the geographical scope of such continuous monitoring should not be limited to the waters under Japanese jurisdiction, but should extend to all potentially affected areas, indicating that Japan must work closely with relevant countries and national organizations to fulfill its obligations under international laws.

In addition to the requirement of continuous monitoring and information transparency, it is necessary to adjust the implementation of discharge plans accordingly. While emphasizing these obligations of conduct, it must be recognized that continuous monitoring is not conducive to the safety of the marine environment if Japan rejects the adjustment to its discharge plan accordingly. It is recalled that the requirements under the UNCLOS, nuclear safety treaties, and international environmental laws are intended to oblige states to achieve the result of minimizing damage to the marine environment. Therefore, it is necessary for Japan to remain open to adjustments of the discharge plan during the whole process and to take full account of the results of monitoring and evaluation for the purpose of minimizing the damage to the marine environment "as far as practicable."

3.3 Planning the complete restoration of marine ecology and full compensation for potential losses after the discharge

As mentioned above, Japan is obligated to conduct continuous and comprehensive EIAs prior to and during the discharge of Fukushima nuclear-contaminated water to develop preventive policies as well as to prevent, control, and reduce environmental damage and significant transboundary adverse impacts. In addition, EIAs can play an even more important role. Planning the complete restoration of marine ecology and full compensation for potential losses after discharge should be considered an integral step in the overall EIA process.

On the one hand, the Draft Articles on Responsibility of States for Internationally Wrongful Acts remind us that "[E]very internationally wrongful act of a State entails the international responsibility of that State."[38] An internationally wrongful act is a breach of an international obligation committed by a state, and it consists of two elements:

(a) There is conduct consisting of an action or omission attributable to the State under international law; (b) that conduct constitutes a breach of an international obligation of the State.[39]

It is noteworthy that Japan has violated several international obligations, including the duty to conduct EIA and international cooperation, prior to the implementation of its discharge plan; therefore, it is likely to be immediately subject to state responsibility to compensate affected countries and repair the damage if the discharge of nuclear contaminated is found to cause any transboundary environmental damage. Simultaneously, assuming that Japan's conduct is in accordance with international law, the rules of international law on transboundary damage liability provide that such liability need not be based on wrongfulness, but depends solely on the consequences of the damage (Sucharitkul, 1995). In other words, whenever any environmental damage is caused by the Fukushima water discharge, the state that is thus harmed can immediately claim transboundary damage from Japan in this regard.

On the other hand, the "polluter pays principle" refers to the duty of polluters who cause environmental damage to pay compensation and repair the damage. The Rio Declaration on Environment and Development clearly states the following:

National authorities should endeavor to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution.[40]

The "polluter pays principle" can be traced back as far as several conventions that prescribe responsibilities for damage caused by hazardous activities, and the original purpose of these conventions was to make the party that caused the result of the damage to compensate the victim (Luppi et al., 2012). The "polluter pays principle" suggests that the cost of pollution should be borne by those who cause it. The meaning of this principle and its application to cases and situations remain open to interpretation; however, there is no doubt that the principle is accepted in the domestic laws of almost all countries (Bugge, 2009). It should be noted that in the *Rhine Chlorides* case, the tribunal observed that the principle is embodied in several bilateral and multilateral international conventions and is enforced to varying degrees, but the tribunal did not consider it to be part of general international law.[41]

Nevertheless, regardless of whether the "polluter pays principle" applies in inter-state relations, at least in the case of the Fukushima nuclear contaminated water discharge, the principle can be applied to defend the rights and interests of coastal neighbors who may be severely affected by its pollution and suffer damage to their own interests. In fact, according to the domestic laws of the countries concerned, residents of the Fukushima coast and citizens of South Korea and China can file lawsuits against the Japanese government and TEPCO, either individually or in the form of a delegation, regarding the discharge of Fukushima nuclear-contaminated water.

38 Draft Articles on Responsibility of States for Internationally Wrongful Acts, Yearbook of the International Law Commission, 2001, vol. II (Part Two), Art. 1.

39 Draft Articles on Responsibility of States for Internationally Wrongful Acts, Art. 2.

40 Rio Declaration on Environment and Development, A/CONF.151/5/Rev.1, Principle 16.

41 PCA, The Rhine Chlorides Arbitration concerning the Auditing of Accounts (The Netherlands/France), Award (English Translation)of 13 May 2014, para. 103.

According to the international law regime, a proper EIA is not only required to determine potential damage, but also requires the parties to clarify possible preventive and remedial measures on that basis (Craik, 2008). In view of the potential claims for compensation, Japan should plan for the complete restoration of marine ecology and full compensation for potential losses in each phase of environmental impact assessment based on the assessment results, that is, the likelihood and severity of transboundary damage from the discharge. Although there are no specific rules to follow with respect to such preventive measures, some approaches common to environmental law can be considered. Specifically, the Japanese government may set up a special fund in advance for the payment of possible civil and interstate claims, which is not difficult considering Japan's financial capacity (ISA, 2017). Furthermore, regarding possible problems including excess and cumulative effects of radioactive elements, it is necessary for Japan to develop a viable contingency plan so that the adverse environmental effects can be effectively eliminated or mitigated at that time.

Overall, the Japanese government's decision to discharge post-accident nuclear contaminated water into the sea has no precedent in human history. However, the current system of international law still demonstrates its applicability and extensibility, providing a series of rules and guidelines for the necessary EIA procedures to be applied. Nevertheless, we also note that a considerable number of rules are too general or vague to fully address the complex legal issues related to EIAs in the Fukushima incident and do not demonstrate sufficient enforceability. It is necessary for the international community to consider from a long-term perspective, jointly develop the legal regime, and establish effective mechanisms for international cooperation to effectively implement EIAs and prevent potential damage from the disposal of post-accident nuclear contaminants.

4 Constructing the EIA cooperative mechanism for the disposal of nuclear accident contaminants

While international law has provided Japan with procedures and substantive criteria for the proper implementation of the EIA concerning the discharge of Fukushima water into the sea, the ultimate settlement of the international dispute among relevant parties is a far more complex issue, including the approach to ensuring Japan's compliance with these requirements and establishing the reliability of the results of the EIA. This reflects the lack of cooperation and mutual trust among states and its causes as the Fukushima incident has developed to date, which has triggered international disputes and weakened the potential of the international community's co-governance on this common problem. Therefore, it further proposes that, given the risk of nuclear accidents in the future, it is necessary for states to establish a collaborative EIA mechanism of a permanent nature to address related issues arising from the disposal of nuclear contaminants post-accidents.

4.1 Reflections on the international legal framework for EIAs on the disposal of nuclear accident contaminants

4.1.1 Dysfunction of the international legal framework

In the Fukushima incident, although international legal documents and general laws provided the legal framework as well as some specific requirements for the EIA, as discussed above, the rules in the paper failed to work as well as they should. Ever since the discharge plan was announced, Japanese citizens, potentially affected states, and international organizations have expressed strong criticism toward the Japanese government's decision. The essential dispute mainly lies in whether the Fukushima water planned to be discharged meets environmental standards and what potential effects it has on the marine environment. Even though the risks of Fukushima nuclear contaminated water to the marine environment, biodiversity, and human health have not been scientifically confirmed, the international community's concerns do not appear to be unfounded.

In fact, shortly after the Fukushima nuclear accident, TEPCO discharged 11,500 tons of nuclear-contaminated water directly into the sea without reporting or negotiating with potentially affected countries and the public, the radioactivity of which exceeded Japan's domestic law standards on nuclear water discharge by tens of times (CNN, 2011). Consequently, within 57 days, the radiation would spread to most of the Pacific Ocean (GEOMAR Helmholtz Centre for Ocean Research Kiel, 2012). After the Japanese government officially announced its discharge plan, TEPCO released in 2022 that the concentration of strontium-90 was found to be about three times the national standard value during testing, and it was defended as a temporary phenomenon, but its cause remains unreported (Global Times, 2022). Experts from Japan also noted that more than 60 percent of Fukushima water contains excessive radioactive substances, and it is doubtful whether they can be effectively removed. Moreover, the Japanese media reported multiple times that fish with excessive radioactive elements were found in neighboring waters (China Nuclear Power Website, 2022).

Nevertheless, Japan unilaterally decided and promoted the discharge of Fukushima nuclear-contaminated water into the sea under the circumstances of inadequate EIA, non-transparent information, and existing bad records, which sparked a lot of opposition in the international community. At the 31st Meeting of States Parties to the UNCLOS, China vehemently criticized that the Japanese side did not fully consult with stakeholders, including neighboring countries, and did not seriously respond to the concerns of all parties, let alone address them. More importantly, the Japanese government has failed to ensure that information is transparent and reliable, especially that provided unilaterally by the TEPCO (Greenpeace, 2020). Similarly, the Republic of Korea states that Japan's plan to release nuclear-contaminated water into the sea poses a threat to the security of neighboring countries and the safety of the marine environment. Japan's unilateral decision without adequate consultation with potentially affected countries is

intolerable (Ministry of Foreign Affairs of the Republic of Korea, 2021). Countries including Russia and the Philippines, international organizations such as the Pacific Islands Forum (PIF), and non-governmental organizations such as Greenpeace have also explicitly expressed their concerns about the lack of proper assessment and opaque information about Japan's discharge plan.

Nevertheless, despite the Japanese government's discharge plan and its implementation having been found to be in violation of EIA obligations, Japan continues to press ahead with the discharge, which opponents have been unable to do anything about except repeatedly protest against. From this perspective, the established international legal framework for EIAs, which was once considered sound and strong, faced the challenge of difficult enforceability and lack of effectiveness during the Fukushima Incident.

4.1.2 Deficiencies of the international legal framework

Unlike the domestic law system, there is no centralized authority in international law that is responsible for compelling a state to fulfill its international legal obligations or bear international responsibility for an internationally wrongful act. The interaction between the subjects of international law, mainly states and international organizations, drives the implementation of international law and determines its effectiveness (Fitzmaurice, 1956). Furthermore, in the contemporary regime of international law, as the aversion of most members of the international community to unilateral coercion has deepened, international cooperation has become the dominant mode of such state interaction (Hofer, 2017). When further reflecting on the dysfunction of our international legal framework for EIAs in the Fukushima incident, we find that the reasons behind it may be complex, but two aspects related to international cooperation should be focused on.

On the one hand, the inter-state cooperation required by the legal framework between planning relevant activities and those potentially affected has not been fully achieved. In the Fukushima incident, Japan and most of the potentially affected parties have failed to cooperate; instead, they see each other as "adversaries" due to a lack of mutual trust and communication.

Since the beginning, the Japanese government and TEPCO have repeatedly emphasized that the radiation impact of the "treated water" stored in the tanks is extremely low, but they have not provided comprehensive information on the testing or assessment result of the potential environmental impacts (China Daily, 2022). However, because tanks storing the Fukushima water are located in Japanese territory and the discharge will take place in waters under Japanese jurisdiction, the opposition is not given an opportunity to obtain credible data and other evidence without the consent of the Japanese government and can only repeatedly express its apprehension. It has left the two sides in a stalemate: the opposing side continues to exert diplomatic pressure, while Japan tends to ignore it and sticks to the implementation of its discharge plan.

In this regard, it can be found that the root cause of the current disputes between Japan and opposing parties is the lack of mutual trust and necessary collaboration. On the one hand, the Japanese government has tried to prove to the international community the harmlessness of its discharge plan by submitting reports on the testing of nuclear-contaminated water and by IAEA endorsement (IAEA, 2022b). On the other hand, potentially affected states do not trust the information provided by the Japanese government, suspecting that it has not provided all the assessment results, and complaining that EIAs should include more factors and be conducted under effective supervision (The Government of the PRC, 2021).

The international legal framework for nuclear waste disposal is a topic that has been discussed for a long time (Spector and Shields, 1979; Swazo, 1996). So far, the IAEA has developed a guiding classification scheme for nuclear waste management, which includes, among other things, estimating the requirements for safe isolation time based on the radiotoxicity of the nuclear waste and determining the disposal method according to the degree of hazard (Ojovan and Steinmetz, 2022). The problem is that this guideline is not binding and its appropriateness for disposing of contaminants after a nuclear accident has not been demonstrated. In other words, there is an under-appreciated gap in international law between the disposal of nuclear waste generated during conventional activities, and the disposal of nuclear contaminants abnormally generated after a nuclear accident.

The lack of cooperation among all potentially affected parties is equally worrisome. As mentioned earlier, many countries, international organizations, and non-governmental organizations have expressed deep concern for or protested the Japanese government's decision to discharge Fukushima water into the sea in a frank manner. Each has different or the same views on how the EIA on Japan's discharge plan should be conducted, but communication and collaboration have not been sufficiently achieved.

For the relevant parties, this singular fight is detrimental. Their concerns can easily be ignored, as a lone protest does not put enough pressure, including "the reputational and direct sanctions," on the Japanese government, let alone elicit the reconsideration of the implementation of the EIA prior to the discharge (Guzman, 2022). For Japan, this lack of cooperation may also be troubling. This is because the Japanese government must deal with pressure from each side separately, where different suggestions, claims, and complaints are presented, not only increasing the difficulty of the task of information sharing but also consuming more resources. This situation makes it likely that the Japanese government will be confused about the specific items on its "need-to-be-resolved" list.

In other words, while established international law on EIA has provided the international community with the framework and specific requirements of the Fukushima incident, the flaws in the design of the cooperative mechanism became a source of undermining mutual trust and reducing the effectiveness of the rules. Therefore, the issue of how to achieve healthy interaction among states to facilitate the proper implementation of EIA in this incident now and in the future is extremely critical.

4.2 Turning crisis into opportunity: toward a collaborative EIA mechanism with multi-stakeholder participation

Japan and potentially affected states are at odds with the EIA of Fukushima nuclear contaminated water discharge, and it is expected that the dispute may intensify as Japan's discharge plan enters the implementation phase. The EIAs conducted and the information provided by the Japanese government is not sufficient to dispel the relevant parties' concerns on environmental safety. In this case, while international treaties, customary international law, and general principles of international law provide some procedural and substantive rules to oblige Japan to fulfill its EIA obligations, the authority in the house of international law is the state, after all (Sohn, 1995[405-406]). As in so many moments in history, "law is not enough," and the effectiveness of international law ultimately depends on the decisions and actions of states (Sohn, 1995[399]). It is more difficult to concretize general rules in international law to induce the relevant states to properly implement their obligations than to formulate and identify rules.

Japan's plan to release Fukushima nuclear contaminated water is the first attempt in human history to discharge post-accident nuclear contaminants into the sea, but it will likely not be the last, especially with the precedent set by the Japanese government. This has forced international lawyers and all researchers concerned with the safety of the marine environment to consider how the EIA can be made more effective in practice to avoid or minimize environmental risks. From a more general perspective, we should be aware that the Fukushima incident not only poses a major crisis for the marine environment and inter-state relations, but also provides a valuable opportunity for the international community to revisit the issue of the EIA of post-accident nuclear contaminant disposal. To make EIA and transboundary EIA effectively contribute to marine environmental protection, the international law framework needs to be improved through the development of treaties or soft laws. Perhaps more importantly, given the problems and disputes exposed in the Fukushima incident, it is necessary to establish a cooperative EIA mechanism of a permanent nature to respond appropriately to future nuclear accidents that are probable to occur as long as there are nuclear installations in operation.

Regarding membership under the envisaged mechanism, it is obvious that countries, especially those with deployed nuclear facilities, should be included, and potentially affected countries, such as small island states and those with long coastlines, should also be given significant consideration. It is also necessary for international organizations, including the IAEA, the International Food and Agriculture Organization (FAO), the World Health Organization (WHO), the International Maritime Organization (IMO), and the United Nations Human Rights Council (UNHRC), to be included as formal members. This is partly because of their essential position in current international environmental governance in terms of intellect, policy, law, etc., and partly to help more countries that have not yet decided to join the mechanism to contribute indirectly to nuclear and environmental security. In addition, representatives of NGOs and citizen groups with an interest in the subject should consider granting informal membership or observer status to support and monitor the operation of the mechanism (Vance and Rangeley, 2019). In particular, the presence and expression of the views of representatives from potentially affected areas should be considered necessary when specific events occur.

In terms of purpose and function, the envisaged mechanism among states and international organizations may contribute transparency, credibility, and accountability to the more appropriate and effective EIA of contaminant disposal post-nuclear accident. However, it should be recognized that attempts to set overly detailed binding rules may make countries more hesitant to join, as issues related to nuclear energy use and regulation have always been considered to be of great relevance to national security and national interests. In general, a more prudent and feasible design for the positioning of the envisaged mechanism, especially in the initial stage, is regarding it as a platform for political negotiation/consultation to advance the proper EIA under a framework agreement that reaffirms existing EIA obligations and international cooperation obligations under international law, without expecting to prescribe too many specific normative requirements once and for all. Of course, during the operation of the collaborative mechanism, relevant treaties as well as customary international law may be developed according to the needs and practices of states.

To be specific, first, the collaborative mechanism should aim at promoting information transparency on the process and results of EIAs. Regarding acts that potentially cause transboundary environmental damage, international law imposes an obligation of international cooperation with potentially affected states and a strict obligation of environmental impact assessment on the state concerned.[42] In view of the concerns and worries that nuclear contaminant disposal, especially in the form of discharge into the sea, vapor emissions, etc., may increase in the international community, it would be responsible for including potentially affected states and major international organizations whose purposes are relevant in the EIA decision and implementation process. The involvement of relevant parties helps them obtain credible information and remove concerns so that they can adjust their policies accordingly.

Second, as discussed above, during the Fukushima Incident, much of the distrust of the Japanese government stemmed from a lack of involvement in its EIAs. In this sense, the proper use of the collaborative mechanism can significantly improve the current lack of mutual trust. On the one hand, the envisioned mechanism could include potentially affected states in the decision and design process prior to the implementation of the EIA. This allows the relevant parties to better understand the decision-making process related to the disposal of nuclear contaminants. Meanwhile, sufficient cooperation will enable all parties to present their views on the scope and modalities of EIAs under the mechanism and to fully consult on them, avoiding reasonable concerns from being ignored, and effectively strengthening the comprehensiveness and scientific nature of the assessment. On the other hand, this mechanism allows EIAs to be conducted under adequate supervision, increases the credibility of the data produced and the conclusions drawn from them, and prevents countries from questioning the reliability of EIAs that have been conducted for reasons such as "prior convictions."

42 UNCLOS, Art. 197-206.

Finally, international cooperation will greatly enhance the capability of the EIA and help prevent and reduce environmental damage from the disposal of nuclear contaminants more accurately and effectively. The technology capability and resources that an individual state can devote to EIAs are limited, especially when considering the testing, monitoring, and assessment of such hazardous substances as post-accident nuclear contaminants. Simultaneously, considering the influence of ocean currents, trade winds, and other factors, EIAs are often conducted not only within a state's jurisdictional areas, but can also extend to a regional or even global scale (Bastmeijer, 2008). This significantly increases the difficulty of implementing a proper EIA. In this sense, collaborative mechanisms may help solve these real problems (Xu and Tan, 2023). All parties participating in the mechanism are encouraged or required, if they agree, to aid with EIA, including technical assistance, resource and personnel support, and jurisdictional facilitation.

After discussing the establishment of the collaborative mechanism to advance EIAs on the disposal of post-accident nuclear contaminants and reviewing the Fukushima incident and intractable disputes between countries, it can be seen as an opportune time to launch such a mechanism. Given that excessive disagreement has put the settlement of the dispute concerning the discharge of the Fukushima water into limbo, it is necessary and motivating for the states involved to consider finding another way out. In this context, an initiative to establish a collaborative mechanism under a general framework, with a vision of addressing immediate and longer-term challenges, may be a wiser choice for both potentially affected countries, Japan, and national organizations, other than to continue to blame each other under the circumstance that international rules are not sufficiently specific and sound. The collaborative mechanism is expected to be a valuable and necessary platform for relevant countries to move toward effective negotiation and resolution of current and future differences, especially when considering the decades-long monitoring and evaluation required for the discharge of Fukushima nuclear-contaminated water (TEPCO, 2022).

5 Conclusion

The Japanese government's decision to discharge contaminated water from the 2011 Fukushima nuclear accident into the sea sparked widespread protests and criticism as soon as it was announced. Much of the international community's concerns stem from the inadequacy and unreliability of Japan's EIA in its release plan. Although there has been no sufficient scientific evidence to prove the damage of the release of the Fukushima water to the marine environment and human health, it raises concerns about the conformity between Japan's discharge and its EIA obligations under the law of the sea, international laws on nuclear safety, and international environmental laws, as it has not properly included all potential impacts to the extent of its best capability, and the EIA was not conducted in accordance with the due diligence and proportionality principles.

Given Japan's insistence on promoting the implementation of its discharge plan, the constraints and guidelines of the EIA obligations under international law for the various stages of discharge can contribute to the prevention and mitigation of potential environmental risks. The preliminary assessment or/and further formal assessment of all reasonable factors discovered is necessary for the discharge of each batch of treated water, and the obligation to cooperate with and notify relevant countries and international organizations should be considered. The rules of international law require Japan to maintain continuous monitoring and transparency of information during the discharge and adjust the discharge plan according to the results of the assessment. Considering the uncertainty of the impact of discharge and the geographical scope potentially affected, Japan is required to plan the complete restoration of marine ecology and full compensation for potential losses caused by the discharge in advance.

It is observed that the current legal regime offers applicable rules for Fukushima contaminated water discharge, but is far from being adequately specific to clarify all the ambiguities, and it fails to provide a suitable cooperative mechanism, which has led to disagreements and disputes between countries on this environmental impact assessment. Nevertheless, Fukushima provides a valuable opportunity for the international community to reflect on existing rules and develop them to better address the treatment of nuclear contaminants after a nuclear accident, which is not only happening now but will almost certainly cause problems in the future. In this regard, we propose that a collaborative mechanism incorporating national and international organizations, and citizen representatives is necessary to promote transparency, credibility, and scientific validity of EIAs and to enhance the limited capacity of the individual state. To achieve this common vision, all countries must work with solidarity to effectively safeguard the shared interests of the international community, avoid politicization of relevant issues, and ultimately achieve a proper solution to the issue.

Author contributions

XC: Conceptualization, Formal analysis, Writing – original draft. QX: Funding acquisition, Methodology, Project administration, Supervision, Writing – original draft.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This article is funded by National Social Science Foundation Project No. 21&ZD244, National Social Science Foundation Project No. 218ZD226 and Fundamental Research Funds for the Central Universities Project No. 23JNQN04.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Anzai, K., Ban, N., Ozawa, T., and Tokonami, S. (2011). Fukushima daiichi nuclear power plant accident: facts, environmental contamination, possible biological effects, and countermeasures. *J. Clin. Biochem. Nutr* 50 (1), 2–8. doi: 10.3164/jcbn.D-11-00021

Bastmeijer, C. J. (2008). *Theory and practice of transboundary environmental impact assessment* Vol. Vol. I (Leidon: Martinus Nijhoff Publishers).

Bugge, H. C. (2009). "The Polluter Pays Principle: Dilemmas of Justice in National and International Contexts." in *Environmental Law and Justice in context*, 1st ed., ed. by J. Ebbesson and P. Okowa. (Cambridge: Cambridge University Press), 411–428. doi: 10.1017/CBO9780511576027.022

Chen, X., and Xu, Q. (2022). Reflections on international dispute settlement mechanisms for the Fukushima contaminated water discharge. *Ocean Coast. Manage.* 226, 106282. doi: 10.1016/j.ocecoaman.2022.106278

China Daily (2022) *Safety first must be priority for Fukushima water: China Daily editorial*. Available at: https://global.Chinadaily.com.cn/a/202211/23/WS637e2ecaa31049175432b7ec.html (Accessed 10 November 2023).

China Nuclear Power Website (2022) *IAEA working group revisits Fukushima*. Available at: https://lite-ra.com/2021/04/post-5852_2.html (Accessed 10 November 2023).

CNN (2011) *Japan official apologizes for dumping radioactive water into Pacific*. Available at: http://edition.cnn.com/2011/WORLD/asiapcf/04/04/Japan.nuclear.reactors/index.html (Accessed 10 November 2023).

Corten, O. (1999). The notion of "reasonable" in international law: legal discourse, reason and contradictions. *Int. Comp. Law Q.* 48, 613–625. doi: 10.1017/S0020589300063454

Cottier, T., Echandi, R., Leal-Arcas, R., Liechti-McKee, R. G., Payosova, T., Sieber-Gasser, C., et al. (2012). "The principle of proportionality in international law," in *NCCR Trade Regulation Working Paper*.

Craik, N. (2008). *The international law of environmental impact assessment: Process, substance and integration* (New York: Cambridge University Press), 161–174.

Dong, S. (2022). Study of marine environmental impact assessment of Fukushima's nuclear wastewater. *Pacific J.* 30, 87–89.

Elbaradei, M., Nwogugu, E., and Rames, J. (1995). International law and nuclear energy: Overview of the legal framework. *IAEA Bull.* 37, 16–25.

Fitzmaurice, G. G. (1956). The foundations of the authority of international law and the problem of enforcement. *Modern Law Rev.* 19, 1–13. doi: 10.1111/j.1468-2230.1956.tb00340.x

GEOMAR Helmholtz Centre for Ocean Research Kiel. (2012). *Fukushima - The fate of contaminated waters*. Available at: https://www.geomar.de/en/news/article/fukushima-the-fate-of-contaminated-waters (Accessed 10 November 2023).

Global Times. (2022). *The sea is not Japan's dustbin, nor the Pacific Ocean its sewer: Chinese FM*. Available at: https://www.globaltimes.cn/page/202209/1275581.shtml (Accessed 10 November 2023).

Gold, E. (2006). *Gard Handbook on Protection of the Marine Environment* Vol. 64. Ed. E. Gold (Arendal, Norway: Gard AS).

Greenpeace (2020) *Contaminated Water Crisis*. Available at: https://www.greenpeace.org/static/planet4-Japan-stateless/2020/10/ba82306e-radioactivewater_jp_fin.pdf (Accessed 10 November 2023).

Greenpeace East Asia (2021) *A Quick Read on the radioactive water in Fukushima - What makes it different?* Available at: https://www.greenpeace.org/eastasia/blog/6540/a\-quick-read-on-the-radioactive-water-in-fukushima-what-makes-it\-different (Accessed 10 November 2023).

Guzman, A. T. (2022). A compliance-based theory of international law. *Calif. L. Rev.* 90, 1823–1888.

Hofer, A. (2017). The developed/developing divide on unilateral coercive measures: legitimate enforcement or illegitimate intervention? *Chin. J. Int. Law* 16, 175. doi: 10.1093/chinesejil/jmx018

IAEA. (2011). *Fukushina Nuclear Accident Update*. Available at: https://www.iaea.org/newscenter/news/fukushima-nuclear-accident-update-log-15#:~:text=The%20Japanese%20Nuclear%20and%20Industrial%20Safety%20Agency%20%28NISA%29,as%20a%20level%207%20%22Major%20Accident%22%20on%20INES (Accessed 10 November 2023).

IAEA. (2022a). *Fukushima Daiichi Status Updates*. Available at: https://www.iaea.org/newscenter/focus/fukushima/status-update (Accessed 10 November 2023).

IAEA. (2022b). *IAEA Releases First Report on Safety of Planned Water Discharge from Fukushima Daiichi Site*. Available at: https://www.iaea.org/newscenter/pressreleases/iaea-releases-first-report-on-safety-of-planned-water-discharge-from-fukushima-daiichi-site (Accessed 10 November 2023).

IAEA. (2023). *Japan to release Fukushima water into ocean from Aug. 24*. Available at: https://news.un.org/en/story/2023/08/1140037 (Accessed 10 November 2023).

ISA. (2017). *Draft Regulations on Exploitation of Mineral Resources in the Area*. Available at: https://isa.org.jm/files/files/documents/25c-wp1-en-advance.pdf (Accessed 10 November 2023).

Kersten, C. M. (2009). Rethinking transboundary environmental impact assessment. *Yale J. Int. Law* 34, 173.

KFB (2021) 福島第一原発の設備でトラブル、汚染水の浄化処理を停止 *(Equipment problems at the Fukushima Daiichi nuclear power plant The purification process of contaminated water was stopped)*. Available at: https://www.yomiuri.co.jp/science/20210902-OYT1T50278/#:~:text=%E6%9D%B1%E4%BA%AC%E9%9B%BB%E5%8A%9B%E3%81%AF%EF%BC%92%E6%97%A5%E3%80%81,%E3%81%84%E3%82%8B%E3%81%A8%E7%99%BA%E8%A1%A8%E3%81%97%E3%81%9F%E3%80%82 (Accessed 10 November 2023).

Knox, J. H. (2002). The myth and reality of transboundary environmental impact assessment. *Am. J. Int. Law* 96, 291–319. doi: 10.2307/2693925

Koh, T. (1982) *Remarks by Tommy T.B. Koh, of Singapore President of the Third United Nations Conference on the Law of the Sea*. Available at: https://cil.nus.edu.sg/wp-content/uploads/2015/12/Ses1-6.-Tommy-T.B.-Koh-of-Singapore-President-of-the-Third-United-Nations-Conference-on-the-Law-of-the-Sea-_A-Constitution-for-the-Oceans_.pdf (Accessed 10 November 2023).

Koskenniemi, M. (2017). *The politics of international law* (Routledge: The Nature of International Law), 355–384.

Luppi, B., Parisi, F., and Rajagopalan, S. (2012). The rise and fall of the polluter-pays principle in developing countries. *Int. Rev. Law Econ.* 32, 135–144. doi: 10.1016/j.irle.2011.10.002

Men, W. (2021). Discharge of contaminated water from the Fukushima Daiichi Nuclear Power Plant Accident into the Northwest Pacific: What is known and what needs to be known. *Mar. pollut. Bull.* 153, 112984–112987. doi: 10.1016/j.marpolbul.2021.112984

Ministry of Foreign Affairs of the PRC (2021) *Foreign Ministry Spokesperson Wang Wenbin's Regular Press Conference on June 11, 2021*. Available at: https://www.fmprc.gov.cn/mfa_eng/xwfw_665399/s2510_665401/t1883214.shtml (Accessed 10 November 2023).

Ministry of Foreign Affairs of the Republic of Korea (2021) *Japanese Government Provides Answer to ROK's Note Verbale Regarding Former's Position on Disposal of Treated Water at Fukushima Daiichi Nuclear Power Station*. Available at: https://www.mofa.go.kr/eng/brd/m_5676/view.do?seq=320650&srchFr=&amp%3BsrchTo=&amp%3BsrchWord=&amp%3BsrchTp=&amp%3Bmulti_itm_seq=0&amp%3Bitm_seq_1=0&amp%3Bitm_seq_2=0&amp%3Bcompany_cd=&amp%3Bcompany_nm (Accessed 10 November 2023).

Nandan, S. N., and Rosenne, S. (1995). *United nations convention on the law of the sea 1982: A commentary* Vol. Vol.II (Boston: Martinus Nijhoff), 122.

NHK (2021) *Undersea tunnel planned to release treated water*. Available at: https://www3.nhk.or.jp/nhkworld/en/news/20210824_24/ (Accessed 10 November 2023).

Ojovan, M. I., and Steinmetz, H. J. (2022). Approaches to disposal of nuclear waste. *Energies* 15 (20), 7804. doi: 10.3390/en15207804

Pallemaerts, M. (2014). *International environmental law from Stockholm to Rio: Back to the future?* (Routledge: Greening International Law), 1–19.

Popiel, B. R. (1994). From customary law to environmental impact assessment: A new approach to avoiding transboundary environmental damage between Canada and the United States. *BC Envtl. Aff. L. Rev.* 22, 447.

Preiss, E. L. (1999). The international obligation to conduct an environmental impact assessment: The ICJ case concerning the Gabcikovo-Nagymaros project. *NYU Envtl. LJ* 7, 307.

Prime Minister of Japan and His Cabinet (2021a) *Basic Policy on handling of ALPS treated water at the Tokyo Electric Power Company Holdings' Fukushima Daiichi Nuclear Power Station*. Available at: https://www.ca.emb-Japan.go.jp/2021_shared_images/Basic_Policy_on_Handling_of_ALPS_treated_water.PDF (Accessed 10 November 2023).

Prime Minister of Japan and His Cabinet (2021b) *Meeting of Ministers, etc. on Nuclear Decommissioning, Contaminated Water and Treated Water Countermeasures (5th)*. Available at: https://www.kantei.go.jp/jp/singi/hairo_osensui/dai5/index.html (Accessed 10 November 2023).

Proelss, A. (2017). *United Nations Convention on the Law of the Sea. A Commentary*. Ed. C. H. Beck. (Munich, Germany: Verlag C. H. Beck oHG, Wilhelmstraße), 1278–1375.

Rajamani, L., and Peel, J. (2021). *The Oxford handbook of international environmental law* (New York: Oxford University Press), 454–463.

Reuters, (2023) *Japan to release Fukushima water into ocean from Aug. 24*. Available at: https://www.reuters.com/world/asia-pacific/Japan-release-fukushima-water-into-ocean-starting-aug-24-2023-08-22/ (Accessed 10 November 2023).

Ryall, J. (2022) *Radioactive rockfish caught near Fukushima nuclear plant prompts Japan to suspend shipments*. Available at: https://www.scmp.com/week-asia/health-environment/article/3166415/radioactive-rockfish-caught-near-fukushima.

Sohn, L. B. (1995). Sources of international law. *Ga. J. Int'l Comp. L* 25, 399–406.

Spector, L. S., and Shields, G. B. (1979). Nuclear waste disposal: an international legal perspective. *Nw. J. Int'l L. Bus* 1, 569.

Sucharitkul, S. (1995). State responsibility and international liability under international law. *Loy. LA Int'l Comp. LJ* 18, 821–822.

Swazo, S. (1996). The future of high-level nuclear waste disposal, state sovereignty and the tenth amendment: Nevada v. Watkins. *Natural Resour. J.* 36 (1), 127–144.

Tanaka, M. (2003). Lessons from the protracted MOX plant dispute: A proposed protocol on marine environmental impact assessment to the United Nations convention on the law of the sea. Mich. *J. Int'l L* 25, 418–419.

TEPCO. (2020). *TEPCO Releases Report on Treated Water Disposal*. Available at: https://www.tepco.co.jp/en/hd/newsroom/reports/archives/2020/pr20200327-e.html (Accessed 10 November 2023).

TEPCO. (2022). *Our Responsibilities to Fukushima*. Available at: https://www.tepco.co.jp/en/hd/responsibility/index-e.html (Accessed 10 November 2023).

The Government of the PRC (2021) *Fukushima nuclear contaminated water discharged into the sea has endless consequences*. Available at: http://www.gov.cn/xinwen/2021-05/17/content_5607536.htm (Accessed 10 November 2023).

Vance, A., and Rangeley, R. (2019). *Non-Governmental Organization Roles in Shaping Future Ocean Governance and Management. In The Future of Ocean Governance and Capacity Development* (Boston: Brill Nijhoff), 53–58.

World Nuclear Association (2022) *Fukushima Daiichi Accident*. Available at: https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-daiichi-accident.aspx (Accessed 10 November 2023).

Xu, Q., and Tan, Z. (2023). Building a maritime community with a shared future: Scholarly reflections on China's new ocean vision. *Mar. Policy* 149, 105508. doi: 10.1016/j.marpol.2023.105508

Yamaguchi, M. (2017) *Nuclear plant must release contaminated water*. Available at: https://Japantoday.com/category/national/nuclear-plant-must-release-contaminated-water?comment-order=latest (Accessed 10 November 2023).

Yamaguchi, M. (2023) *Fukushima nuclear plant operator says first round of wastewater release is complete*. Available at: https://abcnews.go.com/International/wireStory/fukushima-nuclear-plants-operator-round-wastewater-release-complete-103084731 (Accessed 10 November 2023).

Yang, T. (2018). The emergence of the environmental impact assessment duty as a global legal norm and general principle of law. *Hastings LJ* 70, 525.

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 12 March 2024
DOI 10.3389/fmars.2024.1364554

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Sami Ur Rahman,
Shifa Tameer-e-Millat University, Pakistan
Malieka Farah Deeba,
Ibadat International University, Pakistan

*CORRESPONDENCE
M. Jahanzeb Butt
jahanzebbutt1988@gmail.com

†These authors have contributed equally to this work and share first authorship

RECEIVED 02 January 2024
ACCEPTED 23 February 2024
PUBLISHED 12 March 2024

CITATION
Zhang S, Wu Q, Butt MJ, Lv Y-M and Wang YE (2024) Coastal cities governance in the context of integrated coastal zonal management: a sustainable development goal perspective under international environmental law for 'coastal sustainability'. *Front. Mar. Sci.* 11:1364554. doi: 10.3389/fmars.2024.1364554

COPYRIGHT
© 2024 Zhang, Wu, Butt, Lv and Wang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Coastal cities governance in the context of integrated coastal zonal management: a sustainable development goal perspective under international environmental law for 'coastal sustainability'

Shijun Zhang[1†], Qian Wu[1†], M. Jahanzeb Butt[1*], Yan-Ming Lv[2] and Yan-E-Wang[2]

[1]Institute of Eco-Environmental Forensics, Economic and Environmental Research Institute, School of Law, Shandong University, Qingdao, Shandong, China, [2]Department of Justice, Qingdao Maritime Court, Qingdao, China

Literature on integrated coastal zonal management (ICZM) for coastal sustainability from a legal perspective provided significant measures. Recently, sustainable development goals (SDGs) have become a focus in ICZM literature, which establishes coastal goals and connects these goals with other goals. Although integrating coastal goals into ICZM under international law challenges the existing models presented in the literature, the comprehensive literature review (CLR) methodology is appropriate for observing the current literature and provides a way-forward for coastal goals. Therefore, through this research, a CLR on ICZM literature is conducted to observe how far SDGs are integrated for coastal sustainability. The CLR identified that coastal city governance is a pertinent part of ICZM, and the coastal goals are devised in the form of environmental goals of SDG – 14 (life below water). This CLR examines the anthropogenic connections of waste, sanitation, and emissions management and urban planning with coastal ecosystems under the ICZM system. For such purposes, governance tools of science-policy integration under international law and policy for sustainable development are utilized to form an obligatory framework. The CLR further provided coordination, adaptivity, monitoring, and capacity-building tools, which were utilized thoroughly throughout the literature and can be incorporated with the SDGs in a multilevel governance framework of ICZM. Throughout the study, international law formulating SDGs is pivotal to be transplanted successfully into the ICZM governance processes.

KEYWORDS

Integrated Coastal Zonal Management (ICZM), International Environmental Law (IEL), Sustainable Development Goal - 14 (SDG - 14), coastal cities governance, science-policy, legal framework

1 Introduction

The coastal areas (including coastal cities) serve as ecosystems between terrestrial and marine environments. Due to such transactions between ocean and land, coastal cities are impacted by pollution in both terrestrial and marine ecosystems. Atmospheric pollution (or climate change) is causing sea-level rise, which may lead to coastal flooding and ocean acidification Caffyn and Jobbins, 2003). Moreover, due to such pollution, fisheries are under severe threat, and water quality in the oceans is deteriorating. This is mainly because of inefficient governance of waste and sewerage in coastal cities, which is a significant challenge for coastal sustainability Caffyn and Jobbins, 2003). The coastal cities as ecosystems face different combinations of problems, but in particular, attention is given to the marine environment, fisheries preservation, and coral reefs (Gonzalez-Bernat and Clifton, 2017).

Albeit, in some ways, the ongoing tradeoffs between increasing population and the utilisation of more coastal regions question the sustainability of coastal cities (Sekovski et al., 2012). With this comes the need to address the governance challenges in the coastal cities. The differences in the aforementioned governance mechanisms are significant in coasts because collectively, such mechanisms affect the substance of what governance does, how governance actors do it, and what is governed for the sustainability of coastal cities (Cicin-Sain, 1993). In this scenario, governing coastal cities is complex, multiple, anthropogenic, and compoundable.

The latest Sustainable Development Agenda 2030 (also known as Sustainable Development Goals or SDGs) is helpful for the further development of Integrated Coastal Zone Management (ICZM) systems Hutton et al., 2018). A legal framework under international law can be adopted to govern coastal cities to mitigate land-based and atmospheric pollution and operationalize the SDGs in the ICZM systems (Islam and Shamsuddoha, 2018). Most of the research in this context suggests that land-based pollution mainly emerges from the coastal cities in the form of waste, sewerage, and industrial effluents, and atmospheric pollution consists of contamination of air due to combustion engines (including motor vehicles, industry, and shipping) (Liang and Li, 2020).

A variety of literature exists on the impacts of coastal cities' governance on coastal sustainability with ICZM, governance, and management perspectives (Gonzalez-Bernat and Clifton, 2017). However, a smaller amount of literature exists on the legal perspectives of ICZM with SDG advancements. Perhaps one of the reasons behind such scarcity is the lack of legal (academic) experts on the subject of coastal, ocean, and marine environmental governance (Knecht, 1994). Therefore, this research adopted a comprehensive literature review (CLR) methodology to review the existing literature on SDGs and the legal perspective of ICZM. The literature collected indicates what needs to be done and how to empower ICZM with SDGs and legal perspectives.

The CLR methodology is adopted in the next section, providing a firm basis for operationalizing international law in the context of ICZM for coastal sustainability. The methodology initially defined 'coastal sustainability' in the context of governing coastal cities in ICZM systems, selection criteria of the CLR have been presented, and selected research articles for this CLR are discussed in a manner that provided governance tools for evaluation of SDG – 14. The following sections take governance tools of science-policy, adaptivity, coordination, monitoring, and capacity-building as approaches in ICZM systems for coastal sustainability. Significant recommendations on international law and governance framework in ICZM systems for coastal sustainability follow the conclusion.

2 Methodology – CLR

A better method to achieve 'coastal sustainability' as a concept is the primary objective of this research. In this context, 'coastal sustainability' is defined in terms of Sustainable Development Goal – 14 (SDG – 14' life below water') (Zhang et al., 2023). The two coastal goals in SDG – 14 urged for sustainable management of coastal ecosystems to "avoid significant adverse impacts, including by strengthening their resilience, and act for their restoration, and conservation of at least 10 percent of coastal areas, consistent with national and international law and based on the best available scientific information" (Zulfiqar and Butt, 2021). The coastal goals in the context of SDGs invoke effective implementation of international law Waldmüller et al., 2019). Therefore, the citing literature or articles are collected depending upon the relative significance of each of the governance mechanisms impacting the sustainable development of the coastal cities under ICZM systems and international law.

Given the above, the methodology of CLR has utilized the terminologies of governance tools repeatedly reflected in ICZM systems. The governance tools in terms of SDGs are directly related to Sustainable Development Goal – 17 (SDG – 17' peace, justice, and strong institutions') and SDG – 14 to develop a framework for ICZM under international law (Colard-Fabregoule, 2020). A coordinated, cooperative, and consistent method has been presented connecting two coastal goals as demonstrated in SDG – 14: protecting complex ecosystems (including marine, terrestrial, and atmospheric environments) (Final list of proposed Sustainable Development Goal indicators, 2016; Gupta and Nilsson, 2017; Bartram et al., 2018). ICZM and the governance of coastal cities form an interconnected governance that seeks a combination or cohesion of various governance mechanisms at diverse levels and hierarchies (Kardos, 2012). The cited articles are replete with data on anthropogenic interconnections of the SDGs related to the coasts and the driving forces in the identified governance mechanisms (Tait and Lyall, 2017).

While examining the articles on regional and national ICZM systems, it became apparent that the pressure of interdependence of numerous authorities requires an integrated but flexible governance mechanism (Teampău, 2020). It is necessary to take into account international and local authorities and stakeholders if the sustainability of the coasts is to be achieved (Eisma et al., 2005; White et al., 2006). This research aims to develop a governance framework of interconnected SDGs in the context of coastal sustainability, which is impacted by the coastal cities. Therefore, the following two sub-sections of this section provide search criteria, selected or citing articles, and interconnected SDGs with coastal sustainability and governance tools of ICZM. The search

criterion is well defined in the following subsection, which adopts various keywords related to ICZM, coastal sustainability, and governance of coastal cities. The results produced through the methodology and its application on ICZM systems paved the way for further discussion, and it was concluded that a legal basis through a legal framework under international law for the implementation of ICZM is an obligation.

2.1 Selection criterion

The literature on ICZM provides a flexible and real-time solution-based approach to the governance of coastal cities Bin et al., 2009). ICZM recognizes that at national levels in any State, the policies are heterogeneous and rigid, which cannot be changed, and with thorough negotiations, a coordination mechanism can be developed to govern multiple authorities for sustainable development (Hatziolos, 1997). In this context, ICZM provides objectives with governance tools: coordination, monitoring, adaptivity, capacity building, law and policy, science and policy, and reporting and evaluation (Cicin-Sain et al., 1998).

The keywords initially employed in the search criteria (in the databases of Scopus and Web of Science) were 'law and policy' and 'science and policy' with 'ICZM' as a keyword/key term. After the initial search, it was analyzed that 'coastal sustainability' in the context of 'ICZM' and 'coastal cities sustainability' integrates the concepts of 'law,' 'policy,' and 'scientific knowledge' into one single framework for policy or rulemaking. Therefore, 'law and policy' and 'science and policy' concepts are integrated and applied in diverse forms such as 'ICZM for coastal sustainability,' 'governance of coastal cities,' 'law for ICZM,' and 'scientific information in ICZM.'

The selection process of the research articles is based on the governance tools provided by the ICZM. The literature selected with a search criterion of 'law' and governance tools of 'coordination,' 'monitoring,' 'adaptivity,' 'capacity building,' 'law and policy,' 'science and policy,' and 'reporting and evaluation' is presented in the ICZM systems repetitively (Nursey-Bray et al., 2014). Adding 'law,' 'sustainability,' and 'coasts' into ICZM provides the dimensional literature of SDGs integrating with 'law,' 'policy,' 'governance,' and 'ICZM' (Tobey et al., 2010). After reviewing numerous articles, fifty-six were selected for this CLR based on keywords. In the context of ICZM, it was discovered during the CLR that the two search criteria, 'coordination' and 'adaptivity,' reflect the intertwined elements in the context of the law. Similarly, 'monitoring,'' reporting' and 'evaluation' are organized horizontally and presented interconnectedly as core elements or ICZM under law. Therefore, the elements of ICZM were amalgamated as i) Coordination and Adaptivity, ii) Monitoring, Reporting, and Evaluation, and iii) Capacity Building to present the data in an improved format (Figure 1 and Table 1).

The primary reason for selecting and modifying the search criterion is to ensure that ICZM, law, and governance connect with coastal sustainability. The two coastal goals for sustainable development provide a requirement for novel means of governance in the context of ICZM. After thoroughly reading and analyzing various research articles, fifty-six were selected, and they discussed the multidimensions of ICZM for sustainable coastal development. From a legal perspective, only twelve articles are indicated through this CLR. In contrast, other articles identify complex challenges to the governance of coastal cities and their anthropogenic connections relating to SDGs.

2.1.1 Coordination and adaptivity

a. 39 Articles analyzed coordination and adaptivity as the primary tool of ICZM;

b. 42 Articles suggested that coordination and adaptivity are required for the sustainability of the coastal areas, including coastal cities;

c. 11 Articles emphasized the importance of legal mechanisms for coordination and adaptivity in the context of coastal sustainability;

d. 09 Articles suggested the operationalization of scientific information in the ICZM for coordination and adaptivity. As shown in Figure 2.

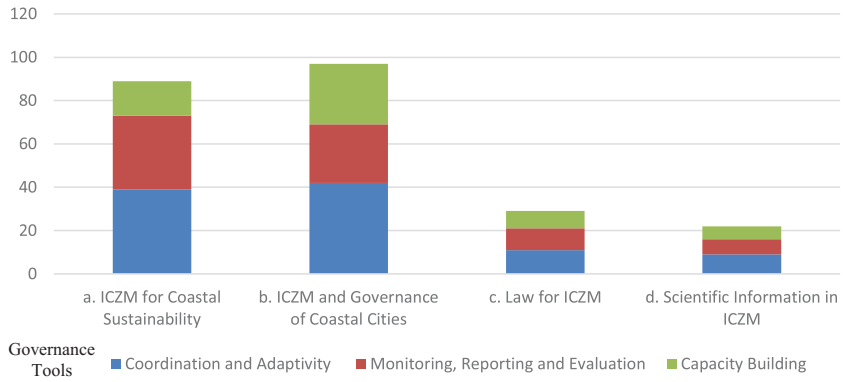


FIGURE 1
Search Criterion and No of Citing Literature in Accordance of the Given Values in terms of Governance Tools. CLR for this research and data provided in Table 1.

TABLE 1 Selected Literature for this CLR.

Sr no	Title	Journal	Year
1.	Implications of the Earth Summit for Ocean and Coastal Governance	Ocean Development & International Law	1993
2.	Implementing Agenda 21: oceans, coasts and the Barbados outcomes in the Pacific region	Ocean & Coastal Management	1995
3.	Canada's Atlantic Coastal Action Program: A community-based approach to collective governance	Ocean & Coastal Management	1997
4.	Considerations in Developing a Functional Approach to the Governance of Large Marine Ecosystems	Ocean Development & International Law	1999
5.	Using Stakeholder Decision-making Simulation to Teach Integrated Coastal Management	Journal of Geography in Higher Education	2001
6.	Governance Profiles and the Management of the Uses of Large Marine Ecosystems	Ocean Development & International Law	2001
7.	Governance Capacity and Stakeholder Interactions in the Development and Management of Coastal Tourism: Examples from Morocco and Tunisia	Journal of Sustainable Tourism	2003
8.	Indicators to measure governance performance in integrated coastal management	Ocean & Coastal Management	2003
9.	Improving science applications to coastal management	Marine Policy	2003
10.	Constructs of sustainability in coastal management	Marine Policy	2004
11.	Legal and Policy Dimensions of Coastal Zone Monitoring and Control: The Case in Ghana	Ocean Development & International Law	2004
12.	Integrated Coastal Management in Philippine Local Governance: Evolution and Benefits	Coastal Management	2006
13.	Network Governance and Policy Integration—the Case of Regional Coastal Zone Planning in Norway	European Planning Studies	2007
14.	Limits of governability: Institutional implications for fisheries and coastal governance	Marine Policy	2007
15.	The Role of Participatory Governance and Community-Based Management in Integrated Coastal and Ocean Management in Canada	Coastal Management	2007
16.	Principles for sustainable governance of the coastal zone: In the context of coastal disasters	Ecological Economics	2007
17.	Governing Coastal Spaces: The Case of Disappearing Science in Integrated Coastal Zone Management	Coastal Management	2007
18.	Facts, Fictions, and Failures of Integrated Coastal Zone Management in Europe	Coastal Management	2007
19.	Stimulating Vertical Integration in Coastal Management in a Federated Nation: The Case of Australian Coastal Policy Reform	Coastal Management	2009
20.	Fisheries and coastal governance as a wicked problem	Marine Policy	2009
21.	Overcoming Governance and Institutional Barriers to Integrated Coastal Zone, Marine Protected Area, and Tourism Management in Sri Lanka	Coastal Management	2009
22.	Governance of Marine Protected Areas in East Africa: A Comparative Study of Mozambique, South Africa, and Tanzania	Ocean Development & International Law	2010
23.	Assessing Progress Toward the Goals of Coastal Management	Coastal Management	2010
24.	Practicing Coastal Adaptation to Climate Change: Lessons from Integrated Coastal Management	Coastal Management	2010
25.	Megacities in the coastal zone: Using a driver-pressure-state-impact-response framework to address complex environmental problems	Estuarine, Coastal and Shelf Science	2012
26.	Integrated coastal zone management under authoritarian rule: An evaluation framework of coastal governance in Egypt	Ocean & Coastal Management	2012
27.	Implementing integrated coastal management in a sector-based governance system	Ocean & Coastal Management	2012
28.	Mobilising Knowledge for Coastal Governance: Re-Framing the Science–Policy Interface for Integrated Coastal Management	Coastal Management	2013
29.	Coastal and Ocean Governance in the Seas of East Asia: PEMSEA's Experience	Coastal Management	2013
30.	Enhancing the knowledge-governance interface: Coasts, climate and collaboration	Ocean & Coastal Management	2013
31.	The development of world oceans & coasts and concepts of sustainability	Marine Policy	2013
32.	England's evolving marine and coastal governance framework	Marine Policy	2014
33.	A sustainable development goal for the ocean and Coasts: Global ocean challenges	Marine Policy	2014

(Continued)

TABLE 1 Continued

(Continued)

TABLE 1 Continued

Sr no	Title	Journal	Year
	benefit from regional initiatives supporting globally coordinated solutions		
34.	Queensland's Coastal Planning Regime: The Extent of Participation in Coastal Governance	Planning Practice & Research	2014
35.	Drawing a line in the sand: managing coastal risks in the City of Cape Town	South African Geographical Journal	2015
36.	Impact of maritime transport emissions on coastal air quality in Europe	Atmospheric Environment	2014
37.	The coproduction of knowledge and policy in coastal governance: Integrating mussel fisheries and nature restoration	Ocean & Coastal Management	2015
38.	Sustainable Coastal Science-Policy-Practice Interface Development: Municipal Coastal Governance Indicator System	International Journal of Environmental Science	2016
39.	The Baltic Sea as a time machine for the future coastal ocean	Science Advances - Oceanography	2018
40.	Analysing the legal framework of marine living resources management in Bangladesh: Towards achieving Sustainable Development Goal 14	Marine Policy	2018
41.	Defining the qualitative elements of Aichi Biodiversity Target 11 with regard to the marine and coastal environment in order to strengthen global efforts for marine biodiversity conservation outlined in the United Nations Sustainable Development Goal 14	Marine Policy	2018
42.	Mangrove management for climate change adaptation and sustainable development in coastal zones	Journal of Sustainable Forestry	2018
43.	Coastal and marine conservation strategy for Bangladesh in the context of achieving blue growth and sustainable development goals (SDGs)	Environmental Science and Policy	2018
44.	A capital approach for assessing local coastal governance	Ocean & Coastal Management	2019
45.	Examining linkages between ecosystem services and social wellbeing to improve governance for coastal conservation in Jamaica	Ecosystem Services	2019
46.	Managing coastal protection through multi-scale governance structures in Romania	Marine Policy	2019
47.	Land-sea interactions and coastal development: An evolutionary governance perspective	Marine Policy	2019
48.	Challenges and opportunities in promoting integrated coastal zone management in Algeria: Demonstration from the Algiers coast	Ocean and Coastal Management	2019
49.	The Marine Plan Partnership for the North Pacific Coast – MaPP: A collaborative and co-led marine planning process in British Columbia	Marine Policy	2020
50.	Transforming coastal and marine management: Deliberative democracy and integrated management in New South Wales, Australia	Marine Policy	2020
51.	Governance and the coastal condition: Towards new modes of observation, adaptation and integration	Marine Policy	2020
52.	Regional public policy for Integrated Coastal Zone Management in Central America	Ocean & Coastal Management	2020
53.	Multilevel governance of coastal flood risk reduction: A public finance perspective	Environmental Science and Policy	2020
54.	Using a resilience thinking approach to improve coastal governance responses to complexity and uncertainty: a Tasmanian case study, Australia	Journal of Environmental Management	2020
55.	Coordinated planning effort as multilevel climate governance: Insights from coastal resilience and climate adaptation	Geoforum	2020
56.	Building resilience to natural hazards through coastal governance: a case study of Hurricane Harvey recovery in Gulf of Mexico communities	Ecological Economics	2020

(Continued)

Authors' Search Criteria through Different Mediums (Web of Science and Scopus).
The selected literature analyzed is from 1993 to 2020 because the latest literature in the context of ICZM is still in development, and before 1993, the literature was almost obsolete. While narrowing down the selection of articles to observe the implementation of ICZM with governance tools, the following are the findings of this CLR:

2.1.2 Monitoring, reporting, and evaluation

a. 34 Articles suggested vital means of monitoring, reporting, and evaluation mechanisms for effective ICZM;

b. 27 Articles argued that without effective monitoring, reporting, and evaluation, coastal sustainability cannot be achieved;

c. 10 Articles provide national and regional legal mechanisms for monitoring, reporting, and evaluation;

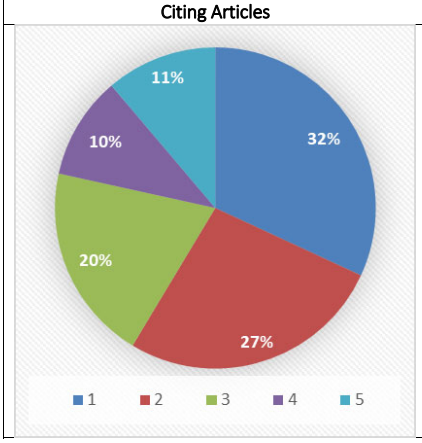
d. 07 Articles recommend the integration of scientific knowledge in monitoring, reporting, and evaluation of policy mechanisms for sustainable coastal development. As shown in Figure 2.

2.1.3 Capacity building

a. 16 Articles suggested capacity building of the authorities for effective ICZM;

b. 28 Articles suggested capacity building and training for coastal sustainability;

c. 08 Articles suggested a thorough and professional transfer of legal and policy knowledge to authorities;



Citing Articles	No	Governance Tools	Operationalization
	1	Coordination and Adaptivity	Effective monitoring through Adaptive Governance Mechanism
	2	Monitoring, Reporting, and Evaluation	Inter/Intra-Sectoral Reporting and Evaluation Mechanisms
	3	Capacity Building	Building Capacity of Authorities with Stakeholder Integration Measures for Sustainable Outcomes
	4	Legal and Policy Frameworks	Adequate Legislation under International Law
	5	Science-Policy Integration	Integrating Knowledge and Scientific Information in Policy

FIGURE 2
Governance Tools expanded through literature in terms of law, science, and policy integration. Various Citing Articles as mentioned in the Table 1 Interconnected SDGs in the Context of Coastal Sustainability.

d. 06 Articles suggested scientific integration into policy frameworks of various authorities for capacity building. As shown in Figure 2.

The governance tools provided in the citing articles connect the ICZM governance elements with those provided in SDG – 17 (Bisaro et al., 2020). Furthermore, the legal, policy, and scientific knowledge elements of ICZM connect with SDG – 14 (Visbeck et al., 2014). From a legal and policy framework perspective, most of the articles focused on national or regional governance dimensions with theoretical and normative methodologies. The list below provides a more precise articulation of the selected, researched, and analyzed articles in the context of SDG – 17 which provides means of implementation and revitalization of partnerships (or coherence among authorities) for sustainable development:

1. The core elements of coordination and adaptivity for coastal governance, as reflected in literature for policy coordination and coherence for sustainable development, are well presented in SDG 17.13 – 17.15 Waldmüller et al., 2019);
2. Monitoring, reporting, and evaluation are the tools effectively presented in SDG – 17.19 in terms of building on existing initiatives to develop measurements of progress on sustainable development (Zhu et al., 2021);
3. Capacity building for effective governance is highlighted in the literature, and SDG 17.9 also urged for enhanced international support for implementing effective and targeted capacity-building to implement all the Sustainable Development Goals (Olsen, 2010);
4. The legal and policy framework for ICZM is discussed in fewer articles but is well-articulated in SDG 14 (Islam and Shamsuddoha, 2018);
5. The articles on SDG 14 thoroughly stressed integrating scientific knowledge into policy or decision-making Hutton et al., 2018).

The citing articles also identify complex coastal problems and their anthropogenic connections relating to SDGs—the discontinuity between the interconnections among governance mechanisms of coastal cities under the ICZM system (Dunning, 2020). The citing articles recognize that a crucial obstacle in the implementation of ICZM is often unidirectional dependencies on the coastal commons (Kim et al., 2020). While suggesting policy integration, the articles examine multiple dimensions impacting coastal sustainability, which include coastal goals, ocean goals, environmental goals, and governance tools (Jozaei et al., 2020).

The first coastal goal in SDGs is 14.2 for "prevention of coastal pollution," which is intertwined with goals 14.1 and 14.2 of "protection of the marine environment" (Bisaro et al., 2020). Similarly, SDG 14.5, "conservation and preservation of coastal areas" under the "international law and based on the best available scientific information," connects with SDG 14.a to "increase scientific knowledge, develop research capacity and transfer marine technology in order to improve ocean health and to enhance the contribution of marine biodiversity" and 14.c for "enhancement of the conservation and sustainable use of oceans and its resources by implementing international law" Caviedes et al., 2020).

Furthermore, this goal-based approach is interconnected with SDG – 6 on "ensure availability and sustainable management of water and sanitation for all" and SDG – 11 on "making cities and human settlements inclusive, safe, resilient and sustainable" (Final list of proposed Sustainable Development Goal indicators, 2016; Van Assche et al., 2020). SDG – 6.3 urges to "improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse," and SDG – 11.6 urges to "reduce the adverse environmental impact of cities, including by paying special attention to municipal and other waste management" (Final list of proposed Sustainable Development Goal indicators, 2016; Brooks et al., 2022).

Similarly, the goal of coastal and marine conservation, as presented in SDG - 14.5, calls for mitigation and reduction of coastal flooding and ocean acidification (Diggon et al., 2022). This goal is primarily connected with SDG – 13 on "taking urgent action to combat climate change and its impacts," SDG – 13.1 for "strengthening resilience to climate-related hazards," and 13.b for

"effectively addressing climate change" (Khelil et al., 2019). The two goals in the context of coastal cities governance are attached to SDG – 11.6 on "reducing the adverse per capita environmental impact of cities by paying special attention to air quality" (Schlüter et al., 2020).

3 Analysis of CLR

While connecting the dots in the literature on 'legal and policy frameworks' and 'science-policy integration for ICZM,' new literature on 'coastal sustainability' and 'SDGs for oceans and the coasts' provides suggestions based on international environmental law (IEL) and United Nations Convention on Law of the Sea (UNCLOS) (United Nations Educational, Scientific and Cultural Organization, 1982; Văidianu et al., 2020). However, the concepts of "ICZM for coastal sustainability', 'ICZM for coastal cities,' 'legal-governance of coastal cities,' and 'science-policy integration in ICZM' under international law and policy standards are not analyzed in a single context throughout the literature Chan et al., 2019). The primary reason behind such paucity in the existing literature is the obsoleteness of current ICZM practices (Hershman et al., 1999; McLaughlin and Cooper, 2010).

3.1 Literature review on ICZM systems

It has been identified in the literature that ICZM systems are limited to coastal development, and management is restricted to the management of coastal areas. The authorities governing coastal cities, climate, environment, waste, and sewerage perform their functions in ICZM systems with limited control and influence (Fletcher et al., 2011; Tabet and Fanning, 2012; Grech et al., 2013). While evaluating the expansion of ICZM systems as suggested in the literature, the findings suggest that current ICZM systems focus on one or another governance mechanism that may impact coastal sustainability directly or indirectly Celliers et al., 2020). For example, the recent literature on 'coastal sustainability' from the 'climate change' perspective provides valuable suggestions for mitigation of ocean acidification, rising sea levels, and coastal flood risk Chow, 2018). However, the literature provides suggestions that appear to be problematic while implementing 'climate change' within legal parameters (McFadden et al., 2009).

Furthermore, the findings of CLR identify various anthropogenic interconnections of 'coastal sustainability' and 'ICZM' with the development and governance of ports, shipping, traffic, climate, and coastal cities (Rees et al., 2018, p. 14). Such literature suggested that if the given governance mechanisms are integrated within ICZM, it will become a laborious system due to the interdependence of the authorities, conflicting interests, and utilization of power and knowledge (Cicin-Sain et al., 1998; Viana et al., 2014). Contrariwise, there are strong arguments supporting the development of new means of ICZM to address 'coastal sustainability,' 'climate sustainability,' 'oceans sustainability,' and 'coastal cities sustainability' through different scales of governance and innovative solutions (Reusch et al., 2018).

Preventing marine and coastal pollution requires adequate scientific knowledge, efficient research capacity, and effective marine technology (Kudrenickis et al., 2016). As suggested through the literature, scientific knowledge is about 'Science-Policy Integration for ICZM' reflected in the 'governance tools' throughout the literature, as mentioned above and shown in Figure 3 (van der Molen et al., 2015). Furthermore, the coastal, ocean, and environmental goals require effective 'legal and policy frameworks' as provided under international law and presented in the literature for ICZM systems (Figures 3, 4). The goals-based approach of 'coastal sustainability' is well presented in SDGs 14.1 – 14.5, and the tools of 'ICZM' are suggested in SDGs 14.a and 14.b. Such development in literature evolved after 2010, as shown in Figures 3, 4 (Viana et al., 2014).

In the broad context, this goal means to "sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience and take action for their restoration and enhance the conservation and sustainable use of oceans and their resources" (Colenbrander et al., 2015). In the context of this CLR, the protection of coastal ecosystems requires the governance tools as mentioned above, and in applying these tools to the governance mechanisms, there shall be policy integration and institutional coordination between different authorities at different levels as provided below:

1. Municipal authorities governing waste and sewerage in coastal cities and marine environmental protection authorities, usually central or within the state/province (Colenbrander et al., 2015).
2. Motor vehicle control authority (at the central or provincial level), traffic management authority (at the district or local level), and climate change/atmospheric pollution control governing authority (at the central or sub-national level) (Zafrin et al., 2014).
3. Authorities governing fisheries, climate change authorities, and authorities governing coastal cities (Visbeck et al., 2014).

3.2 Literature review from the legal perspective of ICZM

Another question that arises through the analysis is how these authorities can be integrated under the current ICZM systems. In such a case, it can be argued that such arrangements in governance mechanisms are inorganic (Fletcher et al., 2014). On the other hand, this research argues that the structure is polycentric because 'polycentric governance' in ocean governance and marine environmental protection is a self-arranging pattern of authority. In terms of law, polycentric governance is organic, arranged under the law patterns for 'sustainability.' On the other hand, 'coordination and adaptivity,' 'monitoring, reporting and evaluation,' 'capacity building,' 'legal and policy frameworks', and 'science-policy integration' as tools of ICZM are replete in adaptive governance under IEL (Stojanovic and Farmer, 2013). Therefore, vertical and horizontal integration of the authorities through multilevel governance can be formed to resolve the complex issues of 'coastal sustainability' observed while conducting this CLR (Morrison et al., 2017).

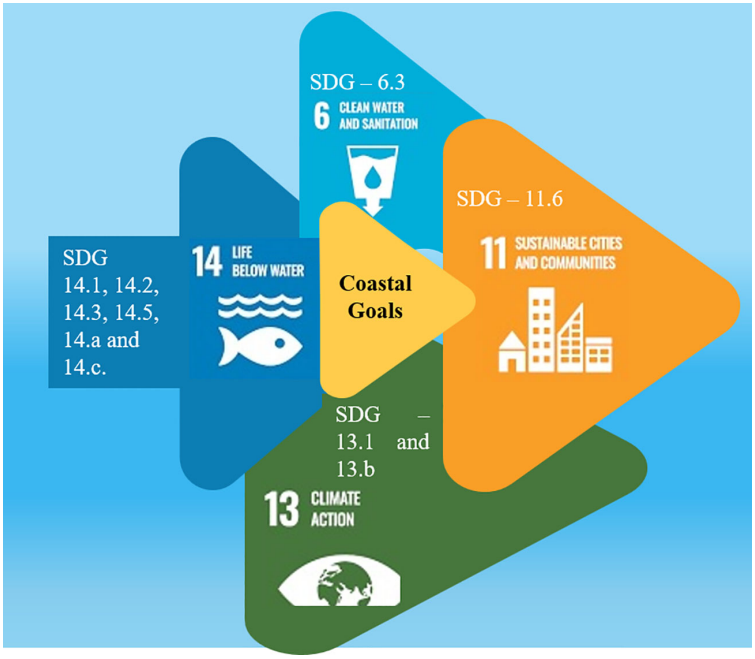
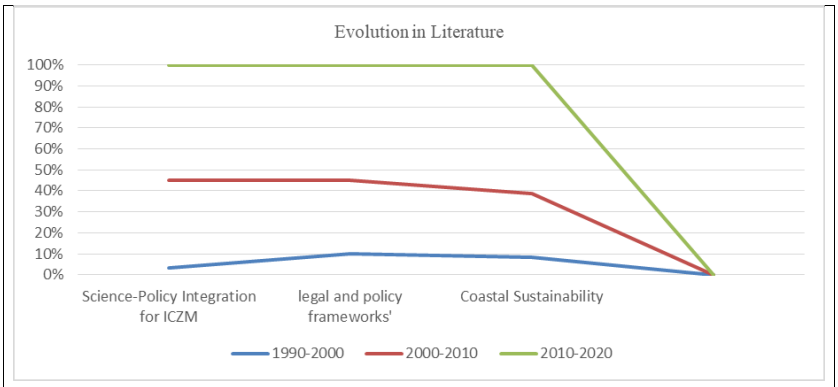


FIGURE 3
Interconnected SDGs with Coastal Goals. CLR and Discussion above.



Search Terms	Years 1990 – 2000	2000 – 2010	2010 – 2020
Science-Policy Integration for ICZM	1	12	16
Legal and Policy Frameworks	2	7	11
Coastal Sustainability	3	11	22

FIGURE 4
Citing Literature on Legal Governance Tools in ICZM for Coastal Sustainability. CLR as mentioned in Table 1.

The literature from the legal perspective of 'coastal sustainability' provides significant means of utilizing normative values of soft-law declarations or national or regional strategies (Rees et al., 2018, p. 11). However, the literature does not provide much clarity on how the legal obligations can be incorporated into 'ICZM' for 'coastal sustainability' (Harrould-Kolieb and Hoegh-Guldberg, 2019). Although there is prospective literature on IEL and UNCLOS dealing with marine environmental protection, fisheries preservation, and ocean conservation, 'coastal sustainability' is amalgamated with typical approaches that do not consider the direct impacts of diverse governance mechanisms as mentioned above (United Nations Educational, Scientific and Cultural Organization, 1982; Miles et al., 1995; Ali, 2004).

The primary requirement for developing new means of ICZM is the multiplexity of governance mechanisms at some level that operate for substantive coastal goals (Visbeck et al., 2014; Timko et al., 2018). As ICZM cannot stand alone anymore, the SDGs under IEL have paved the way for tools of governance mechanisms in the form of multilevel governance. It has been observed that control and effective governance of waste, sewerage, and atmospheric

pollution can be integrated into ICZM with multilevel governance methods Chua, 2013). The legal frameworks forwarding adaptive and polycentric governance mechanisms for sustainable oceans and coastal ecosystems have become obsolete.

In this case of multilevel governance, adaptive and polycentric governance can be integrated with the tool-based approach of ICZM (Bremer and Glavovic, 2013). Science-policy integration, law and policy frameworks, coordination and adaptivity, monitoring, reporting and evaluation, and capacity building are effective tools (Ehler, 2003; Nursey-Bray et al., 2014). Although approaching a more updated form of 'coastal sustainability' under SDGs is challenging due to the strong connections of diverse ecosystems, SDG – 14 formulates a goal-based approach and interconnects with SDGs – 6, 11, and 17 for 'coastal sustainability' in the context of 'coastal cities governance' (Taljaard et al., 2012). Therefore, applying such a multilevel governance mechanism is able to address coastal flooding, ocean acidification, marine pollution, and harmful impacts on fisheries (Harrould-Kolieb and Hoegh-Guldberg, 2019).

UNCLOS provided a scientific, logical, and precisely coherent approach to marine environmental protection through various means of governance. From the IEL perspective, the Rio Declaration on Environment and Development (Rio Declaration) and the United Nations Framework Convention on Climate Change (UNFCCC) established various mechanisms for the protection of the marine environment (United Nations, 1992; United Nations Educational, Scientific and Cultural Organization, 1992; Tabet and Fanning, 2012). Although the coastal goals or preservation of coastal ecosystems was not substantially incorporated in both the international commitments, the Rio Declaration established coastal goals in terms of "protection of the oceans, all kinds of seas, including enclosed and semi-enclosed seas, and coastal areas and the protection, rational use and development of their living resources" (Miles et al., 1995; United Nations, 2002).

The Rio Declaration establishes a mechanism of coastal ecosystem protection. In this way, it can be said that the Rio Declaration provides a commentary to UNCLOS besides literature and establishes the legal basis for collaborative governance of coastal city authorities (for waste, sewerage, and atmospheric pollution governance and control) (Visbeck et al., 2014; van der Molen et al., 2015). The literature advanced the Rio Declaration agendas of coastal governance by suggesting data and information sharing mechanisms, assessment and evaluation, capacity building, preventive measures, and precautionary approaches (Stojanovic and Farmer, 2013).

Rio Declaration (Chapter 17 of Agenda 21) works as a policy instrument for ICZM because it urges for "integration of sectoral programs on sustainable development for (coastal) settlements, agriculture, tourism, fishing, ports and industries affecting the coastal area" (United Nations, 2002). Further, it provides that sustainable planning and governance of the coastal cities and the ports from development and management perspectives are necessary for coastal sustainability (Fletcher, 2001). The literature on the Rio Declaration suggested that the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention), Montreal Guidelines for the Protection of the Marine Environment from Land-Based Sources (Montreal Guidelines), International Convention for the Prevention of Pollution from Ships (MARPOL), and International Convention for the Prevention of Pollution of the Sea by Oil (OILPOL) governs the marine environment and also deals with coastal pollution prevention from ship source of pollution (United Nations Educational, Scientific and Cultural Organization, 1954; United Nations Educational, Scientific and Cultural Organization, 1972b; United Nations Educational, Scientific and Cultural Organization, 1973; Weston's and Carlson, 2015).

The literature was further enhanced in the field of ICZM through the Aichi Biodiversity Target – 11 (for the conservation of the coastal and marine areas) (Jonas and Lucas, 2011). Aichi Biodiversity Targets are on the agenda of the Convention on Biological Diversity (CBD) and are dealt with through the Convention Concerning the Protection of the World Cultural and Natural Heritage (World Heritage Convention) (United Nations Educational, Scientific and Cultural Organization, 1972a; United Nations Educational, Scientific and Cultural Organization, 1992; Rees et al., 2018). The regional and national legislative developments under UNCLOS and the Rio Declaration provide scientific dimensions of coastal cities' and ports' policies. The vertical and horizontal integration presented in UNCLOS and Rio Declaration also provides implementation mechanisms (Ali, 2004; Wescott, 2009). These mechanisms significantly integrate stakeholders in national legislative frameworks through spatial planning and governance.

The literature analyzed top-down, bottom-up, and cross-sectoral governance of ecosystems within ICZM systems of various States. A strong analysis of the governance mechanisms of atmospheric pollution of coastal cities, ports, and shipping with their substantial impacts on coastal floods and ocean acidification exists (Jentoft and Chuenpagdee, 2009; Bisaro et al., 2020). The literature criticized national and regional governance mechanisms because UNFCCC is still ineffective (United Nations Educational, Scientific,and Cultural Organization, 1992; Hermwille et al., 2017). After the enactment of the Paris Agreement and Kyoto Protocol (as parts of UNFCCC), IMO improved the regulation of atmospheric pollution from ships in the form of Sulphur 2020 and GHG Emissions Frameworks. However, with limited applicability, IMO's mechanisms are not satisfactory in terms of ocean acidification and coastal flood risk because port and coastal city authorities do not have the capacity to control and regulate such emissions effectively (Rothenberg and Nicksin, 2008; Miola et al., 2011; Galaz et al., 2012).

Most of the literature suggests that the integration of authorities governing atmospheric pollution shall collaborate with environmental and marine authorities to observe coastal flood risk and ocean acidification as relative problems (Kudrenickis et al., 2016). Literature also highlighted the national efforts to integrate governance of port, shipping, and coastal cities

governance within ICZM systems under IEL and UNCLOS (Rees et al., 2018, p. 14; Schlüter et al., 2020; Văidianu et al., 2020). The efforts to protect coastal ecosystems are regarding applying preventive and precautionary measures in planning and while implementing, including prior assessment and systematic observation (Vince and Hardesty, 2017). Such scientific integration into policy is the notion of the Rio Declaration for spatial planning and governance and adopting a coherent approach that is applicable to adaptive and polycentric governance to share responsibility (United Nations, 2002). Such efforts resolve political ambiguity associated with coastal sustainability and put in place effective ICZM systems. It has been urged that besides national integration or regional coherence, there is a need for international cooperation in the governance of ocean and coastal ecosystems, which may include IMO, United Nations Educational, Scientific, and Cultural Organization (UNESCO), the Intergovernmental Oceanographic Commission (IOC), United Nations Development Programme (UNDP) and United Nations Environment Programme (UNEP) (Juda, 1999; Mahon et al., 2010).

4 International legal framework for ICZM to achieve coastal sustainability

Climate change and marine pollution are global issues that require international, regional, and multilateral (sub-regional) cooperation and national, sub-national, and local action (Ehler, 2003). From a coastal sustainability perspective, inculcating ICZM in any such cooperation mechanism and action, international legal framework building national policies on climate change and marine environmental protection becomes relevant (Baird et al., 2009). However, the CLR and analysis above settled that international, regional, and national legal frameworks are not adequate in dealing with the risks faced by coastal sustainability (Ward et al., 2013). Therefore, this section provides an international legal framework for ICZM based on the above CLR, analysis, and existing IEL and UNCLOS mechanisms.

4.1 Legal framework and governance tools for coastal sustainability

As already discussed, the international legal framework for coastal sustainability has been provided in SDG – 14 in the form of goals. Such goals are part of UNCLOS and the Rio Declaration urging the mitigation of adverse impacts on marine and coastal ecosystems (United Nations Educational, Scientific and Cultural Organization, 1982; United Nations, 2002; Harrould-Kolieb and Hoegh-Guldberg, 2019). SDG – 14 establishes that significant adverse effects particularly emerge from land-based sources, including marine debris and nutrient pollution (Bigagli, 2016; Final list of proposed Sustainable Development Goal indicators, 2016). The results of this CLR found that the impact of waste and sewerage on coastal sustainability is higher than other sources of pollution, in particular of the coastal cities (Reusch et al., 2018). The CLR also analyzed the impacts of climate change on coastal sustainability, including ocean acidification and coastal flooding. It has also been established that coastal flooding risk, ocean acidification, atmospheric pollution, and climate change are not unidimensional issues (Baird et al., 2009; Harrould-Kolieb and Hoegh-Guldberg, 2019).

Coastal sustainability issues require an enhanced understanding of the issues from multiple dimensions. Setting climate change issues within ICZM systems requires a coordinated effort of multiple governing mechanisms from and across international, regional, national, and local levels (West, 2003). It also establishes that SDG – 14, in terms of land-based pollution of the coastal cities, is interconnected with SDGs – 6, 11, and 15. Furthermore, climate change and coastal sustainability connect SDG – 14 with SDGs 11, 13, and 15 (Gallagher et al., 2004). Therefore, the basic legal framework in terms of IEL and UNCLOS is required to mitigate land-based and atmospheric pollution from coastal cities as per the scope of this research under the governance tools mentioned above.

4.1.1 Coordination and adaptivity - effective monitoring through adaptive governance mechanism

Integrating coastal sustainability with terrestrial and ocean ecosystems requires coordination and adaptivity among national, sub-national, and local governance mechanisms. Expansion of the ICZM framework for such governance mechanisms recognizes the need for flexibility and allows for adaptations in different ecosystems and their governance (Hovik and Stokke, 2007). Explicitly focussing on the issues of ICZM, any governance solution may generate further problems (West, 2003; Jentoft, 2007). Ports, shipping, and coastal tourism are quite relevant governance mechanisms for ICZM, which challenge coastal sustainability (Van Assche et al., 2020). Therefore, the appraisal of integration at this juncture is more conflicting and thus represents contradictory interests vertically and horizontally among governing authorities (Pittman and Armitage, 2016).

Coordination and adaptivity promote shared responsibility, capacity, knowledge and data sharing, and co-evaluation of policy implementation programs (Ali, 2004). As ICZM faces diverse challenges of overlapping jurisdictions, conflicting interests, and fragmentation, coordinated efforts in a single direction are not easily grasped. The coast is a liminal space with the ocean on the one side and land on the other (Hovik and Stokke, 2007). In this era of complexity, taking climate change as a particular challenge is a multidimensional, multi-sectoral, and multi-jurisdictional question (Jozaei et al., 2020). Waste and sanitation management through a scale of land-sea interaction is also indented as a cross-sectoral concern (Colenbrander et al., 2015; Kudrenickis et al., 2016; Khelil et al., 2019; Van Assche et al., 2020). Similarly, the development and planning of coastal cities and ports involve multiple authorities with or without coordination (Sekovski et al., 2012). The literature analyzed through this CLR suggested that governance of the coastal cities for sewerage and waste mitigation and control

requires precautionary and preventive measures (Jentoft, 2007). The principles of 'precautionary and preventive measures' are well defined in the CBD, UNFCCC Rio Declaration, and UNCLOS, and all the IEL urges to enhance mechanisms of coordination and adaptivity for such pollution control.

Legal frameworks under IEL and UNCLOS are not limited to a specific implementation of any definite policy. In ICZM systems, IEL and UNCLOS may not go beyond coastal and marine environmental protection authorities but are capable of calibrating within various governance mechanisms under multiple governing authorities as networks and collaborations (Powell et al., 2009; Galaz et al., 2012). Adaptivity in governance is a flexible and knowledge-sharing collaboration involving diverse authorities to coordinate the management of ecosystems (Vugteveen et al., 2015). Moreover, collaboration and adaptivity in governance integrate vertically, and polycentricity focuses on horizontal integration for effective implementation Chaffin et al., 2014). As there is a multiplication of authorities as well as a wide diversity of networks from local to national and regional levels in ICZM, adaptivity poses issues of coordinated means of implementation (Tobey et al., 2010). Considering the adverse impacts of pollution on coastal sustainability, adaptivity, and coordination, a mechanism to enable horizontal cooperation among port, shipping, urban, coastal, and ocean authorities and vertically and nationally, sub-national, and local authorities is needed.

The core elements identified through this CLR in SDGs for coordination and adaptivity are provided in SDG – 17, which enhances adaptivity and coordination among SDG – 14, 13, and 7 to improve the efficiency of the authorities to handle climate-related hazards and to enable access to clean energy at international, regional and national levels (Miola et al., 2011; Sekovski et al., 2012; Final list of proposed Sustainable Development Goal indicators, 2016). Further, the elements promote processes to build and raise capacity for effective emission mitigation strategies (including clean energy), and with target 14.a to transfer marine technology in order to improve ocean health and marine biodiversity, its applicability on ports and shipping emissions seems effective for ICZM (Rothenberg and Nicksin, 2008; Final list of proposed Sustainable Development Goal indicators, 2016). In terms of coastal cities' emissions management, SDG – 11 urges paying particular attention to air quality and reducing adverse environmental impacts. Along with SDG – 13, the stakeholders are able to influence policy for climate change measures at the national level (Ballinger, 2015; Final list of proposed Sustainable Development Goal indicators, 2016).

4.1.2 Monitoring, reporting, and evaluation inter/intra-sectoral reporting and evaluation mechanisms

Coordination and adaptivity devices that share governance create co-benefits by establishing mechanisms within a transparent system of governance (United Nations Educational, Scientific and Cultural Organization, 1992; Puppim de Oliveira et al., 2011). Further, the transparency for evaluation, monitoring, and reporting is established in the Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (Aarhus Convention) (United Nations Educational, Scientific and Cultural Organization, 1998; Mason, 2010). Under the Aarhus Convention, UNCLOS and UNFCCC set flexible means of implementation and promoted cooperative monitoring, reporting, and evaluation mechanisms by sharing responsibility (Bodansky, 1991; Benioff et al., 2010). As the form of international obligations as provided in the IEL, the Rio Declaration conveyed a mechanism to establish a coherent monitoring program to control land-based pollution (waste and sewerage) and climate change (atmospheric pollution) from the coastal cities (United Nations, 2002).

In terms of SDG – 14, coastal sustainability requires a 'coherent monitoring program to control the effluent discharge and emissions through shipping and port activities and the coastal cities' and 'conservation of coastal areas' Chemane et al., 1997; Kim et al., 2020). Further, it develops shared responsibility, adaptive capacity, knowledge and data sharing mechanisms, and co-evaluation of policy implementation programs. Interpretation of IEL through literature forwards the mechanism of adaptivity and coordination by providing a network of authorities monitoring, evaluating, and reporting coastal sustainability issues at different scales (Miles et al., 1995).

UNCLOS adopted a more scientific, logical, precise, and coherent approach by establishing mechanisms of monitoring, evaluation, data-sharing, and scientific cooperation among the States and within the States to curb the land-based sources of marine pollution (Bauerlein, 1994; Lawrence Juda, 2001; Analysing the legal framework of marine living resources management in Bangladesh: Towards achieving Sustainable Development Goal 14, 2018). Functionally, coordination and adaptivity in governance are mechanisms to develop cohesion among various governance mechanisms through performing checks and balances as they provide cross-sectoral dimensions of transparency in the form of monitoring, reporting, and evaluation (Homsy et al., 2019). As a result of this CLR, the governance tools of monitoring, reporting, and evaluation propose that data and information sharing, coordinated monitoring, and sharing of innovative strategies at various governance levels through national authorities via coastal, environmental, or ocean authorities play a significant role in coastal sustainability (Kudrenickis et al., 2016; Reusch et al., 2018; Caviedes et al., 2020; Diggon et al., 2022).

The element of coordination in monitoring, data information, and technology sharing is applicable while developing local cross-border integration, or it may take a bottom-up approach through national integration (Visbeck et al., 2014). Rethinking ICZM under the measures of monitoring, reporting, and evaluation establishes close connections of coastal goals of SDG – 14 with SDG – 17, which involve national, sub-national, and local governance mechanisms to evaluate coastal sustainability. Reporting coastal flood risk and ocean acidification to climate governing authorities and marine pollution to coastal city authorities are practical forms of application of these governance tools (Duxbury and Dickinson, 2007; Kim, 2012; Taljaard et al., 2012).

4.1.3 Capacity building - building capacity of authorities with stakeholder integration measures for sustainable outcomes

Effective implementation of governance tools, as mentioned above, requires enhanced capacity of authorities and stakeholder integration to help authorities in building capacity. Furthermore, such implementation calls for enhanced scientific cooperation, research capacity, and technology transfer at all levels (McFadden et al., 2009). It is already established that the UNCLOS or UNFCCC urges to enhance scientific knowledge to improve the ocean ecosystem and the contribution of marine biodiversity (Kim, 2012). In such terms, SDG – 17 encourages the development of policy coherence and coordination, respect for international policy space, multi-stakeholder partnerships, and enhanced capacity for data, monitoring, and accountability. The agenda for the coastal goals realizes the weaknesses in governance and requests the stakeholders to develop capacity through coordination, adaptivity, and continuous negotiation (Gupta and Nilsson, 2017).

Integrating governance, law, and policy for coastal sustainability into one framework is a difficult task that calls for global and national cooperation. SDG – 14 urges the developed states to transfer marine technology and scientific knowledge through coordination and adaptivity to least developed and developing States to improve ocean health (Granit et al., 2014). Therefore, governance mechanisms provided in SDG – 17 are taken as critical elements of coordination, adaptivity, monitoring, reporting, evaluation, and capacity-building in ICZM. The governance tools of SDG – 17 are reflected throughout this CLR, identifying the gaps in governance and covering those gaps through the capacity-building of various authorities. Capacity building presents a formula of coordination within and between authorities, building on the premise that ICZM is a means of achieving coastal sustainability.

4.1.4 Legal and policy frameworks in regions and states - adequate legislation under international law

Interpretation and potential extension of the IEL and UNCLOS for the development of a legal framework effectively governing coastal cities and atmospheric pollution are significant governance tools for coastal sustainability. At national and regional levels, the authorities and stakeholders on the coasts are encountering new responsibilities that require continuous scientific integration, institutional reforms, and new approaches (Duxbury and Dickinson, 2007). Therefore, evolutionary legal frameworks are necessary to resolve such annexed policy issues considering coordination, adaptivity, monitoring, and reporting issues (Schlüter et al., 2020).

The regional initiatives for ocean governance built on the 'Global and Regional Cooperation' notion under UNCLOS and the Rio Declaration have promoted sustainable coastal solutions (Someya et al., 1992). Partnerships in Environmental Management for the Seas of East Asia are good examples, and the European ICZM model is another (McKenna et al., 2008; Chua, 2013). Although inconsistencies and fragmentations exist at various levels, the recent shifting paradigm shows that the European ICZM model has realized that consistent long-term actions are strategically coherent rather than vertically integrated (Shipman and Stojanovic, 2007; Fletcher et al., 2014). This strategic coherence is holistically based on a bottom-up approach and is flexible for diverse cooperation mechanisms (Zafrin et al., 2014).

Cross-border governance for the land-sea interaction under UNCLOS and the Rio Declaration is significantly applicable to coastal sustainability (United Nations, 2002) (As mentioned in Table 2). Similarly, UNFCCC, CBD, and World Heritage Convention promote regional and international partnerships for atmospheric pollution control and coastal conservation. Therefore, establishing the legal basis for coastal sustainability in ICZM systems is forwarded through the UNCLOS, UNFCCC, CBD, and World Heritage Convention as a goal and Rio Declaration and SDGs as mechanisms (As mentioned in Table 2). Rio Declaration also provides the mechanism of adaptivity and coordination by providing network organization, collaboration process, and coordination of multiple authorities at different scales (Miles et al., 1995). Therefore, a legal framework promotes conflict management and resolution tools, vertical and horizontal harmonization, and coordinated capacity building for ICZM implementation.

4.1.5 Science-policy integration – integrating knowledge and scientific information in policy

Scientific knowledge integration into policymaking is a phenomenon presented in the UNCLOS advanced through the Rio Declaration. Scientific research and policy integration with stringent rules and regulations occur with the final negotiation of UNCLOS (Juda, 1999). UNCLOS adopted a more scientific and legal approach by establishing mechanisms of governance with data and knowledge. Rio Declaration rationalizes the UNCLOS across the rights and obligations for scientific knowledge into policy mechanisms (Hildreth, 1999; Forrest, 2006). This enhanced the use of precautionary and preventive measures in any governance mechanism (Visbeck et al., 2014; van der Molen et al., 2015).

Establishing the legal basis for scientific knowledge into ICZM as a policy mechanism forwards information sharing, joint monitoring and evaluation, and capacity building (Stojanovic and

TABLE 2 Applicable International Environmental Laws for Coastal Sustainability.

Law	Application for Coastal Sustainability
UNCLOS & Montreal Guidelines	Protection of Marine Environment from Land-Based Pollution
Rio Declaration	Establishing a Mechanism of Coastal Ecosystem Protection
London Convention, MARPOL & OILPOL	Prevention of Ship Source of Pollution including Dumping and Oil
CBD	Preservation of Marine and Coastal Biodiversity
UNFCCC, Kyoto Protocol and Paris Agreement	Prevention of Atmospheric Pollution and Climate Change Strategies

CLR of this Research, as mentioned above.

Farmer, 2013). Issues of coastal flood risk and ocean acidification require enhanced scientific knowledge and incorporation of science into policymaking at all levels (Kudrenickis et al., 2016). Atmospheric pollution control of the coastal cities requires scientific assessment and control with coastal flooding and ocean acidification perspectives (Jentoft and Chuenpagdee, 2009; Bisaro et al., 2020). Such scientific knowledge in policymaking is also forwarded in the UNFCCC, Kyoto Protocol, and Paris Agreement (Rothenberg and Nicksin, 2008; Miola et al., 2011; Galaz et al., 2012). Such integration of scientific knowledge into policymaking forwards diverse approaches of ICZM at various levels (Rees et al., 2018, p. 14; Schlüter et al., 2020; Văidianu et al., 2020).

CLR suggested that aspects of science-policy integration are regarding the application of systematic observation, which should be a national agenda implemented through sub-national and local authorities (Vince and Hardesty, 2017). The notion of the Rio Declaration is the science-policy integration mechanism at various levels. Planning coastal cities with scientific integration and knowledge that shall mitigate coastal flood risk, ocean acidification, and land-based pollution control are pertinent issues presented in SDGs. SDG – 14, in this way, connects with SDGs – 13 and 17 for scientific and knowledge integration for coastal sustainability.

4.2 Coastal conservation and pollution prevention as goal

The findings of this CLR indicated that shipping and port governance are inclusive issues for coastal sustainability. This research focused on coastal city governance (sanitation and waste governance), which characterizes coastal sustainability from a legal perspective. This CLR shows that the governance tools of ICZM are with the coastal goals-based approach and are connected with the targets of SDGs directly impacting coastal sustainability, as provided below and presented in Table 3.

1. Sustainable management of the coasts under Target – 14.2 includes land-sea interactions and climate change impacts, and it connects with SDG – 6 (Clean Water and Sanitation), SDG – 11 (Sustainable Cities and Communities), and SDG – 14 (Life on Land). Target – 14.3, although not coastal and is an ocean goal, relates to the coastal flooding risk, which further connects it with SDG – 14.5 for the conservation of coastal areas (Mahon et al., 2010; Jonas and Lucas, 2011; Khelil et al., 2019). Thus, SDG – 14.3 relates to SDG – 13 (Climate Change) and SDG – 7 (Clean and Affordable Energy) in a specific dimension of the port, shipping, and urban emissions management (Rothenberg and Nicksin, 2008; Miola et al., 2011; Kim, 2012).
2. SDGs 13 and 7 are to improve flexibility and adaptivity to handle climate-related hazards and enable access to clean energy at international, regional, and national levels (Miola et al., 2011; Sekovski et al., 2012; Final list of proposed Sustainable Development Goal indicators, 2016). Further, it promotes processes to build and raise capacity for effective emission mitigation strategies (including clean energy), and with target 14.a to transfer marine technology in order to improve ocean health and marine biodiversity, its applicability on ports and shipping emissions seems effective for ICZM (Rothenberg and Nicksin, 2008; Final list of proposed Sustainable Development Goal indicators, 2016). Regarding coastal cities' emissions management, SDG – 11 urges paying particular attention to air quality and reducing adverse environmental impacts. Along with SDG – 13, the stakeholders are able to influence policy for climate change measures at the national level (Ballinger, 2015; Final list of proposed Sustainable Development Goal indicators, 2016).
3. The strategies entailed in SDG – 11 to develop economic, social, and environmental links between urban, peri-urban, and rural areas and help least-developed countries build sustainable infrastructure are supportive of mitigating

TABLE 3 Governance Tools Utilised for Coastal Sustainability through SDGs framework and IEL.

Coastal Goals SDG – 14	Coordination and Adaptivity	Monitoring, Reporting and Evaluation	Capacity Building	Legal Framework	Science Policy
Coastal Pollution Prevention	SDG – 11 - Support positive economic, social and environmental links between urban, peri-urban and rural areas	SDG – 17 – for Monitoring, Reporting and Evaluation	Increase scientific knowledge and develop research capacity and transfer marine technology in order to improve ocean health and to enhance the contribution of marine biodiversity to the development	consistent with national and international law (UNCLOS, Convention on Biological Diversity, World Heritage Convention and Chapter 17 of Agenda 21)	SDG – 14 and all other SDGs based on the best available scientific information.
Preservation of Coastal Areas	SDG – 13 Integrate climate change measures into national policies.	SDG – 17 – for Monitoring, Reporting and Evaluation		UNFCCC, Kyoto Protocol and Paris Agreement)	

The discussion of this CLR.

population pressures on coastal cities (Sekovski et al., 2012; Final list of proposed Sustainable Development Goal indicators, 2016). Providing inclusive and sustainable urbanization by providing more benefits and developing capacity for participatory and sustainable settlement planning and management under SDG – 14 and 15 underpins that populations reaching coastal cities will reduce (Ballinger, 2015; Final list of proposed Sustainable Development Goal indicators, 2016). Further, adopting the ecosystem and biodiversity into national and local planning and increasing the number of cities is consistent with developing national legislation for the conservation of coastal areas.

5 Conclusion

Due to anthropogenic connections, pressures on coastal ecosystems are increasing within the ICZM systems, significantly demanding inclusive governance mechanisms. The SDGs promote anthropogenic governance, and addressing the vulnerability to coastal sustainability is becoming increasingly essential. However, the conflict between trade and sustainability in coastal cities and regions challenges the effective implementation of coastal goals. Development and implementation of adaptivity and coordination in ICZM systems with monitoring, evaluation, reporting, and scientific information under international law should be imperative. The coastal goals can act as a framework for the establishment of national, regional, and international regimes for ICZM. Improved stakeholder integration, emphasizing the impact on shipping, ports, and coastal cities' governance mechanisms, facilitates the successful application of the ICZM. Stakeholders' concerns can be addressed through a policy mechanism of 'participation' in ICZM systems to address trade and sustainability's conflicting interests and create a balance between both. The ICZM mechanism provides tools to adequately mitigate coastal flood risk by coping with ocean acidification and sea-level rise, including protecting ecosystems from coastal hazards and sufficiently conserving coastal areas.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

SZ: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing. QW: Writing – original draft, Writing – review & editing. MB: Formal analysis, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. Y-ML: Formal analysis, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. Y-EW: Formal analysis, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. The funding for this fieldwork was provided by Institute of Eco-Environmental Forensics. This research work was supported by the Research Project: "Theoretical Contributions of Law and Policy in Marine Environmental Preservation and Ocean Development Programme, Environmental Integration and Justice Department" (Funding No: 1324-MJB-2022.) provided to Institute of Eco-Environmental Forensics, Economic and Environmental Law Institute, Shandong University, Qingdao, China.

Acknowledgments

The authors acknowledge the resources provided by the Institute of Eco-Environmental Forensics, School of Law, Shandong University.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Ali, K.-D. (2004). Legal and policy dimensions of coastal zone monitoring and control: the case in Ghana. *Ocean Dev. Int. Law* 35, 179–194. doi: 10.1080/00908320490434284

Baird, R., Simons, M., and Stephens, T. (2009). Ocean acidification: A litmus test for international law. *Carbon Clim. Law Rev.* 3, 459–471. doi: 10.21552/CCLR/2009/4/116

Ballinger, R. (2015). "On the edge: coastal governance and risk," in *Risk governance: the articulation of hazard, politics and ecology*. Ed. U. Fra.Paleo (Springer Netherlands, Dordrecht), 373–394. doi: 10.1007/978-94-017-9328-5_20

Bartram, J., Brocklehurst, C., Bradley, D., Muller, M., and Evans, B. (2018). Policy review of the means of implementation targets and indicators for the sustainable development goal for water and sanitation. *NPJ Clean Water* 1, 1–5. doi: 10.1038/s41545-018-0003-0

Bauerlein, P. C. (1994). The united nations convention on the law of the sea & (and) US ocean environmental practice: are we complying with international law. *Loyola Los Angel. Int. Comp. Law J.* 17, 899.

Benioff, R., de Coninck, H., Dhar, S., Hansen, U., McLaren, J., and Painuly, J. (2010). *Strengthening Clean Energy Technology Cooperation under the UNFCCC: Steps toward Implementation* (Golden, CO (United States: National Renewable Energy Lab.(NREL). Available at: https://www.eldis.org/document/A59713.

Bigagli, E. (2016). The international legal framework for the management of the global oceans social-ecological system. *Mar. Policy* 68, 155–164. doi: 10.1016/j.marpol.2016.03.005

Bin, C., Hao, H., Weiwei, Y., Senlin, Z., Jinkeng, W., and Jinlong, J. (2009). Marine biodiversity conservation based on integrated coastal zone management (ICZM)—A case study in Quanzhou Bay, Fujian, China. *Ocean Coast. Manage.* 52, 612–619. doi: 10.1016/j.ocecoaman.2009.10.006

Bisaro, A., de Bel, M., Hinkel, J., Kok, S., Stojanovic, T., and Ware, D. (2020). Multilevel governance of coastal flood risk reduction: A public finance perspective. *Environ. Sci. Policy* 112, 203–212. doi: 10.1016/j.envsci.2020.05.018

Bodansky, D. (1991). Protecting the marine environment from vessel-source pollution: UNCLOS III and beyond. *Ecol. Law Q.* 18, 719–777.

Bremer, S., and Glavovic, B. (2013). Mobilizing knowledge for coastal governance: re-framing the science–policy interface for integrated coastal management. *Coast. Manage.* 41, 39–56. doi: 10.1080/08920753.2012.749751

Brooks, K., Barclay, K., Grafton, R. Q., and Gollan, N. (2022). Transforming coastal and marine management: Deliberative democracy and integrated management in New South Wales, Australia. *Mar. Policy* 139, 104053. doi: 10.1016/j.marpol.2020.104053

Caffyn, A., and Jobbins, G. (2003). Governance capacity and stakeholder interactions in the development and management of coastal tourism: examples from Morocco and Tunisia. *J. Sustain. Tour.* 11, 224–245. doi: 10.1080/09669580308667204

Caviedes, V., Arenas-Granados, P., and Barragán-Muñoz, J. M. (2020). Regional public policy for Integrated Coastal Zone Management in Central America. *Ocean Coast. Manage.* 186, 105114. doi: 10.1016/j.ocecoaman.2020.105114

Celliers, L., Rosendo, S., Costa, M. M., Ojwang, L., Carmona, M., and Obura, D. (2020). A capital approach for assessing local coastal governance. *Ocean Coast. Manage.* 183, 104996. doi: 10.1016/j.ocecoaman.2019.104996

Chaffin, B., Gosnell, H., and Cosens, B. (2014). A decade of adaptive governance scholarship: synthesis and future directions. *Ecol. Soc* 19, 56. doi: 10.5751/ES-06824-190356

Chan, C., Armitage, D., Alexander, S. M., and Campbell, D. (2019). Examining linkages between ecosystem services and social wellbeing to improve governance for coastal conservation in Jamaica. *Ecosyst. Serv.* 39, 100997. doi: 10.1016/j.ecoser.2019.100997

Chemane, D., Motta, H., and Achimo, M. (1997). Vulnerability of coastal resources to climate changes in Mozambique: a call for integrated coastal zone management. *Ocean Coast. Manage.* 37, 63–83. doi: 10.1016/S0964-5691(97)00073-2

Chow, J. (2018). Mangrove management for climate change adaptation and sustainable development in coastal zones. *J. Sustain. For.* 37, 139–156. doi: 10.1080/10549811.2017.1339615

Chua, T.-E. (2013). Coastal and ocean governance in the seas of east asia: PEMSEA's experience. *Coast. Manage.* 41, 99–119. doi: 10.1080/08920753.2013.768517

Cicin-Sain, B. (1993). Sustainable development and integrated coastal management. *Ocean Coast. Manage.* 21, 11–43. doi: 10.1016/0964-5691(93)90019-U

Cicin-Sain, B., Knecht, R. W., Knecht, R., Jang, D., Fisk, G. W., and Policy, U. (1998). "Setting the stage for integrated coastal management," in *Integrated coastal and ocean management: concepts and practices* (Delaware, USA: Island Press), 121–135.

Colard-Fabregoule, C. (2020). "Chapter 7 - maritime spatial planning: A means of organizing maritime activities measured iin terms of sustainable development goals," in *Global commons: issues, concerns and strategies*. Eds. M. B. Pillai and G. G. Dore (New Delhi, India: SAGE Publishing India), 95.

Colenbrander, D., Cartwright, A., and Taylor, A. (2015). Drawing a line in the sand: managing coastal risks in the City Of Cape Town. *South Afr. Geogr. J.* 97, 1–17. doi: 10.1080/03736245.2014.924865

Diggon, S., Bones, J., Short, C. J., Smith, J. L., Dickinson, M., Wozniak, K., et al. (2022). The Marine Plan Partnership for the North Pacific Coast – MaPP: a collaborative and co-led marine planning process in British Columbia. *Mar. Pol.* 142, 104065. doi: 10.1016/j.marpol.2020.104065

Dunning, K. H. (2020). Building resilience to natural hazards through coastal governance: a case study of Hurricane Harvey recovery in Gulf of Mexico communities. *Ecol. Econ.* 176, 106759. doi: 10.1016/j.ecolecon.2020.106759

Duxbury, J., and Dickinson, S. (2007). Principles for sustainable governance of the coastal zone: In the context of coastal disasters. *Ecol. Econ.* 63, 319–330. doi: 10.1016/j.ecolecon.2007.01.016

Ehler, C. N. (2003). Indicators to measure governance performance in integrated coastal management. *Ocean Coast. Manage.* 46, 335–345. doi: 10.1016/S0964-5691(03)00020-6

Eisma, R.-L. V., Christie, P., and Hershman, M. (2005). Legal issues affecting sustainability of integrated coastal management in the Philippines. *Ocean Coast. Manage.* 48, 336–359. doi: 10.1016/j.ocecoaman.2005.04.009

Final list of proposed Sustainable Development Goal indicators (2016). Available online at: https://sustainabledevelopment.un.org/content/documents/11803Official-List-of-Proposed-SDG-Indicators.pdf.

Fletcher, S. (2001). Using stakeholder decision-making simulation to teach integrated coastal management. *J. Geogr. High. Educ.* 25, 367–378. doi: 10.1080/03098260120067628

Fletcher, S., Jefferson, R., Glegg, G., Rodwell, L., and Dodds, W. (2014). England's evolving marine and coastal governance framework. *Mar. Policy* 45, 261–268. doi: 10.1016/j.marpol.2013.09.007

Fletcher, S., Kawabe, M., and Rewhorn, S. (2011). Wetland conservation and sustainable coastal governance in Japan and England. *Mar. pollut. Bull.* 62, 956–962. doi: 10.1016/j.marpolbul.2011.02.048

Forrest, C. (2006). Integrated coastal zone management: A critical overview. *WMU J. Marit. Aff.* 5, 207–222. doi: 10.1007/BF03195105

Galaz, V., Crona, B., Österblom, H., Olsson, P., and Folke, C. (2012). Polycentric systems and interacting planetary boundaries — Emerging governance of climate change–ocean acidification–marine biodiversity. *Ecol. Econ.* 81, 21–32. doi: 10.1016/j.ecolecon.2011.11.012

Gallagher, A., Johnson, D., Glegg, G., and Trier, C. (2004). Constructs of sustainability in coastal management. *Mar. Policy* 28, 249–255. doi: 10.1016/j.marpol.2003.08.004

Gonzalez-Bernat, M. J., and Clifton, J. (2017). "Living with our backs to the sea": A critical analysis of marine and coastal governance in Guatemala. *Mar. Policy* 81, 9–20. doi: 10.1016/j.marpol.2017.03.003

Granit, J., Lymer, B. L., Olsen, S., Lundqvist, J., and Lindström, A. (2014). "Water governance and management challenges in the continuum from land to the coastal sea–spatial planning as a management tool," in *Stockholm international water institute* (Stockholm: Stockholm International Water Institute), 1–19. Available at: https://www.siwi.org/wp-content/uploads/2015/09/Paper-22-Spatial-Planning-Land-to-Coast-web.pdf.

Grech, A., Bos, M., Brodie, J., Coles, R., Dale, A., Gilbert, R., et al. (2013). Guiding principles for the improved governance of port and shipping impacts in the great barrier reef. *Mar. pollut. Bull.* 75, 8–20. doi: 10.1016/j.marpolbul.2013.07.013

Gupta, J., and Nilsson, M. (2017). "Toward a multilevel action framework for sustainable development goals," in *Governing through goals: Sustainable Development Goals as governance innovation*. Eds. F. Biermann and N. Kanie (MIT Press, Cambridge, Massachusetts, USA), 275–333. Available at: https://www.google.com/books/edition/Governing_Through_Goals/W7zaDgAAQBAJ?hl=en&gbpv=0.

Harrould-Kolieb, E. R., and Hoegh-Guldberg, O. (2019). A governing framework for international ocean acidification policy. *Mar. Policy* 102, 10–20. doi: 10.1016/j.marpol.2019.02.004

Hatziolos, M. E. (1997). A World Bank framework for ICZM with special emphasis on Africa. *Ocean Coast. Manage.* 37, 281–294. doi: 10.1016/S0964-5691(97)00060-4

Hermwille, L., Obergassel, W., Ott, H. E., and Beuermann, C. (2017). UNFCCC before and after Paris – what's necessary for an effective climate regime? *Clim. Policy* 17, 150–170. doi: 10.1080/14693062.2015.1115231

Hershman, M. J., Good, J. W., Bernd-Cohen, T., Goodwin, R. F., Lee, V., and Pogue, P. (1999). The effectiveness of coastal zone management in the United States. *Coast. Manage.* 27, 113–138. doi: 10.1080/089207599263811

Hildreth, R. (1999). Institutional and legal arrangements for coastal management in the asia pacific region. *Pangea* 1, 39.

Homsy, G. C., Warner, M. E., and Liu, Z. (2019). "Multilevel governance," in *Global encyclopedia of public administration, public policy, and governance*. Ed. A. Farazmand (Springer International Publishing, Cham), 1–5. doi: 10.1007/978-3-319-31816-5_1775-1

Hovik, S., and Stokke, K. B. (2007). Network governance and policy integration—the case of regional coastal zone planning in Norway. *Eur. Plan. Stud.* 15 (7), 927-944. doi: 10.1080/09654310701356647

Hutton, C. W., Nicholls, R. J., Lázár, A. N., Chapman, A., Schaafsma, M., and Salehin, M. (2018). Potential tradeoffs between the sustainable development goals in coastal Bangladesh. *Sustainability* 10, 1108. doi: 10.3390/su10041108

Islam, M. M., and Shamsuddoha, M. (2018). Coastal and marine conservation strategy for Bangladesh in the context of achieving blue growth and sustainable development goals (SDGs). *Environ. Sci. Policy* 87, 45–54. doi: 10.1016/j.envsci.2018.05.014

Jentoft, S. (2007). Limits of governability: Institutional implications for fisheries and coastal governance. *Mar. Policy* 31, 360–370. doi: 10.1016/j.marpol.2006.11.003

Jentoft, S., and Chuenpagdee, R. (2009). Fisheries and coastal governance as a wicked problem. *Mar. Policy* 33, 553–560. doi: 10.1016/j.marpol.2008.12.002

Jonas, H., and Lucas, S. (2011). "Legal aspects of aichi biodiveristy target 11," in *Working paper* (International Development Law Organisation, Switzerland), 23. Available at: https://www.iucn.org/sites/dev/files/import/downloads/t11_scoping_paper_final.pdf.

Jozaei, J., Mitchell, M., and Clement, S. (2020). Using a resilience thinking approach to improve coastal governance responses to complexity and uncertainty: a Tasmanian case study, Australia. *J. Environ. Manage.* 253, 109662. doi: 10.1016/j.jenvman.2019.109662

Juda, L. (1999). Considerations in developing a functional approach to the governance of large marine ecosystems. *Ocean Dev. Int. Law* 30, 89–125. doi: 10.1080/009083299276203

Kardos, M. (2012). The reflection of good governance in sustainable development strategies. *Proc. - Soc Behav. Sci.* 58, 1166–1173. doi: 10.1016/j.sbspro.2012.09.1098

Khelil, N., Larid, M., Grimes, S., Le Berre, I., and Peuziat, I. (2019). Challenges and opportunities in promoting integrated coastal zone management in Algeria: Demonstration from the Algiers coast. *Ocean Coast. Manage.* 168, 185–196. doi: 10.1016/j.ocecoaman.2018.11.001

Kim, R. E. (2012). Is a new multilateral environmental agreement on ocean acidification necessary? *Rev. Eur. Community Int. Environ. Law* 21, 243–258. doi: 10.1111/reel.12000.x

Kim, H., Marcouiller, D. W., and Woosnam, K. M. (2020). Coordinated planning effort as multilevel climate governance: Insights from coastal resilience and climate adaptation. *Geoforum* 114, 77–88. doi: 10.1016/j.geoforum.2020.05.023

Knecht, R. W. (1994). Essay: Emerging international goals and principles and their influence on national ocean governance. *Coast. Manage.* 22, 177–182. doi: 10.1080/08920759409362229

Kudrenickis, I., Ernsteins, R., and Kaulins, J. (2016). Sustainable coastal science-policy-practice interface development: municipal coastal governance indicator system. *Int. J. Environ. Sci.* 1, 255.

Lawrence Juda, T. H. (2001). Governance profiles and the management of the uses of large marine ecosystems. *Ocean Dev. Int. Law* 32, 43–69. doi: 10.1080/00908320150502195

Liang, J., and Li, Y. (2020). Resilience and sustainable development goals based social-ecological indicators and assessment of coastal urban areas ——A case study of Dapeng New District, Shenzhen, China. *Watershed Ecol. Environ.* 2, 6–15. doi: 10.1016/j.wsee.2020.06.001

Mahon, R., Fanning, L., McConney, P., and Pollnac, R. (2010). Governance characteristics of large marine ecosystems. *Mar. Policy* 34, 919–927. doi: 10.1016/j.marpol.2010.01.016

Mason, M. (2010). Information disclosure and environmental rights: the aarhus convention. *Glob. Environ. Polit.* 10, 10–31. doi: 10.1162/GLEP_a_00012

McFadden, L., Penning-Rowsell, E., and Tapsell, S. (2009). Strategic coastal flood-risk management in practice: Actors' perspectives on the integration of flood risk management in London and the Thames Estuary. *Ocean Coast. Manage.* 52, 636–645. doi: 10.1016/j.ocecoaman.2009.10.001

McKenna, J., Cooper, A., and O'Hagan, A. M. (2008). Managing by principle: A critical analysis of the European principles of Integrated Coastal Zone Management (ICZM). *Mar. Policy* 32, 941–955. doi: 10.1016/j.marpol.2008.02.005

McLaughlin, S., and Cooper, J. A. G. (2010). A multi-scale coastal vulnerability index: A tool for coastal managers? *Environ. Hazards* 9, 233–248. doi: 10.3763/ehaz.2010.0052

Miles, G., Fuavao, V., and Smith, A. (1995). Implementing Agenda 21: oceans, coasts and the Barbados outcomes in the Pacific region. *Ocean Coast. Manage.* 29, 125–138. doi: 10.1016/0964-5691(96)00014-2

Miola, A., Marra, M., and Ciuffo, B. (2011). Designing a climate change policy for the international maritime transport sector: Market-based measures and technological options for global and regional policy actions. *Energy Policy* 39, 5490–5498. doi: 10.1016/j.enpol.2011.05.013

Morrison, T. H., Adger, W. N., Brown, K., Lemos, M. C., Huitema, D., and Hughes, T. P. (2017). Mitigation and adaptation in polycentric systems: sources of power in the pursuit of collective goals. *Wiley Interdiscip. Rev. Clim. Change* 8, 479. doi: 10.1002/wcc.479

Nursey-Bray, M. J., Vince, J., Scott, M., Haward, M., O'Toole, K., Smith, T., et al. (2014). Science into policy? Discourse, coastal management and knowledge. *Environ. Sci. Policy* 38, 107–119. doi: 10.1016/j.envsci.2013.10.010

Olsen, S. B. (2010). Assessing progress toward the goals of coastal management. *Coast. Manage.* 30, 325. doi: 10.1080/089207502900309

Pittman, J., and Armitage, D. (2016). Governance across the land-sea interface: A systematic review. *Environ. Sci. Policy* 64, 9–17. doi: 10.1016/j.envsci.2016.05.022

Powell, R. B., Cuschnir, A., and Peiris, P. (2009). Overcoming governance and institutional barriers to integrated coastal zone, marine protected area, and tourism management in Sri Lanka. *Coast. Manage.* 37, 633–655. doi: 10.1080/08920750903194272

Puppim de Oliveira, J. A., Balaban, O., Doll, C. N. H., Moreno-Peñaranda, R., Gasparatos, A., Iossifova, D., et al. (2011). Cities and biodiversity: Perspectives and governance challenges for implementing the convention on biological diversity (CBD) at the city level. *Biol. Conserv.* 144, 1302–1313. doi: 10.1016/j.biocon.2010.12.007

Rees, S. E., Foster, N. L., Langmead, O., Pittman, S., and Johnson, D. E. (2018). Defining the qualitative elements of Aichi Biodiversity Target 11 with regard to the marine and coastal environment in order to strengthen global efforts for marine biodiversity conservation outlined in the United Nations Sustainable Development Goal 14. *Mar. Policy* 93, 241–250. doi: 10.1016/j.marpol.2017.05.016

Reusch, T. B. H., Dierking, J., Andersson, H. C., Bonsdorff, E., Carstensen, J., Casini, M., et al. (2018). The Baltic Sea as a time machine for the future coastal ocean. *Sci. Adv.* 4, 1–16. doi: 10.1126/sciadv.aar8195

Rothenberg, E. B., and Nicksin, R. S. (2008). Latest developments in international maritime environmental regulation. *Tulane Marit. Law J.* 33, 137.

Schlüter, A., Van Assche, K., Hornidge, A.-K., and Văidianu, N. (2020). Land-sea interactions and coastal development: An evolutionary governance perspective. *Mar. Policy* 112, 103801. doi: 10.1016/j.marpol.2019.103801

Shamsuzzaman, M. M., and Islam, M. M. (2018). Analysing the legal framework of marine living resources management in Bangladesh: Towards achieving Sustainable Development Goal 14. *Mar. Policy* 87, 255–262. doi: 10.1016/j.marpol.2017.10.026

Sekovski, I., Newton, A., and Dennison, W. C. (2012). Megacities in the coastal zone: Using a driver-pressure-state-impact-response framework to address complex environmental problems. *Estuar. Coast. Shelf Sci.* 96, 48–59. doi: 10.1016/j.ecss.2011.07.011

Shipman, B., and Stojanovic, T. (2007). Facts, fictions, and failures of integrated coastal zone management in europe. *Coast. Manage.* 35, 375–398. doi: 10.1080/08920750601169659

Someya, A., Kato, H., and Kaneko, A. (1992). Report on the basic legal structure and current movement on port and coastal zone in Japan. *Coast. Manage.* 20, 49–72. doi: 10.1080/08920759209362163

Stojanovic, T. A., and Farmer, C. J. Q. (2013). The development of world oceans & coasts and concepts of sustainability. *Mar. Policy* 42, 157–165. doi: 10.1016/j.marpol.2013.02.005

Tabet, L., and Fanning, L. (2012). Integrated coastal zone management under authoritarian rule: An evaluation framework of coastal governance in Egypt. *Ocean Coast. Manage.* 61, 1–9. doi: 10.1016/j.ocecoaman.2012.01.006

Tait, J., and Lyall, C. (2017). "New modes of governance: developing an integrated policy approach to science, technology, risk and the environment?" in *New modes of governance.* (Edinburgh, Scotland, United Kingdom: Routledge), 177–188.

Taljaard, S., Slinger, J. H., Morant, P. D., Theron, A. K., van Niekerk, L., and van der Merwe, J. (2012). Implementing integrated coastal management in a sector-based governance system. *Ocean Coast. Manage.* 67, 39–53. doi: 10.1016/j.ocecoaman.2012.06.003

Teampău, P. (2020). Trouble in paradise: Competing discourses and complex governance in the Romanian danube delta. *Mar. Policy* 112, 103522. doi: 10.1016/j.marpol.2019.103522

Timko, J., Le Billon, P., Zerriffi, H., Honey-Rosés, J., de la Roche, I., Gaston, C., et al. (2018). A policy nexus approach to forests and the SDGs: tradeoffs and synergies. *Curr. Opin. Environ. Sustain.* 34, 7–12. doi: 10.1016/j.cosust.2018.06.004

Tobey, J., Rubinoff, P., Robadue, D., Ricci, G., Volk, R., Furlow, J., et al. (2010). Practicing coastal adaptation to climate change: lessons from integrated coastal management. *Coast. Manage.* 38, 317–335. doi: 10.1080/08920753.2010.483169

United Nations. (1992). United nations conference declaration on environment and development. (Rio de Janeiro, Brazil and New York, United States: UN Doc. A/CONF.151/26 (vol. I)). Available online at: https://www.un.org/en/conferences/environment/rio1992.

United Nations. (2002) United nations, report of the world summit on sustainable development. Available online at: http://www.un.org/jsummit/html/documents/summit_docs/131302_wssd_report_reissued.pdf.

United Nations Educational, Scientific and Cultural Organization. (1972a). *Convention concerning the protection of the world cultural and natural heritage* (Paris, France: United Nations Treaty Series). Available online at: https://treaties.un.org/Pages/showDetails.aspx?objid=08000002800fece0&clang=_en.

United Nations Educational, Scientific and Cultural Organization. (1972b). *Convention for prevention of marine pollution by dumping of wastes and other matter* (London, United Kingdom: United Nations Treaty Series). Available online at: https://treaties.un.org/pages/showDetails.aspx?objid=08000002800fdd18.

United Nations Educational, Scientific and Cultural Organization. (1998). *Convention on access to information, public participation in decision-making and access to justice in environmental matters* (Aarhus, Denmark: United Nations Treaty Series). https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-13&chapter=27.

United Nations Educational, Scientific and Cultural Organization. (1992). *Convention on biological diversity* (Rio de Janeiro, Brazil and New York, United States: United Nations Treaty Series). Available online at: https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-8∓chapter=27&clang=_en.

United Nations Educational, Scientific and Cultural Organization. (1973). *International convention for prevention of pollution from ships* (London, United Kingdom: United Nations Treaty Series). Available online at: https://treaties.un.org/pages/showDetails.aspx?objid=0800000280291139.

United Nations Educational, Scientific and Cultural Organization. (1954). *The international convention for the prevention of pollution of the sea by oil* (London, United Kingdom: United Nations Treaty Series). Available online at: https://treaties.un.org/doc/Publication/UNTS/Volume%20327/volume-327-I-4714-English.pdf.

United Nations Educational, Scientific and Cultural Organization. (1982). United nations convention on law of the sea. (Montego Bay, Jamaica: UNTS). Available online at: https://treaties.un.org/Pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XXI-6&chapter=21&Temp=mtdsg3&clang=_en.

United Nations Educational, Scientific and Cultural Organization. (1992). United nations framework convention on climate change. (Rio de Janeiro, Brazil and New York, United States: UNTS). Available online at: https://treaties.un.org/Pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XXVII-7&chapter=27&Temp=mtdsg3&clang=_en.

Văidianu, N., Tătui, F., Ristea, M., and Stănică, A. (2020). Managing coastal protection through multi-scale governance structures in Romania. *Mar. Policy* 112, 103567. doi: 10.1016/j.marpol.2019.103567

Van Assche, K., Hornidge, A.-K., Schlüter, A., and Vaidianu, N. (2020). Governance and the coastal condition: Towards new modes of observation, adaptation and integration. *Mar. Policy* 112, 1–10. doi: 10.1016/j.marpol.2019.01.002

van der Molen, F., Puente-Rodríguez, D., Swart, Jac., A. A., and van der Windt, H. J. (2015). The coproduction of knowledge and policy in coastal governance: Integrating mussel fisheries and nature restoration. *Ocean Coast. Manage.* 106, 49–60. doi: 10.1016/j.ocecoaman.2015.01.012

Viana, M., Hammingh, P., Colette, A., Querol, X., Degraeuwe, B., Vlieger, I., et al. (2014). Impact of maritime transport emissions on coastal air quality in Europe. *Atmos. Environ.* 90, 96–105. doi: 10.1016/j.atmosenv.2014.03.046

Vince, J., and Hardesty, B. D. (2017). Plastic pollution challenges in marine and coastal environments: from local to global governance. *Restor. Ecol.* 25, 123–128. doi: 10.1111/rec.12388

Visbeck, M., Kronfeld-Goharani, U., Neumann, B., Rickels, W., Schmidt, J., van Doorn, E., et al. (2014). A Sustainable Development Goal for the Ocean and Coasts: Global ocean challenges benefit from regional initiatives supporting globally coordinated solutions. *Mar. Policy* 49, 87–89. doi: 10.1016/j.marpol.2014.02.010

Vugteveen, P., van Katwijk, M. M., Rouwette, E., Lenders, H. R., and Hanssen, L. (2015). Developing an effective adaptive monitoring network to support integrated coastal management in a multiuser nature reserve. *Ecol. Soc.* 20, 59. doi: 10.5751/ES-07228-200159

Waldmüller, J. M., Jamali, H., and Nogales, N. (2019). Operationalizing sustainable development goals in vulnerable coastal areas of Ecuador and Pakistan: marginalizing human development? *J. Hum. Dev. Capab.* 20, 468–485. doi: 10.1080/19452829.2019.1666810

Ward, P. J., Pauw, W. P., Van Buuren, M. W., and Marfai, M. A. (2013). Governance of flood risk management in a time of climate change: the cases of Jakarta and Rotterdam. *Environ. Polit.* 22, 518–536. doi: 10.1080/09644016.2012.683155

Wescott, G. (2009). Stimulating vertical integration in coastal management in a federated nation: the case of Australian coastal policy reform. *Coast. Manage.* 37, 501–513. doi: 10.1080/08920750903044824

West, M. B. (2003). Improving science applications to coastal management. *Mar. Policy* 27, 291–293. doi: 10.1016/S0308-597X(03)00038-1

Weston's and Carlson ed. (2015). "V.I.24 montreal guidelines for the protection of the marine environment against pollution from land–based sources (With annexes)," in *Int. Law world order west. Carlsons basic doc*. Available at: https://referenceworks.brillonline.com/entries/international-law-and-world-order/vi24-montreal-guidelines-for-the-protection-of-the-marine-environment-against-pollution-from-landbased-sources-with-annexes-SIM_032947.

White, A., Deguit, E., Jatulan, W., and Eisma-Osorio, L. (2006). Integrated coastal management in philippine local governance: evolution and benefits. *Coast. Manage.* 34, 287–302. doi: 10.1080/08920750600686687

Zafrin, S., Rosier, J., and Baldwin, C. (2014). Queensland's coastal planning regime: the extent of participation in coastal governance. *Plan. Pract. Res.* 29, 331–349. doi: 10.1080/02697459.2013.872916

Zhang, S., Butt, M. J., and Zulfiqar, K. (2023). Interconnected principles of ocean governance through science-policy integration under the judgements of the international dispute settlement bodies. *Sci. Prog.* 106, 368504231205395. doi: 10.1177/00368504231205395

Zhu, X., Zuklin, T., and Zhang, Y. (2021). Enhancing and promoting national environmental goals through local integrated coastal management initiatives and legislation: Evidence from Xiamen. *Ocean Coast. Manage.* 207, 104706. doi: 10.1016/j.ocecoaman.2019.01.002

Zulfiqar, K., and Butt, M. J. (2021). Preserving community's environmental interests in a meta-ocean governance framework towards sustainable development goal 14: A mechanism of promoting coordination between institutions responsible for curbing marine pollution. *Sustainability* 13, 9983. doi: 10.3390/su13179983

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 25 March 2024
DOI 10.3389/fmars.2024.1341222

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Christian Prip,
Fridtjof Nansen Institute, Norway
Oran Young,
University of California, Santa Barbara, United States

*CORRESPONDENCE
Jinpeng Wang
wangjinpeng@ouc.edu.cn

RECEIVED 20 November 2023
ACCEPTED 11 March 2024
PUBLISHED 25 March 2024

CITATION
Wang J and Zhang Y (2024) The area-based management tools coordination between IMO and BBNJ agreement regimes and its implications on vessel pollution control. *Front. Mar. Sci.* 11:1341222. doi: 10.3389/fmars.2024.1341222

COPYRIGHT
© 2024 Wang and Zhang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

The area-based management tools coordination between IMO and BBNJ agreement regimes and its implications on vessel pollution control

Jinpeng Wang[1,2]* and Yiwei Zhang[1]

[1]School of Law, Ocean University of China, Qingdao, China, [2]Institute of Marine Development of Ocean University of China, Qingdao, China

The International Maritime Organization (IMO), as a specialized agency of the United Nations responsible for the safety and security of international shipping and the prevention of pollution from ships, has applied two main area-based management tools (ABMTs): the "Special Areas" established under the MARPOL 73/78; and the "Particularly Sensitive Sea Areas" (PSSAs) established under the IMO resolutions. The new Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ agreement) stipulates the establishment of a comprehensive system of ABMTs to conserve and sustainably use areas beyond national jurisdiction. Strengthening coordination in the use of ABMTs established by the IMO and the BBNJ Agreement is important for vessel pollution control in the high seas. The IMO is a stakeholder for relevant proposals and consultations on proposals regarding the establishment of ABMTs in the BBNJ Agreements, and can provide information on the implementation of them. The Conference of the Parties (COPs) to the BBNJ Agreement can also make recommendations to the IMO and its parties to promote the adoption of special areas and PSSAs. This article respectively elaborates on the practices and effect of ABMTs of the IMO and explores the relevant rules of the BBNJ agreement and their enforcement. Then this article discusses the possible approaches for the ABMTs coordination between the IMO and the BBNJ agreement regimes and their implications on vessel pollution Control in the high seas. Overall, relevant rules of the BBNJ agreement shall be interpreted and applied in a manner that does not undermine relevant legal instruments of the IMO. Meanwhile, it is necessary to promote cooperation and coordination between the COPs to the BBNJ Agreement and the IMO under the idea of conserving ecosystem integrity, gradually forming a normal cooperation and information exchange mechanism.

KEYWORDS

area-based management tools (ABMTs), International Maritime Organization (IMO), marine biological diversity, areas beyond national jurisdiction (ABNJ), vessel pollution control

1 Introduction

The International Maritime Organization (IMO), as a specialized agency of the United Nations responsible for ensuring the safety, security, and environmental protection of international shipping, strives to promote safe, secure, efficient, and sustainable shipping through international cooperation (IMO, 2022). Currently, the IMO employs two primary area-based management tools for shipping: "Special Areas", established under Amendments to the Protocol of 1978 Relating to the International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL 73/78)[1]; and "Particularly Sensitive Sea Areas" (PSSA), designated under the IMO Revised Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas (IMO, 2006). The new Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ agreement) stipulates the establishment of a comprehensive system of ABMTs for the conservation and sustainable use of Areas Beyond National Jurisdiction (ABNJ). The third part of the BBNJ Agreement, "measures such as area-based management tools, including marine protected areas" specifies objectives, area of application, proposals, publicity and preliminary review of proposals, consultations on and assessment of proposals, establishment of area-based management tools, including marine protected areas, decision-making, emergency measures, implementation, monitoring and review. The BBNJ Agreement have open for signature on 20 September 2023. The BBNJ Agreement provides explicit rules for the establishment of ABMTs beyond national jurisdiction, promoting the establishment of such tools in high seas. Strengthening coordination in the use of ABMTs established by the IMO and the BBNJ Agreement is important for vessel pollution control in the high seas. In this article, we provide an overview of the legal framework and practices for the IMO's ABMTs for vessel pollution control in the second section, elaborates Special Area under MARPOL and UNCLOS and the IMO's PSSA regime. The third section explains the ABMTs regime under the BBNJ Agreement, including the process of establishing ABMTs, and relevant international cooperation and coordination issues. The fourth section conducts an analysis on coordination between IMO and BBNJ Agreement regimes for vessel pollution control, paving the way for a set of proposals for coordination between the ABMTs of them.

1 MARPOL 73/78 is an umbrella term that usually includes the International Convention for International Convention for the Prevention of Pollution from Ships, 1973 and the Protocol of 1978 relating to the International Convention for the Prevention of Pollution from Ships, 1973.

2 The IMO's ABMTs for vessel pollution control

2.1 Concepts of the Special Area and PSSA

2.1.1 The Special Area under MARPOL and UNCLOS

The MARPOL Convention, adopted on 2 November 1973, and its 1978 Protocol were responses to a series of tanker accidents during the 1880s, exemplified by the "Torrey Canyon". MARPOL 73/78 designates certain sea areas as "Special Areas" where, for technical reasons related to sea conditions, ecology, and maritime traffic, special enforcement measures are required to prevent marine pollution from ships (IMO, 2002b). These Special Areas are established to afford a higher level of protection to vulnerable sea regions with unique ecological conditions and factors such as heavy maritime traffic, limited water exchange, extreme ice conditions, and endangered marine species (IMO, 2023a). Special Areas can encompass multiple countries and may be fully or semi-enclosed within seas. Notable examples include the Mediterranean, the Black Sea, the Baltic Sea, the Red Sea, and the Persian Gulf, which were among the first identified as Special Areas necessitating enhanced marine protection. Different annexes of MARPOL 73/78, namely Annexes I, II, V, and VI, regulate the special sea areas concerning oily substances, noxious liquid substances, sewage, and garbage from ships, respectively. Additionally, ABNJ, such as the Antarctic and the Southern Ocean (south of 60°S), were later included within the scope of Special Areas (UNGA, 2007).

Article 211, paragraph 6, of the 1982 United Nations Convention on the Law of the Sea (UNCLOS), acknowledges the existence of Special Areas as provided by MARPOL 73/78. The Special Areas established under MARPOL 73/78 are not subject to mandatory restrictions and may extend into the high seas. In contrast, UNCLOS, under Article 211, specifies that a Special Area must be clearly delineated within the exclusive economic zone (EEZ) of the coastal State (United Nations Convention on the Law of the Sea, 1982). The coastal State may require the adoption of laws and regulations for the prevention, reduction and control of pollution from ships in specific areas of the EEZ where, for recognized technical reasons, related to oceanography, area usage, resource conservation, and navigation, necessitate special mandatory measures for pollution prevention (United Nations Convention on the Law of the Sea, 1982). The Special Area regime in UNCLOS serves as a framework provision, dependent on the regime established by MARPOL. If a coastal State intends to adopt and implement special mandatory measures for its Special Area that go beyond the international rules and national laws referred to in Article 211, paragraph 1, it must obtain the substantive approval of the competent international organization, the IMO (Yingchun, 2009). At present, Special Areas are designated within the framework of MARPOL, and no designations have been made under UNCLOS.

2.1.2 The IMO's PSSA regime

The PSSA regime was introduced to address the limitations of the Special Areas regime. However, upon the issuance of the first

relevant IMO resolution, uncertainties arose regarding the positioning of PSSAs—whether they should be viewed as a stand-alone concept or as a measure to strengthen the Special Areas regime (Roberts, 2006b). To oversee the PSSA regime, the Marine Environment Protection Committee (MEPC) has been designated by IMO. In 1991, the IMO Assembly adopted Resolution A. 720 (17), which outlined the "Guidelines for the Designation of Special Areas and the Identification of Particularly Sensitive Sea Areas", setting criteria for the identification of PSSAs (IMO, 1992). Nonetheless, the complex and lengthy identification process posed challenges, and for seven years, only Cuba's Sabana-Camagwasüey Archipelago was identified as a PSSA. To improve practicality and efficiency, Resolution A. 885(21) supplemented the Procedures for the Identification of PSSAs and the Adoption of Associated Protective Measures (APM) (IMO, 1999). Subsequently, to further streamline the process, the MEPC finalized a draft Assembly resolution on the "Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas" (IMO, 2002a). These new guidelines received approval from the IMO Assembly during its 22nd session in 2001, resulting in the formal adoption of Resolution A. 927(22) (IMO, 2002a), which replaced Resolutions A. 720(17) and A. 885(21) (IMO, 1999). As of now, the most recent guidance document on the identification and designation of PSSAs is Resolution A. 982(24). Versions of resolutions on PSSAs are displayed in Table 1.

A PSSA is an area that requires extra protection through IMO action because of its importance for acknowledged ecological, socio-economic, or scientific features, which may be vulnerable to harm by international maritime activities (IMO, 2002a). PSSAs are established by IMO resolutions and are not legally binding on non-members or even member states as it is not included in the text of the UNCLOS (Roberts, 2005). The criteria for identifying a PSSA and the criteria for designating a Special Area are not mutually exclusive and sometimes even overlap (IMO, 2023b). As for the defined area, PSSAs can be applied to ABNJ and are not restricted to the EEZ of the coastal State, but the 18 PSSAs identified to date are all located within national jurisdiction (IMO, 2023c). The salient characteristics of Special Areas and PSSAs are compared in Table 2.

TABLE 1 Versions of resolutions on PSSAs.

Adoption Time	Resolution	Outline	Characteristics and Progress
6 November 1991	Resolution A.720(17)	Guidelines for the Designation of Special Areas and the Identification of Particularly Sensitive Sea Areas	• Overly lengthy and confusing • Failure to set out the process for making determinations • Lack of recognition of values by the international community
25 November 1999	Resolution A.885(21)	Procedures for the Identification of Particularly Sensitive Sea Areas and the Adoption of Associated Protective Measures and Amendments to the Guidelines Contained in Resolution A.720(17)	• Revision of identification procedures • Adjustment of the name of the Protective Measures from "Special Protective Measures" to "Associated Protective Measures"
29 November 2001	Resolution A.927(22)	Guidelines for the Designation of Special Areas under MARPOL 73/78 and Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas	• Distinguish between Special Areas and PSSAs as two topics • Deletion of the description of MPAs in the preliminary version of the guide • Updated ecological criteria and other identification criteria
1 December 2005	Resolution A.982(24)	Revised Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas	• Further updating of the criteria for recognition

2.2 Institutionalization of area-based shipping management tools

2.2.1 Legal basis for the institutionalization process

The institutionalization processes for Special Areas and PSSAs are founded on different legal basis. Special Areas are established under the MARPOL 73/78 and its related by-laws, while PSSAs are established based on IMO Assembly resolutions and MEPC resolutions. Consequently, the establishment of Special Areas and PSSAs differs in terms of timing and procedural steps. Since Special Areas require amendments to MARPOL, the implementation of relevant environmental protection measures can only occur after the amendments have entered into force, resulting in longer processing times. In contrast, the direct consideration of these protection measures by the MEPC and their confirmation in the form of a resolution makes the establishment of PSSAs a relatively simple and quick process.

However, there have been criticisms regarding the legal basis of PSSAs, with some scholars contending that IMO resolutions are non-binding and cannot serve as a proper legal foundation for the implementation of Associated Protective Measures (APM) (Peet, 1994; Roberts et al., 2005). For instance, the identification of the Torres Strait as an extension of the PSSA of the Great Barrier Reef by the MEPC at its 53rd session, as well as the confirmation of the two-way shipping lanes and the mandatory pilotage system developed by Australia, faced challenges from several States regarding its effectiveness (Zhang, 2014). The central issue lies in whether IMO resolutions, which are of a soft law nature only, can serve as a legal basis for establishing relevant APMs in PSSAs and whether a compulsory APM can be established in the absence of a clear treaty-based legal foundation.

TABLE 2 Comparison chart between Special Areas and PSSAs.

	Special Areas	PSSAs
Legal Basis	Article 211 of the UNCLOS MARPOL 73/78	IMO resolutions
Area Scope	Closed and semi-closed seas	No limitation
Criteria for Accreditation	Simultaneously meets the requirements of the three criteria of oceanography, ecology and the specific nature of transportation.	Only one of the ecological, socio-cultural and economic, scientific and educational criteria needs to be met and the region is vulnerable to impacts from international shipping activities.
Protective Measures	Measures covered by MARPOL 73/78 Provisions of the Convention relating to by-laws	any measure that is already available in an existing instrument or any measure that does not yet exist but that should be available as a generally applicable measure and that falls within the competence of IMO (IMO, 2006), and not limited to those measures
Establishment Procedures	Amendments to the MARPOL 73/78 Convention	Direct application by the applicant State, approved by the Marine Environment Protection Committee

On one hand, some scholars argue that the concept of PSSAs is merely a repetition of an existing state of affairs and does not provide a substantive legal meaning due to the weakness of its legal basis. Nevertheless, others suggest that PSSAs could find a legal basis in higher law, such as the UNCLOS, Convention on Biological Diversity and World Heritage Conservation List (Roberts, 2006a). Under the UNCLOS, States have an obligation to protect and preserve the marine environment (United Nations Convention on the Law of the Sea, 1982). And it is argued that the regime of Special Areas in article 211 (6) could provide a basis for the legitimacy of protection measures in certain PSSAs (Gjerde and Freestone, 1994). Moreover, the PSSA Guidelines emphasize that each protection measure must have a clear legal basis, which may exist through amendments or approvals of IMO documents (IMO, 2006). Provided that the legal effects of the concept are generally recognized by coastal States, the concept of PSSAs could then be considered in the context of international customary law (Scovazzi, 2004), with PSSAs being regarded as an application of the precautionary principle (Choi, 2022).

The author believes that more support should be garnered for the establishment of sensitive areas. The IMO is highly rigorous in adopting APMs supported by international law, and a clear legal basis is required through IMO approvals (IMO, 2006). Additionally, "as the Law of the Sea Convention defers to IMO on navigational rules, regulations and standards",[2] IMO resolutions are the *de facto* representative instruments for international vessel pollution control.

2.2.2 The requirements and procedures for the establishment of Special Areas and PSSAs

Special Areas must meet three criteria, each with various scenarios, to be identified as such. These criteria are: (a) oceanographic conditions, such as extreme ice conditions or marine conditions leading to the concentration or retention of hazardous substances in waters or sediments; (b) ecological conditions, involving the presence of endangered marine species necessitating protection from hazardous substances; and (c) vessel traffic characteristics, wherein the discharge of hazardous substances during regular operations is deemed unacceptable in the area (IMO, 2002a).

To establish a new Special Area, an application document is submitted to the MEPC, including relevant supporting information, documentation identifying the area, and MARPOL 73/78 draft amendment. The coastal state consults with other countries through IMO, sends notifications, provides evidence, and awaits IMO review within 12 months. Upon IMO confirmation, the coastal state formulates laws, regulations, and methods for ship pollution control. Before implementation, IMO reviews and approves domestic laws, regulations, and measures exceeding international standards in the Special Area.

The PSSA determination is more lenient in terms of requirement items, and the area should meet at least 1 of the listed 3 criteria and the threat posed by international shipping activities should be present for an application to be made. The criteria are as follows: (a) ecological criteria, whereby the ecology of the area is unique, rare, or constitutes a key spawning or critical habitat for organisms, or possesses significant ecological representation; (b) social, cultural, and economic criteria, wherein the area provides substantial economic benefits and has high human dependence; and (c) scientific and educational criteria, as areas of ecological research significance contributing to baseline and monitoring studies (IMO, 2002a). The subject of the geographical extent of PSSAs is often controversial. Decisions on the size of PSSAs, which depend only on a value judgment as to whether or not their waters require special protection, so vague definitions or unclear provisions in the resolution can lead to ambiguity as to their geographic extent. The proposed size of the Western European PSSA includes areas that MPEC considers not to qualify as PSSAs, but MPEC's reasoning is weak.[3]

The procedure for applying for the designation of a PSSA is relatively simple and swift compared with the designation of a Special Area. The coastal state needs to submit the application together with the relevant protective measures to the MEPC, and the responsible subcommittee will review the materials and finally make the decision (IMO, 2002a). The IMO resolution serves as the basis for the establishment of PSSAs without requiring the support of other international treaties or procedures.

2 IMO, Comments made by the Division for Ocean Affairs and the Law of the Sea of the United Nations (DOALOS) in Connection with Issues Raised in Document LEG 87/16/1 (October 2003), IMO Doc. LEG 87/WP.3, para.9.

3 IMO, 'Designation of a Western European Particularly Sensitive Sea Area', LEG87/16/1(15 September 2003).

2.2.3 Dilemma of common interests in the establishment process

Area-based Shipping Management Tools encounters legal procedural challenges during its establishment. A proposal should be submitted to the MEPC for the designation of a marine area as a Special Area, but there is no explicit subject matter requirement for the proponent of the proposal (IMO, 2002a). Reference is made to the application requirements of the PSSA, which provide that the delineation of a PSSA, in accordance with the Revised Guidelines for the Identification and Designation of PSSAs, requires a coordinated proposal to the IMO by one or more Member Governments in respect of specific sea areas of common interest (IMO, 2006). In practice, several European, American and Oceanian States have actively applied for PSSAs in a joint manner. Notably, the Wadden Sea PSSA, Western European Waters PSSA, and Baltic Sea PSSA are examples of joint applications.

Coastal States rarely agree on how to work together on marine conservation and management (Sandwith et al., 2001). On the high seas, however, there may be an implementation dilemma with regard to the expression "common interest in a PSSA". According to Article 87 of the UNCLOS, the high seas are open to all States, whether coastal or land-locked (United Nations Convention on the Law of the Sea, 1982), and the freedom of the high seas is exercised under the conditions laid down by the UNCLOS and by other rules of international law. Consequently, all States may claim a "common interest" with respect to the high seas.

This raises the issue that it would contradict the principle of common interest if only a small number of Member Governments jointly applied for a PSSA located in the high seas. Conversely, if all Member Governments were required to propose the establishment of such an area, it would not align with the practical realities. A practical solution would involve States parties to a regional agreement or other multilateral agreements, where a particular marine area falls under the agreement's coverage, making a joint proposal that reflects the "common interest" of all concerned States parties (Roberts et al., 2010). However, this approach may not cover all situations due to the existence of preconditions. Taking the Baltic Sea as an example, MEPC, when discussing the proposal to designate parts of the Baltic Sea as a PSSA, had met with strong opposition from the Russian Federation. The Russian Federation believes that all States with an interest in the area participate in the discussion process to form a common special program. The other Baltic States concerned, on the other hand, argued that the area was not part of any waters under Russian jurisdiction and that it did not have a right of veto. The existence of a common interest became the centerpiece of Russia's veto, and the MEPC ultimately did not support Russia, designating the Baltic Sea as a PSSA in addition to Russian waters (Uggla, 2007).

In addition, when analyzing the common interests in a given maritime area, the interests of important flag States have to be taken into account, in addition to the jurisdiction of the coastal State. The uncertainty as to the scope, extent and necessity of the establishment of a broad consensus creates ambiguity in the application process. Perhaps this is one of the reasons why shipping management tools are typically confined to national jurisdictions and difficult to extend effectively to marine ABNJ.

2.3 Status of and conflicts over the APMs in Special Areas and PSSAs

2.3.1 Status of existing measures

International experience has clearly demonstrated that merely marking an area on a chart as being environmentally significant for protection and does not automatically provide protection for that area (Roberts et al., 2010). The identification of protected areas and the adoption of related protective measures are distinct yet interconnected matters (Roberts, 2006b). In terms of the implementation of preventive measures, Special Areas is managed mainly through the relevant bylaw provisions of the MARPOL to achieve environmental protection objectives, employing emission standards to limit the discharge of specific pollutants from ships; whereas PSSA utilize a broader array of APMs, such as restricting ship activities in specific regions (Zhao, 2021). Measures shall start to apply to ships after a period of publicity following the review process.

The protective measures that can be taken in Special Areas are scattered in the discharge rules and specific standards formulated by Annex I, Annex II, Annex IV and Annex V of the MARPOL 73/78, which is reflected in the restrictions and prohibitions of oil pollution, toxic liquids, garbage and air pollutants (IMO, 2023d). The Baltic Sea area is the first Special Area under Annex IV (IMO, 2016). Taking the Baltic Sea as an example, Resolution MEPC.200 (62) stipulates the requirements for sewage discharge and reception facilities of passenger ships operating within a Special Area intending to discharge treated sewage effluent into the sea (IMO, 2011). The emission requirements of the Baltic Sea Zone will come into force in three phases, 2019 for new passenger ships, 2021 for existing passenger ships, and 2023 for existing passenger ships en route directly to or from a port located outside the Special Area and to or from a port located east of longitude 28°10' E within the Special Area that do not make any other port calls within the Special Area (IMO, 2016). In general, regulations prohibit passenger ships from discharging sewage in Special Areas, unless the ship has an approved sewage treatment plant certified by the competent authority (IMO, 2012). When the competent authority checks its type approval certificate, sewage treatment plant installed on passenger ships intended to discharge sewage in specific regions must also fulfill the nitrogen and phosphorus removal norms (IMO, 2012). Sewage from an approved sewage treatment plant operating must not produce visible floating solids nor discolor the surrounding water (IMO, 2011).

Regarding PSSAs, the corresponding APMs are more diverse and selective. From the base option, it covers the strict enforcement of MARPOL discharge regulations, involving restrictions and prohibitions on specific pollutants like oil, garbage, sewage and air pollutions, supplemented by equipment requirements for ships and installation requirements for ship traffic services (IMO, 2006). In addition, APMs also added ships routing measures and other more effective measures to protect the marine environment, such as rounding routes and mandatory pilotage. All ships or certain classes of ships should avoid areas where navigation within the prescribed limits is particularly dangerous or important to avoid casualties (IMO, 2006). Measures that could also be considered include the

adoption of ship routing and reporting systems near or within the area in accordance with the International Convention for the Safety of Life at Sea (SOLAS) and the General Rules for Ship Routing and the Guidelines and Standards for Ship Routing Reporting Systems (IMO, 2006). MEPC was encouraged to provide more specific types of APMs and to specify the effect of APMs on the effectiveness of foreign vessels (Choi, 2022). Table 3 illustrates the currently established PSSAs and their corresponding protection measures.

Despite the establishment of the PSSA regime, only 15 areas have been identified as PSSAs. One noteworthy phenomenon is that most member States have not actively adopted ship routing measures through the establishment of PSSAs. Compared with the cumbersome declaration of PSSAs and APMs, some countries, such as New Zealand and the United States, have opted to seek the consent of the IMO directly for the adoption of separate ship routing measures, so as to achieve the same restraining effect with simpler procedures (Peet, 1994). This raises questions about the value and effectiveness of the existing PSSA regime (Peet, 1994).

2.3.2 Doubts about the power allocation and power conflicts

As mentioned earlier, the designation of a PSSA in terms of its environmental protection value does not alter the existing rights and powers of States to pass ships through the designated area, as stipulated by UNCLOS. Only the realistic application of the APMs can provide a basis for the exercise of those rights for the management of shipping by coastal States (Roberts et al., 2010). However, it is crucial to emphasize that, regardless of the establishment of special maritime zones and APMs, the mandatory effect of such measures cannot affect the rights of States under the UNCLOS, such as the right of innocent passage (Frank, 2005).[4] The conflicts in this context arise from disagreements between the existing rights and powers of the designated area and the power to set relevant APMs and control behavior within the area. While the creation of PSSAs aims to enhance environmental protection, it must be navigated within the confines of UNCLOS provisions. This delicate interplay raises questions about the scope and limitations of PSSA authority. The dynamic between coastal State jurisdiction and flag State rights becomes particularly evident in instances like the application to extend the Great Barrier Reef PSSA to the Torres Strait.

Australia and Papua New Guinea's application in 2003 for the extension of the Great Barrier Reef PSSA to the Torres Strait met with strong protests from other maritime States. The reason behind the opposition was that the Torres Strait, as a "waters forming straits used for international navigation", should be subject to the Transit Passage regime under the UNCLOS, allowing for the exercise of freedom of navigation and overflight for continued, uninterrupted, and expeditious transit (United Nations Convention on the Law of the Sea, 1982). The establishment of a compulsory pilotage requirement would infringe upon the right of transit passage of the flag State. The distribution of powers between flag State jurisdiction and coastal State control in the three maritime areas of the high seas, the EEZ, and the territorial seas further complicates matters.

Any maritime area has the opportunity to apply for designation as a PSSA. However, most of the ABMTs implemented by IMO are under national jurisdiction. Extending PSSAs to the high seas may attract a lot of opposition due to perceived infringements on the

TABLE 3 Currently 15 PSSAs and APMs.

PSSAs	Associated Protective Measures
1. Great Barrier Reef, Australia	compulsory pilotage and a mandatory ship reporting system
1.1 Torres Strait, Australia and Papua New Guinea	a two-way shipping route through the Strait
1.2 South-West Coral Sea, Australia	a two-way shipping route
2. Archipelago of Sabana-Camagüey, Cuba	an area to be avoided by ships, outside of which lie several traffic separation schemes
3. Malpelo Island, Colombia	an area to be avoided by all fishing vessels and large ships in excess of 500 gross tonnage
4. Florida Keys, United States	areas to be avoided by all ships carrying cargoes of oil and hazardous material and all ships greater than 50 meters in length
5. Wadden Sea, Netherlands, Denmark and Germany	a mandatory deep-water route and traffic separation scheme
6. Paracas National Reserve, Peru	an area to be avoided by large ships carrying oil or hazardous materials
7. Western European Waters, Belgium, France, Ireland, Portugal, Spain and United Kingdom	areas to be avoided, outing measures and a mandatory ship reporting system
8. Canary Islands, Spain	areas to be avoided, traffic separation schemes, and a mandatory ship reporting system
9. The Galapagos Archipelago, Ecuador	mandatory ship reporting and two traffic separation schemes
10. Baltic Sea, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland and Sweden	several ship routeing and protective measures, including areas to be avoided, deep-water routes, and traffic separation schemes
11. Papahānaumokuākea Marine National Monument, United States	an extension to areas to be avoided and a mandatory ship reporting scheme for ships of 300 gross tonnage or greater, fishing vessels and all ships that develop an emergency
12. Strait of Bonifacio, France and Italy	mandatory ship reporting for ships of 300 gross tonnage and over
13. Saba Bank, Netherlands	an area to be avoided by ships greater than 300 gross tonnage, and a mandatory no anchoring area designed to prevent damage to the fragile coral banks just beneath the surface of the water
14. Jomard Channel, Papua New Guinea	routeing systems including four, two-way routes and a precautionary area
15. Tubbataha Natural Park, Philippines	an area to be avoided by all ships of 150 gross tonnage and a recommendation for pilotage for large ships and those carrying hazardous materials

4 IMO, 'Torres Strait PSSA Associated Protective Measure – Compulsory Pilotage Submitted by Australia and Papua New Guinea', LEG89/15 (2004).

principle of freedom of the high seas. This principle grants all States the right to exercise freedom of navigation, overflight, laying submarine cables and pipelines, constructing artificial islands and other installations permitted under international law, fishing, and conducting scientific research exclusively for peaceful purposes. The restrictive nature of PSSAs and Special Areas, which limit or prohibit activities such as exploitation and navigation, makes their effective extension to ABNJ challenging, as they will inevitably detract from, or even jeopardize, the exercise of the right to freedom of the high seas by other States.

Coercive measures taken in certain sensitive areas through IMO resolutions might interfere with the rights and interests of other States (Roberts et al., 2010). As the United Nations Division for Ocean Affairs and the Law of the Sea (DOALOS) has pointed out, APMs that violate the principle of freedom of navigation are unacceptable.[5] The designation of the Baltic Sea (except Russian waters) as a PSSA in 2005 sparked intense debate within the IMO, involving a conflict between the fundamental principles of international law balance, territorial sovereignty, and freedom of the high seas (Uggla, 2007). The PSSA has been questioned as to whether the criteria are too broad and too frequently used (Detjen, 2006). Even if these specific measures are taken on the high seas with coercive force, they may still affect the rights and interests of third parties (Roberts et al., 2010). Irrespective of the rules governing Special Areas and PSSAs, these coercive measures cannot impede the rights of states under UNCLOS to pass through designated routes (Frank, 2005). Under the PSSA regime, if States were able to establish specific APMs through IMO resolutions, it is conceivable that they could enforce these measures on the high seas as a condition of entry. IMO has been relatively cautious in adopting these measures.

2.3.3 Coexistence and challenges under the global ocean governance system

Ideally, there is a need for a unified instrument that encompasses various measures to identify and protect a designated area (Gjerde and Ong, 1993; Trinder et al., 1994), enabling the full integration of all relevant activities within the particular area. However, the current situation is marked by chaos. Many route control measures were already in place before the advent of the Area-based Management Tool for shipping. These routing measures, such as those outlined in the International Convention for the Safety of Life at Sea (SOLAS) and the General Provisions for Ship Routing (GPSR), were primarily aimed at enhancing ship navigation safety. Unfortunately, their effectiveness in protecting the marine environment has not been duly recognized. The emergence of Special Areas and PSSAs has partially addressed this gap in Area-based Management Tools for marine protection. Nevertheless, the adoption of APMs under the IMO Area-based Management Tool for shipping is still limited to one sector of ocean governance: shipping (Kachel, 2008). Considering the complementary functions of APMs and the previous coupling of different Area-based Management Tools, the existing framework of global governance for marine protection requires not only the exploration of other entry points for action to protect the marine environment beyond the shipping traffic, but also attention to the conflicts and cooperation between different Area-based Management Tools in the shipping sector.

The pursuit of comprehensive marine protection requires the integration of different regulatory approaches. Although the existing ABMTs for shipping strives to reconcile the traditional governance system outlined in UNCLOS with jurisdictional constraints, it possesses certain limitations. Notably, the IMO's primary focus lies in the regulation of international shipping, particularly vessel traffic characteristics, rather than in the assessment of oceanographic and ecological conditions. Consequently, assessments concerning ecological conditions may be better conducted and validated by other relevant bodies. Moreover, the influence of political pressures within the IMO must not be underestimated. The ambiguity surrounding PSSA criteria, coupled with the strong political influence of certain developed nations (IMO, 2001), may lead to IMO decisions that contradict the principles of intra-generational equity and sustainable development (Kachel, 2008).

The recognition of coherent ecosystems in the ABMTs for shipping was highlighted in the report on the work of the United Nations Informal Consultative Process on Oceans and the Law of the Sea during its seventh meeting. This report concluded that establishing PSSAs facilitates the implementation of an ecosystem approach, allowing additional protective measures to be implemented for vulnerable environments (UNGA, 2006). But the IMO Guidelines are not clearly defined, leaving MEPC with a great deal of leeway in deciding whether a proposal meets the criteria, provoking discussion and controversy. In practice, unlike the characteristics of areas previously granted the status of PSSAs, the Baltic PSSAs and the Western European PSSAs are not large contiguous sea areas, but rather consist of particularly vulnerable fragments of cultural landscapes shaped by human activities. The reason for the dispute is that the definition is vague as to whether there is a requirement for ecological coherence (Kachel, 2008). The ambiguity surrounding PSSA criteria presents a challenge that necessitates a more refined and universally accepted definition, allowing for a clearer delineation of eligible areas. The occurrence and recognition of such a situation needs to be complemented by other ABMTs.

IMO governance on shipping is based on global and regional cooperation. IMO remains as the central focus, while some regionally based initiatives have emerged to higher the ambition level of maritime governance (van Leeuwen, 2015). For example, in some regions the UNEP Regional Seas Programme has mobilized regional cooperation in support of IMO maritime conventions (Chircop, 2019). The Special Area provisions of the MARPOL Convention explicitly reflects regional sensitivity, as a Special Area with stronger standards regarding vessel discharges or emissions than global general requirements. Existing regulations stipulate that member countries must jointly propose the establishment of PSSAs and relevant APMs, posing a substantial

5 IMO, Comments made by the Division for Ocean Affairs and the Law of the Sea of the United Nations (DOALOS) in Connection with Issues Raised in Document LEG 87/16/1 (October 2003), IMO Doc. LEG 87/WP.3.

obstacle to their mandatory implementation. PSSAs necessitate a specified level of harm determination before protective measures can be enacted, making their operational implementation on the high seas unsatisfactory. Despite being non-binding, PSSAs require a demonstrable link between shipping activities and the risk of harm, which can be challenging to establish on the high seas. On the high seas, it can be challenging to establish such links, as collisions between vessels and large marine animals are difficult to recognize, groundings are unlikely to occur, and oil spills at sea may go unreported (Nordtvedt Reeve et al., 2012). Moreover, in practice, the IMO requires that the relevant protective measures must have a clear legal basis; even if they do, it is reluctant to agree to the adoption of such measures if the applicant State fails to make sufficiently clear the need for their application (Roberts, 2007).

2.4 Extrinsic positioning and intrinsic benefits of IMO's ABMTs for shipping

The establishment of the Special Areas and PSSAs system was strongly influenced by the concept of marine protected areas (MPAs). The protection of marine areas under global, regional and national arrangements, as well as under the provisions of the IMO, was extensively described in the 1991 guidelines (IMO, 1992). With the 2001 Guidelines further distinguishing and delineating the elements of MPAs, Special Areas and PSSAs became independent types of special MPAs to safeguard special areas from international shipping activities. There are many scholars who regard them as a specialized type of MPA(G. Kelleher et al., 1995; Agardy, 1997; de la Fayette, 2001) or evaluate them as "true MPAs" because of their broad applicability (Roberts, 2007). Beyond their classification as specialized MPAs, the intrinsic value of IMO Area-based Management Tool for Shipping goes far beyond their surface significance. Certain scholars have affirmed the value of IMO Area-based Management Tool for Shipping (Warren, 1994), recognizing the importance of the regime of Special Areas and PSSAs for the protection, restoration, wise use, understanding and enjoyment of the world's marine heritage (Roberts, 2006b).

Firstly, Special Areas and PSSAs serve as authoritative indicators of the vulnerability of the marine ecosystems with their unique assessment criteria, attracting the attention of governments, researchers, and environmentalists alike. Moreover, the Special Area and PSSA regimes empower the relevant coastal states to adopt targeted APMs. The issue of environmental jurisdiction balance between flag states and coastal states has long been a topic of intense discussion. In cases where flag State regulation is absent or insufficient, the Special Area and PSSA regimes breaks away from the traditional exclusive jurisdiction granted to flag States under the principle of maritime liberalism and expands the jurisdiction of coastal States over the marine environment, which enhances global efforts to address pollution from ships and other maritime activities (Han et al., 2017). Such regimes have been questioned in case-by-case discussions because of their weak legal basis and functional substitutability (Peet, 1994). Critics have argued that the PSSA regime is merely a superficial acknowledgment of the unique character of an area and lacks substantial significance (Molenaar, 1998). They claim that coastal States might use Special Areas and PSSAs as mere political tools to extend their jurisdiction over foreign vessels. According to this view, if existing measures provide sufficient protection, new establishment is redundant; if current measures are inadequate, new ones should not just build on these ineffective measures (Roberts, 2006b).

However, from the point of view of the ecosystem approach and global environmental governance, IMO Area-based management tool system overcomes the fragmentation of maritime zoning jurisdiction and isolated measures under the traditional UNCLOS system of marine environmental management (Jin, 2015). It represents a significant initiative for the coordination, prevention, and control of pollution from ships. As the international community continues to recognize the significance of these management tools, further research and collaboration are necessary to ensure their continued effectiveness in safeguarding our oceans for future generations.

3 The ABMTs regime under the BBNJ agreement

3.1 The process of establishing ABMTs under the BBNJ agreement

States possess the sovereign right, in line with the United Nations Charter and international law principles, to develop and utilize their own resources based on their environmental policies. They also bear the responsibility to undertake appropriate measures, ensuring that activities within their jurisdiction or control do not harm the environment of other States or ABNJ. The legal principles guiding States in assuming equivalent obligations in such areas, like the high seas, remain unclear. Consequently, there is controversy as to whether certain environmental issues that conflict with the traditional legal regime of the freedom of the high seas, including the establishment of ABMTs, such as Marine Protected Areas (MPAs), are justified under international law (Shi and Chang, 2017).

Before the BBNJ Agreement, there was a lack of international legal instrument providing for the establishment of ABMTs or procedures to promote ecological management in international waters. The Special Areas and PSSA criteria in the IMO, however, can be seen as a robust starting point for cooperative conservation efforts, although attempts to apply them in the high seas have proven challenging. Conceivably, without a global agreement to build scientific, legal and technical capacity for managing high seas areas, MPAs may only be established in regions surrounded by developed countries (Nordtvedt Reeve et al., 2012). The BBNJ Agreement provides explicit rules for the establishment of ABMTs beyond national jurisdiction, promoting the establishment of such tools in high seas. The BBNJ Agreement incorporates the objective of "strengthen resilience to stressors, including those related to climate change, ocean acidification and

marine pollution" for the ABMTs regime. This reflects the aim of integrating responses to climate change factors into the system of ABMTs.

The marine scientific research is still developing (Warner, 2017), understanding critical information about the distribution of marine biodiversity and the vulnerability of these ecosystems to human activities is insufficient (De Santo et al., 2019). As a result, there is scientific uncertainty about the specific impacts of human activities on marine ecosystems, the relationship between actions and damage, and how to eliminate the effect. Applying the precautionary approach is to improve the management of conservation and sustainable use of marine biodiversity by guiding the states' behavior based on "scientific uncertainty" (Wagenaar, 2022).

3.1.1 Proposals, consultations on and assessment

Articles 19 and 24 of the BBNJ Agreement stipulated that proposals and emergency measures shall be based on the best available scientific and information, taking into account ecosystem approaches and precautionary approaches. This reflects the BBNJ Agreement's approach to addressing scientific uncertainty, emphasizing both the utilization of the best available science and the prohibition of using the lack of sufficient scientific evidence as a justification for inaction. Regarding the specific content of the proposal, the BBNJ Agreement stipulates that the proposal should provide an explanation of the marine environment and biodiversity within the identified area. Additionally, it should specify relevant scientific inputs and, where available, the traditional knowledge of indigenous peoples and local communities. Subsequently, after the Secretariat receives the proposal and conducts a preliminary review by scientific and technical institutions, the proposal needs further negotiation and evaluation. At this stage, States, in particular adjacent coastal States, bodies of relevant legal instruments and frameworks and relevant global, regional, subregional and sectoral bodies, and indigenous peoples, local communities, the scientific community, civil society, and other relevant stakeholders can submit any additional relevant scientific inputs for the negotiation and evaluation of the proposal.

In the process of formulating proposals, parties shall collaborate and consult with relevant States, bodies of relevant legal instruments and frameworks, and other stakeholders. Additionally, the BBNJ Agreement stipulates ten elements that should be included in the proposal, and further revisions can be made by the Scientific and Technical Body as needed for deliberation and approval by the Conference of the Parties. After receiving a written proposal, the Secretariat should publicize it and submit it to the Scientific and Technical Body for a preliminary review. Subsequently, open negotiations and evaluations of the proposal are conducted with all relevant stakeholders. The Conference of the Parties, based on the final proposal and drafted management plan, taking into account the contributions and scientific input received during the consultation process, and the scientific advice and recommendations of the Scientific and Technical Body, shall makes the final decision, according to the Article 22 of the BBNJ Agreement.

3.1.2 Decision-making

The BBNJ Agreement takes the consensus-based decision-making as the priority. However, the Article 23 of the BBNJ Agreement stipulates that if no consensus is reached, decisions and recommendations on MPAs shall be taken by a three-fourths majority of the Parties present and voting, before which the COPs shall decide, by a two-thirds majority of the Parties present and voting that all efforts to reach consensus have been exhausted. The objective parties cannot be binding by the decisions. But if a party want to make an objection, it needs fulfill some requirements, such as objection shall be based on specific reasons, including the decision is inconsistent with the BBNJ Agreement and the UNCLOS. In addition, the Article 23 stipulates objecting parties to take alternative measures or actions that are equivalent in effect to the decision, and not take measures or actions that would undermine the effectiveness of the decision. The establishment of this voting mechanism provides an opportunity for the smooth establishment and implementation of ABMTs, particularly in cases where there may be differences of opinion on the legitimacy and necessity of such tools. This also would lead to the numerical advantage becoming the dominant factor in the negotiations among dissenting States groups (Buzan, 1981). Therefore, the consensus-based decision-making shall be adhered to whenever possible. The consensus-based decision-making process reflects an art of negotiation. The requirement for consensus means that States can achieve a basic agreement through repeated negotiations and compromises. During this process, there are opportunities for lobbying, negotiation, and transactions among States. This allows States that may suffer losses due to a decision to have a chance for compensation without violating their initially expressed intentions. For IMO's decision making concerning marine environment, consent should be sought from all countries with jurisdiction or in the region of potential impact, reflecting the same idea.

3.1.3 Implementation, monitoring and review

Articles 25 and 26 of the BBNJ Agreement stipulate the implementation, monitoring and review of area-based management tools. Contracting States shall ensure that activities under their jurisdiction or control that take place in ABNJ are conducted consistently with the decisions. This implies that the implementation stage should also adhere to requirements related to the scientific aspects based on the best available science and scientific information. The BBNJ Agreement includes a general obligation for Parties to implement and monitor the implementation of ABMTs, as well a report on the implementation, but does not go into any detail regarding what this will entail (IUCN, 2023). The implementation of existing ABMTs, including the International Maritime Organization's Special Areas and PSSAs, can provide valuable lessons for the COPs of the BBNJ agreement in further developing more detailed implementation rules.

For assessing the effectiveness of the ABMTs, the Scientific and Technical Body should monitor and conduct periodic reviews of the relevant measures. Following the review, the COPs shall take decisions or recommendations on the amendment, extension or revocation of ABMTs on the basis of the best available science and scientific information. Therefore, in the monitoring and review stage of ABMTs, special attention should be given to scientific issues. Monitoring provides data on the current status and trends of biodiversity, offering information for the development of conservation policies and the evaluation of the effectiveness of existing regulations and policies (Schmeller et al., 2017). Monitoring activities can serve as guiding tools to assess formulated strategies and identify factors affecting conservation goals, providing information for adaptive management. Therefore, reasonable monitoring measures can ensure the effectiveness of such tools.

3.2 International cooperation and coordination

The BBNJ Agreement emphasizes cooperation and coordination with relevant legal instruments and frameworks and relevant global, regional, subregional and sectoral bodies (IFBs) with regard to ABMTs. As an implementing agreement for UNCLOS, the BBNJ Agreement shall be interpreted and applied in the context of and in a manner consistent with the UNCLOS. Article V of the BBNJ Agreement endorsed the principle and stipulates that the agreement shall be interpreted and applied in a manner that promotes coherence and coordination with relevant IFBs (United Nations, 2023). Cooperation with relevant IFBs is also stressed in the Article 8 of the BBNJ Agreement. ABMTs including MPAs, are one of the four elements of the "package of issues" in the BBNJ Agreement, a vital tool for biodiversity conservation. Under an ecosystem approach, the establishment and management of MPAs should not be considered solely in terms of States, but rather in terms of ecosystems or bioregions when the ecosystems transcend national boundaries (Convention on Biological Diversity, 2004a). Adopting an ecosystem approach can facilitate integrated ocean management across sectors and sectors (Convention on Biological Diversity, 2004b). Article 7 of the BBNJ Agreement regulates that Parties shall be guided by an ecosystem approach. The application of an ecosystem approach aims to integrate the various legal and management strategies relevant to area- and species-based conservation, address the issue of the current fragmented legal and institutional framework (Wagenaar, 2022).

In addition to MPAs, other forms of ABMTs at the global level include Special Areas and PSSAs established by the IMO, Regional Environmental Management Plans and Areas of Particular Environmental Interest established by ISA, seasonal or year-round area fisheries closures set by regional fisheries management organizations, and vulnerable marine ecosystems (De Santo, 2018). In this perspective, international cooperation and coordination is essential important for the implementation of ABMTs regime of the BBNJ Agreement. International cooperation and coordination is stipulated in nearly all the stages of the established of the ABMTs including MPAs in the BBNJ Agreement, such as consultations on and assessment of proposals (Art. 21), establishment of area-based management tools, including marine protected areas (Art.22), implementation (Art. 25) and monitoring and review (Art.26). This reflects the application of the BBNJ Agreement's the non-prejudice clause in the ABMTs regime. Besides, if an ABMT under the BBNJ Agreement is currently declared by a State or an international organization, it applies only to States that have agreed to establish the ABMT, and non-parties can disregard the measures taken in the ABMT (Petra, 2012). Under the article 25 of the BBNJ Agreement, non-parties that are entitled to become Parties will be encouraged by contracting parties to adopt measures supporting the decisions and recommendations of the COPs on ABMTs. Besides, non-parties shall not be discharged from the obligation to cooperate.

In the realm of global environmental governance, the consideration of national interests by sovereign states often conflicts with the emerging powers in the governance process. As a result, modern international law generally adopts the soft law or framework convention plus protocol model in the environmental field. Currently, the most pressing issue revolves around the legal basis of the PSSA, which lacks a specific international convention. This absence of a clear legal foundation poses potential challenges for the concrete application and future development of the system, necessitating additional support from its own or other shipping management tools to ensure effectiveness. While the existing IMO Area-based Management Tool for shipping is a step in the right direction, it becomes apparent that a more comprehensive strategy is necessary to bridge the gaps and harness the synergies between different ABMTs. The BBNJ Agreement may play an important role in the coordination between different ABMTs for vessel pollution control.

4 Analysis and recommendations on coordination between IMO and BBNJ agreement regimes for vessel pollution control

4.1 Understanding the pursuit of "not undermining" and coordination

To address common challenges faced by humanity, global governance is gradually strengthening, and the role of international organizations is becoming more prominent. In the case of environmental pollution or destruction in the global commons, international law provides a governance framework for coordinated efforts by States and international organizations. International organizations such as the IMO facilitate cooperation among States and establish corresponding international regimes. States, based on their jurisdiction and authorization from international regimes, engage in monitoring and enforcement actions against potential acts of pollution or destruction. The BBNJ Agreement claims that it does not undermine relevant legal instruments and promotes coordination with those instruments, while tries to promotes coherence and coordination with those

instruments. The tension between these two aspects exists. The Article 22 of the BBNJ Agreement as a whole arguably creates a comprehensive framework for ABMTs (Tang, 2024). The COPs of the BBNJ Agreement are mandated to establish arrangements for regular consultations, aimed at enhancing cooperation and coordination with relevant IFBs, as outlined in Article 22(3).The Article 22(4) of the BBNJ Agreement stipulates that the COPs may decide, as appropriate, to develop a mechanism regarding existing ABMTs, adopted by relevant IFBs. The term 'not undermining' could focus on the effectiveness of relevant measures (Langlet and Vadrot, 2023). This implies that "not undermine" is not equivalent to "not interacting" or "not affecting". The COPs could exert influence over relevant IFBs including IMO either directly or indirectly. Consequently, the BBNJ agreement should not undermine the authority of the IMO in the management of shipping, while it can provide such cross-sectoral and ecosystem-based ABMTs to enhance control measures for ship pollution.

4.2 Using compatibility clauses to enhance coordination

The term "competent international organization" in Article 211 (1) and (2) of the UNCLOS refers to the IMO (Nordquist et al., 1991). Similarly, the "generally accepted international rules, procedures, and practices" mentioned in Article 94(5) of the Convention also pertain to the relevant rules, procedures, and practices of the IMO (Nandan et al., 1995). The IMO has played a leading role in controlling ship-source pollution. Designating an area as a PSSA itself does not have legal significance. It is the additional protective measures that provide normative significance to PSSAs. Member States of the IMO are required to take all appropriate measures to ensure that vessels flying their flag comply with these additional protective measures. The BBNJ Agreement will also have an impact on ship pollution activities that threaten the conservation of biodiversity in the high seas. The harmonization of the BBNJ Agreement can be done through 'compatibility clauses'. Many international treaties will set a clause in their texts to deal with the relationship between them and related treaties, such as Article 301 of UNCLOS. These clauses are commonly referred to as "compatibility clauses". The relationship between international treaties is mainly handled with reference to the compatibility clauses in the treaties themselves. Compatibility clauses can play a perfect role in building bridges when dealing with the coordination between international treaties. As mentioned above, on the one hand, the final legal text of the BBNJ Agreement stipulates compatibility clauses in many places and explicitly stipulates coordination and cooperation with other international instruments and legal institutions. For example, Article 5 of the BBNJ Agreement provides a general regulation on the relationship with other relevant international legal instruments and institutions. Article 41 also stipulates the cooperation of all parties with other relevant instruments and institutions in capacity building and marine technology transfer.

The IMO's extensive experience in shipping management facilitates smoother negotiations among stakeholders during the formulation of management measures (Roberts and Tsamenyi, 2007). Relevant measures implemented in PSSAs include measures related to vessel navigation, such as delineating avoidance zones and no-anchor zones, but these measures should not extend beyond the scope of shipping or expand into activities such as fishing or mining (Scovazzi, 2014). The BBNJ Agreement focuses on areas beyond national jurisdiction, adopting a comprehensive perspective aimed at safeguarding marine biodiversity from various threats. However, the potential adoption of measures limiting navigation on the high seas under the COPs of the BBNJ Agreement or by established competent international organizations raises concerns about undermining the existing governance system, wherein the IMO holds a central role in shipping management. There are doubts regarding whether organizations other than the IMO can effectively supervise navigation restrictions and management in ABMTs, given the IMO's unparalleled expertise and experience in international shipping management. Hence, it is imperative that the relevant rules of the BBNJ Agreement are interpreted and applied in a manner that respects and does not undermine the pertinent legal instruments of the IMO, thereby preventing any adverse impacts on the established IMO frameworks.

4.3 Prompting information exchange between the IMO and the BBNJ Agreement

For the coordination and cooperation among international regimes, it is essential to emphasize the coordination role of the COPs among existing international legal instruments and institutions. Cooperation and coordination among international organizations can initially be achieved through voluntary agreements, gradually evolving into stable or regular mechanisms for collaboration and exchange. Stable or regular mechanisms for cooperation and exchange are crucial because the foundation of collaboration is not merely trust but the continuity of relationships. When interactions have the potential to endure over an extended period, participants tend to consider their future together, emphasizing the importance of sustained relationships. Moreover, when participants lack access to effective information, the uncertainty of collective action increases, making international cooperation extremely challenging. Therefore, regular information exchange and sharing between competent international organizations become crucial to facilitate effective communication and collaboration. For example, the IMO has strengthened control over ship black carbon emissions in recent years. In the index of MEPC resolutions and Guidelines related to MARPOL Annex VI, official resolutions or regulations classified as "Black Carbon related documents" are scarce, only "Protecting the Arctic from shipping Black Carbon emissions [MEPC.342(77)]" and "Reporting protocol for voluntary measurement studies to collect Black Carbon data" are available. The relevant resolutions and information can be submitted to the relevant bodies of the BBNJ Agreement through the Secretariat.

Information exchange between the IMO and the BBNJ Agreement is of significant importance for the design and implementation of ABMTs. For instance, the IMO has developed guidelines and standards for the Ship Reporting System, which mandates ships, or specific types carrying particular cargo, to report to coastal states.[6] While most Ship Reporting Systems are within national jurisdiction, there's no explicit prohibition on extending such systems beyond national borders. These systems are also applicable in ABMTs on the high seas, aiding in alerting ships to potential environmental issues such as the presence of ABMTs requiring special attention. Moreover, the Long-Range Identification and Tracking (LRIT), fully implemented by the IMO in 2009, aids in monitoring vessel movements within 1000 nautical miles from the coast, thereby contributing to the implementation of ABMTs established under the BBNJ Agreement. Information exchange is facilitated through communication and interaction between secretariats, authorized by the IMO and the COPs of the BBNJ Agreement.

4.4 Identifying the active role of member States

The States' actions can significantly promote cooperation between regimes or treaties. Through the States with overlapping membership, the generation of new knowledge or ideas may spread from one regime and affect the decision-making of another regime (Bradnee Chambers et al., 2008). Cooperation among international organizations under different departments or treaties the international legal system primarily depends on the actions of individual States (Stoll, 2021). The BBNJ Agreement also stipulates that parties shall promote, as appropriate, the adoption of measures within relevant IFBs of which they are members, to support the implementation of the decisions and recommendations made by the Conference of the Parties regarding the ABMTs. While the BBNJ Agreement does not directly regulate shipping, if ship-source pollution affects the conservation and sustainable use of biodiversity, the BBNJ Agreement's ABMTs may become applicable. Member states can promote coordination between the two institutions.

The IMO, as a sectoral organization with near-universal membership, holds the authority to decide on restrictions impacting the freedom of the high seas, such as limiting navigation in specific areas. These restrictions are obligatory for all its members. However, current practices concerning marine protected areas beyond national jurisdiction do not typically focus solely on limiting navigation on the high seas. It's important to note that measures affecting the freedom of the high seas, including navigation restrictions, necessitate the consent of the States affected to become effective (Freestone, 2018). In practice, the vast majority of navigation measures for ABMTs on the high seas fall under the framework of either the SOLAS or MARPOL Convention (Churchill, 2013). As of March 2, 2024, the SOLAS Convention has been ratified by 168 countries, with ships flying the flags of these countries accounting for 98.91% of the world's total registered tonnage. Similarly, MARPOL has 161 contracting parties, representing 98.89% of the world's total tonnage.[7] It's noteworthy that future members of the BBNJ Agreement often overlap with SOLAS and MARPOL membership. This convergence underscores the importance of member States' actions in facilitating coordination between the regimes of the IMO and the BBNJ Agreement for effective vessel pollution control. As required by the BBNJ Agreement, when proposed measures fall within the scope of IMO's authority, the co-contracting parties can make suggestions to facilitate the IMO in adopting relevant measures.

4.5 Potential application of marine spatial planning

Marine spatial planning contributes to ecosystem-based governance in ABNJ, safeguarding the integrity of ecosystems. While marine spatial planning is predominantly employed within national jurisdictions (European Commission, 2011), its principles are gradually being applied beyond these boundaries. A notable example is the use of marine spatial planning to protect the fragile benthic ecosystems in the Northeast Atlantic from the adverse impacts of deep-sea fishing and to safeguard submarine cables from the effects of deep-sea mining activities (Rayfuse, 2020). The Intergovernmental Oceanographic Commission of UNESCO has been instrumental in advancing the development of marine spatial planning, considering it a public process for analyzing and allocating the spatial and temporal distribution of human activities in specific marine areas to achieve ecological, economic, and social objectives, typically carried out through political processes (Ehler and Douvere, 2009). Under the concept of marine spatial planning, cooperation and coordination can take place between the IMO and the BBNJ Agreement's COPs regarding the application of ABMTs related to vessel pollution control and biodiversity conservation in significant maritime areas.

5 Conclusion

The establishment of the Special Areas and PSSAs system is important for vessel pollution control. Most of the ABMTs implemented by IMO are under national jurisdiction. Special

6 IMO. Resolution MSC.43(64) adopted on 9 December 1994. MSC 64/221 Add. I.

7 Here are the data for Annex I and Annex II of the MARPOL Convention. Annex III: 151 countries have joined, representing 98.54%. Annex IV: 147 countries have joined, representing 96.66%. Annex V: 156 countries have joined. See IMO: Comprehensive information on the status of multilateral Conventions and instruments in respect of which the International Maritime Organization or its Secretary-General performs depositary or other functions, https://www.imo.org/en/About/Conventions/Pages/StatusOfConventions.aspx.

Areas is managed mainly through the relevant bylaw provisions of the MARPOL to achieve environmental protection objectives, employing emission standards to limit the discharge of specific pollutants from ships; whereas PSSA utilize a broader array of APMs, such as restricting ship activities in specific regions. Extending PSSAs to the high seas may attract a lot of opposition due to perceived infringements on the principle of freedom of the high seas. The BBNJ Agreement provides explicit rules for the establishment of ABMTs beyond national jurisdiction, promoting the establishment of such tools in high seas, and emphasizes cooperation and coordination with IMO with regard to ABMTs. It is imperative to foster cooperation and coordination between the COPs to the BBNJ Agreement and the IMO. This collaboration should evolve into a regular mechanism for cooperation and information exchange. Achieving harmonization between the BBNJ Agreement and IMO's regimes can be facilitated through the inclusion of 'compatibility clauses'. To ensure effective coordination of ABMTs between the IMO and BBNJ Agreement regimes, a key emphasis should be placed on the coordinating role of the COPs. Relevant resolutions and information from the IMO can be communicated to the pertinent bodies of the BBNJ Agreement through its Secretariat. Additionally, in cases where ship-source pollution impacts biodiversity conservation and sustainable use, the BBNJ Agreement's ABMTs may come into play. Member states have the opportunity to facilitate coordination on ABMTs between the two institutions. Lastly, under the concept of marine spatial planning, there is an opportunity for cooperation and coordination between the IMO and the BBNJ Agreement's COPs regarding the application of ABMTs.

Author contributions

JW: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Funding acquisition. YZ: Writing – original draft.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This research was supported by the major project of the National Social Science Foundation of China (Grand No.23&ZD166).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Agardy, T. (1997). *Marine Protected Areas and Ocean Conservation* (California: Academic Press). doi: 10.1016/B978-012044455-7/50007-0

Bradnee Chambers, W., K., J. A., and ten H, C. (2008). "Institutional interplay and the governance of biosafety," in *Institutional interplay: Biosafety and trade*. Eds. O. R. Young, W. Bradnee Chambers, J. A. Kim and C. ten Have (United Nations University Press, Tokyo, Japan), 3–19.

Buzan, B. (1981) *Negotiating by Consensus: Developments in Technique at the United Nations Conference on the Law of the Sea*. Available online at: https://www.jstor.org/stable/2201255. doi: 10.2307/2201255

Chircop, A. (2019). The IMO initial strategy for the reduction of GHGs from international shipping: A commentary. *Int. J. Mar. Coast. Law* 34, 482–512. doi: 10.1163/15718085-13431093

Choi, J. (2022). The legal status of Particularly Sensitive Sea Areas (PSSAs): Challenges and improvements for PSSA resolutions. *Rev. Eur. Comp. Int. Environ. Law* 31, 103–114. doi: 10.1111/reel.12420

Churchill, R. (2013). "The growing establishment of high seas marine protected areas: implication for shipping," in *Shipping, Law and the Marine Environment in the 21st Century: Emerging challenges for the Law of the Sea-legal implications and liabilities*. Eds. R. Caddell and D. R. Thomas (Oxon, OX: Lawtext Publishing Limited).

Convention on Biological Diversity (2004a) *Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Seventh Meeting VII/5. Marine and coastal biological diversity*. Available online at: https://www.cbd.int/decisions/cop/?m=cop-07 (Accessed November 20, 2023).

Convention on Biological Diversity (2004b) *Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Seventh Meeting VII/28. Protected areas (Articles 8 (a) to (e))*. Available online at: https://www.cbd.int/decisions/cop/?m=cop-07 (Accessed November 20, 2023).

de la Fayette, L. (2001). The marine environment protection committee: the conjunction of the law of the sea and international environmental law. *Int. J. Mar. Coast. Law* 16, 155–238. doi: 10.1163/157180801X00072

De Santo, E. M. (2018). Implementation challenges of area-based management tools (ABMTs) for biodiversity beyond national jurisdiction (BBNJ). *Mar. Policy* 97, 34–43. doi: 10.1016/j.marpol.2018.08.034

De Santo, E. M., Ásgeirsdóttir, Á., Barros-Platiau, A., Biermann, F., Dryzek, J., Gonçalves, L. R., et al. (2019). Protecting biodiversity in areas beyond national jurisdiction: An earth system governance perspective. *Earth System Governance* 2, 100029. doi: 10.1016/j.esg.2019.100029

Detjen, M. (2006). The Western European PSSA-Testing a unique international concept to protect imperilled marine ecosystems. *Mar. Policy* 30, 442–453. doi: 10.1016/j.marpol.2005.04.002

Ehler, C., and Douvere, F. (2009). *Marine spatial planning: a step-by-step approach toward ecosystem-based management*. IOC Manuals and guides No.53, Paris: UNESCO.

European Commission (2011). *Maritime Spatial Planning in the EU-Achievements and Future Development*. (Luxembourg: Publications Office of the European Union). doi: 10.2771/81687

Frank, V. (2005). Consequences of the prestige sinking for European and international law. *Int. J. Mar. Coast. Law* 20, 1–64. doi: 10.1163/157180805774851553

Freestone, D. (2018). The limits of sectoral and regional efforts to designate high seas marine protected areas. *AJIL UNBOUND* 112, 129–133. doi: 10.1017/aju.2018.45

Gjerde, K., and Freestone, D. (1994). Particularly sensitive sea areas-an important environmental concept at a turning-point. *Int. J. Mar. Coast. Law* 9, 425–468. doi: 10.1163/157180894X00016

Gjerde, K. M., and Ong, D. (1993). Protection of particularly sensitive sea areas under international marine environmental law: Report of the International Meeting of Legal Experts on Particularly Sensitive Sea Areas University of Hull, 20–21 July 1992. *Mar. pollut. Bull.* 26, 9–13. doi: 10.1016/0025-326X(93)90590-G

Han, J., Zhang, S., Lyu, X., and Zheng, M. (2017). Particular Sensitive Sea Area from Perspective of Global Governance. *Navigation of China* 40 (3), 109–112.

IMO (1992). Guideline for the Designation of Special Areas and the Identification of Particularly Sensitive Sea Areas. *Resolution A*. 720 (17).

IMO (1999) *Procedures for the Identification of Particularly Sensitive Sea Areas and the Adoption of Associated Protective Measures and Amendments to the Guidelines Contained in Resolution A.720(17), A 21/Res.885*. Available online at: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/AssemblyDocuments/A.885(21).pdf (Accessed November 20, 2023).

IMO (2001) *Resolution MEPC46/23*. Available online at: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=54a7d0d9967460c72a2bbe99e953699c76fc307e (Accessed November 19, 2023).

IMO (2002a). *Guidelines for the Designation of Special Areas Under MARPOL 73/78 and Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas*. Resolution A22/Res.927.

IMO (2002b) *MARPOL 73/78: consolidated edition* (IMO). Available online at: https://wedocs.unep.org/xmlui/handle/20.500.11822/2381 (Accessed November 19, 2023).

IMO (2006). *Revised Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas*. Resolution A 24/Res.982.

IMO (2011) *Resolution MEPC.200(62)*. Available online at: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.200(62).pdf (Accessed December 24, 2023).

IMO (2012) *Resolution MEPC.227(64)*. Available online at: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.227(64).pdf (Accessed November 19, 2023).

IMO (2016) *Resolution MEPC.275(69)*. Available online at: https://edocs.imo.org/Final (Accessed November 19, 2023).

IMO (2022) *Revised Strategic Plan for the Organization for the Six-year Period 2018 to 2023*. Available online at: https://wwwcdn.imo.org/localresources/en/About/strategy/Documents/A%2032-Res.1149.pdf (Accessed November 19, 2023).

IMO (2023a) *Prevention of Pollution by Garbage from Ships*. Available online at: https://www.imo.org/en/ourwork/environment/pages/garbage-default.aspx (Accessed November 19, 2023).

IMO (2023b) *Particularly Sensitive Sea Areas*. Available online at: https://www.imo.org/en/OurWork/Environment/Pages/PSSAs.aspx (Accessed November 19, 2023).

IMO (2023c) *Protecting vulnerable seas from shipping and marine pollution by International Maritime Organization*. Available online at: https://imohq.exposure.co/protecting-vulnerable-seas-from-shipping-and-marine-pollution (Accessed November 19, 2023c).

IMO (2023d) *Special Areas under MARPOL*. Available online at: https://www.imo.org/en/OurWork/Environment/Pages/Special-Areas-Marpol.aspx (Accessed November 19, 2023d).

IUCN (2023) *The High Seas Biodiversity Treaty:An Introduction to the Agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction*. Available online at: www.twitter.com/IUCN.

Kachel, J. M. (2008). *Particularly Sensitive Sea Areas: The IMO's Role in Protecting Vulnerable Marine Areas* (Berlin Heidelberg: Springer). doi: 10.1007/978-3-540-78779-2

Kelleher, G., Bleakley, C., and Wells, S. (1995) *A global representative system of marine protected areas. Vol.1 : Antarctic, Arctic, Mediterranean, Northwest Atlantic, Northeast Atlantic and Baltic* (Washington, DC: World Bank). Available online at: https://portals.iucn.org/library/node/6893 (Accessed November 19, 2023).

Langlet, A., and Vadrot, A. B. M. (2023). Not 'undermining' who? Unpacking the emerging BBNJ regime complex. *Mar. Policy* 147, 105372. doi: 10.1016/j.marpol.2022.105372

Ma, J. (2014). Study on the system of particularly sensitive sea areas and global marine environment governance. *Tsinghua J. Rule of Law* 22, 368–381.

Molenaar, E. J. (1998). *Coastal State Jurisdiction over Vessel-Source Pollution*. (The Hague: Kluwer Law International).

Nandan, S. N., Rosenne, S., and Grandy, N. R. (1995). *United Nations Convention on the Law of the Sea: A Commentary* (The Hague: Martinus Nijhoff Publishers).

Nordquist, M. H., Grandy, N. R., Rosenne, S., and Yankov, A. (1991). *United Nations Convention on the Law of the Sea 1982: A Commentary* (Dordrecht: Martinus Nijhoff Publishers).

Nordtvedt Reeve, L. L., Rulska-Domino, A., and Gjerde, K. M. (2012). The future of high seas marine protected areas. *Ocean Yearbook Online* 26 (1), 265–289. doi: 10.1163/22116001-92600089

Peet, G. (1994)Particularly sensitive sea areas - A documentary history. In: *International Journal of Marine and Coastal Law*. Available online at: https://heinonline.org/HOL/Page?handle=hein.journals/ljmc9&id=493&div=&collection (Accessed November 19, 2023).

Petra, D. (2012). Marine protected areas in areas beyond national jurisdiction. *Int. J. Mar. Coast. Law* 27, 291–350. doi: 10.1163/157180812X637975

Rayfuse, R. (2020). "Crossing the sectoral divide: modern environmental law tools for addressing conflicting uses on the seabed," in *The Law of the Seabed: Access, Uses, and Protection of Seabed Resources*. Ed. C. Banet (Leiden: Brill Nijhoff), 527–552. doi: 10.1163/9789004391567_024

Roberts, J. (2005). Protecting sensitive marine environments: the role and application of ships' Routeing measures. *Int. J. Mar. Coast. Law* 20, 135–159. doi: 10.1163/157180805774851599

Roberts, J. (2006a). Compulsory pilotage in international straits: the Torres Strait PSSA proposal. *Ocean Dev. Int. Law* 37, 93–112. doi: 10.1080/00908320500474049

Roberts, J. (2006b) *Marine environment protection and biodiversity conservation: the application and future development of the IMO's particularly sensitive sea application and future development of the IMO's particularly sensitive sea area concept area concept*. (Berlin: Springer), 1–289. Available online at: https://ro.uow.edu.au/theses.

Roberts, J. (2007). "Marine environment protection and biodiversity conservation: The application and future development of the IMO's particularly sensitive sea area concept," in *Marine Environment Protection and Biodiversity Conservation: The Application and Future Development of the IMO's Particularly Sensitive Sea Area Concept*, 1–289. doi: 10.1007/978-3-540-37699-6/COVER

Roberts, J., Chircop, A., and Prior, S. (2010). Area-based management on the high seas: possible application of the IMO's particularly sensitive sea area concept. *Int. J. Mar. Coast. Law* 25, 483–522. doi: 10.1163/157180810X525403

Roberts, J., and Tsamenyi, M. (2007). "The regulation of navigation under international law: a tool for protecting sensitive marine environments," in *Law of the Sea, Environmental Law and Settlement of Disputes: Liber Amicorum Judge Thomas A. Mensah*. Eds. T. M. Ndiaye and R. Wolfrum (Leiden: Koninklijke Brill NV).

Roberts, J., Tsamenyi, M., Workman, T., and Johnson, L. (2005). The Western European PSSA proposal: a "politically sensitive sea area." *Mar. Policy* 29, 431–440. doi: 10.1016/j.marpol.2004.07.002

Sandwith, T., Shine, C., Hamilton, L., Sheppard, D., and Phillips, A. (2001) *Transboundary protected areas for peace and co-operation: based on the proceedings of workshops held Bormio (1998) and Gland (2000)*. Available at: https://portals.iucn.org/library/node/7945 (Accessed November 19, 2023).

Schmeller, D. S., Böhm, M., Arvanitidis, C., Barber-Meyer, S., Brummitt, N., Chandler, M., et al. (2017). Building capacity in biodiversity monitoring at the global scale. *Biodivers Conserv.* 26, 2765–2790. doi: 10.1007/s10531-017-1388-7

Scovazzi, T. (2004). Marine protected areas on the high seas: some legal and policy considerations. *Int. J. Mar. Coast. Law* 19, 1–17. doi: 10.1163/157180804773788646

Scovazzi, T. (2014). "Marine protected areas in waters beyond national jurisdiction," in *30 Years after the Signature of the United Nations Convention on the Law of the Sea: the Protection of the Environment and the Future of the Law of the Sea*. Ed. M. C. Ribeiro (Coimbra: Coimbra Editora S.A).

Shi, x., and Chang, Y. (2017). Study on the relationship between HSMPAs and the system of freedom of high seas and its development route. *Chin. J. Maritime Law* 28, 77–86.

Stoll, P.-T. (2021). "A 'New' Law of Cooperation: Collective Action across Regimes for the Promotion of Public Goods and Values versus Fragmentation," in *The Protection of General Interests in Contemporary International Law*. Eds. M. Iovane, F. M. Palombino, D. Amoroso and G. Zarra (Oxford: Oxford University Press), 321–343.

Tang, J. (2024). Form follows function: An initial evaluation of the BBNJ Agreement's achievements regarding the "not undermining" proviso. *Mar. Policy* 159, 105952. doi: 10.1016/j.marpol.2023.105952

Trinder, C., Sparkes, S., and Ottesen, P. (1994). Shipping threats and protection of the great barrier reef marine park-the role of the particularly sensitive sea area concept. *Int. J. Mar. Coast. Law* 9, 507–522. doi: 10.1163/157180894X00034

Uggla, Y. (2007). Environmental protection and the freedom of the high seas: The Baltic Sea as a PSSA from a Swedish perspective. *Mar. Policy* 31, 251–257. doi: 10.1016/j.marpol.2006.08.003

UNGA (2006). *Report on the work of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea at its seventh meeting*. (New York: UN Doc A/61/156).

UNGA (2007). *Oceans and the law of the sea*. (New York: UN Doc A/62/66/Add.2).

United Nations. (2023). *Draft agreement under the united nations convention on the law of the sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction*. Available at: https://digitallibrary.un.org/record/4013217?v=pdf (Accessed March 14, 2024).

United Nations Convention on the Law of the Sea. (1982). *1833 U.N.T.S. 397*. Available at: https://treaties.un.org/doc/Publication/UNTS/Volume%201833/volume-1833-A-31363-English.pdf (Accessed November 19, 2023).

van Leeuwen, J. (2015). The regionalization of maritime governance: Towards a polycentric governance system for sustainable shipping in the European Union. *Ocean Coast. Manag* 117, 23–31. doi: 10.1016/j.ocecoaman.2015.05.013

Wagenaar, T. (2022). A principled approach for BBNJ: An idea whose time has come. *Rev. Eur. Comp. Int. Environ. Law* 31, 399–410. doi: 10.1111/reel.12479

Warner, R. (2017). Environmental Assessment in Marine Areas Beyond National Jurisdiction. In *Proceedings of the Annual Meeting (American Society of International Law)*. 111, 252–255. doi: 10.2307/26628044

Warren, L. M., and Wallace, M. W. (1994). The Donaldson inquiry and its relevance to particularly sensitive sea areas. *International J. Mar. Coastal Law* 9 (4), 523–534. doi: 10.1163/157180894X00043

Yingchun, G. (2009) *Research on Jurisdiction in Exclusive Economic Zone: Particular Areas, Ice-Covered Areas and Particularly Sensitive Sea Area. China Oceans Law Review 2009*. Available online at: https://heinonline.org/HOL/Page?handle=hein.journals/cholr2009&id=736&div=&collection (Accessed November 20, 2023).

Zhang, H. (2014). A study of introducing special region regulations into the environmental protection of south China sea. *Humanities & Soc. Sci. J. Hainan Univ.* 3, 37–42. doi: 10.15886/j.cnki.hnus.2014.03.014

Zhao, C. (2021) *Classification and Development of Area-Based Management Tools in Areas beyond National Jurisdiction. China Oceans Law Review 2021*. Available online at: https://heinonline.org/HOL/Page?handle=hein.journals/cholr2021&id=432&div=&collection (Accessed November 19, 2023).

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 08 April 2024
DOI 10.3389/fmars.2024.1368356

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Nadia Khadam,
Fatima Jinnah Women University, Pakistan
Wen Duan,
Hainan University, China

*CORRESPONDENCE
Yitong Chen
chenyitong@ouc.edu.cn

RECEIVED 10 January 2024
ACCEPTED 26 March 2024
PUBLISHED 08 April 2024

CITATION
Wang X, Zhang M, Liu H, Ma X, Liu Y and Chen Y (2024) ChatBBNJ: a question–answering system for acquiring knowledge on biodiversity beyond national jurisdiction. *Front. Mar. Sci.* 11:1368356. doi: 10.3389/fmars.2024.1368356

COPYRIGHT
© 2024 Wang, Zhang, Liu, Ma, Liu and Chen. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

ChatBBNJ: a question–answering system for acquiring knowledge on biodiversity beyond national jurisdiction

Xiaowei Wang[1], Mingdan Zhang[2], Hao Liu[1], Xiaodong Ma[1], Yingchao Liu[1] and Yitong Chen[2*]

[1]College of Computer Science and Technology, Ocean University of China, Qingdao, China, [2]Law School, Ocean University of China, Qingdao, China

The marine biodiversity in Areas beyond national jurisdiction (ABNJ), encompassing approximately two-thirds of the global ocean, is persistently declining. In 2023, the agreement on the Conservation and Sustainable Use of Marine Biodiversity of Areas Beyond National Jurisdiction (BBNJ) was officially adopted. Implementing the BBNJ Agreement has the potential to effectively meet global needs for preserving marine biodiversity. Nevertheless, the implementation requires dealing with thousands of legal clauses, and the parties participating in the process lack adequate means to acquire knowledge connected to BBNJ. This paper introduces ChatBBNJ, a highly efficient question-answering system that combines a novel data engineering technique with large language models (LLMs) of Natural Language Processing (NLP). The system aims to efficiently provide stakeholders with BBNJ-related knowledge, thereby facilitating and enhancing their comprehension and involvement with the subject matter. The experimental results demonstrate that the proposed ChatBBNJ exhibits superior expertise in the BBNJ domain, outperforming baseline models in terms of precision, recall, and F1-scores. The successful deployment of the suggested system is expected to greatly assist stakeholders in acquiring BBNJ knowledge and facilitating the effective implementation of the BBNJ Agreement. Therefore, this is expected to contribute to the conservation and sustainable use of marine biodiversity in ABNJ.

KEYWORDS

BBNJ agreement, ABNJ, LLMS, nlp, intelligent question-answering

1 Introduction

Areas beyond national jurisdiction (ABNJ) face persistent degradation of marine biodiversity (Humphries and Harden-Davies, 2020). A United Nations agreement on the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction (the BBNJ Agreement) was formally adopted in August 2023 (United Nations, 2023). The

BBNJ Agreement regulates four key elements concerning ocean governance: marine genetic resources; area-based management tools, including marine protected areas; environmental impact assessments; and capacity building and marine technology transfer (Tessnow-von Wysocki and Vadrot, 2020). It will act as a governance mechanism to achieve conservation and sustainable use of marine biodiversity in ABNJ (Tiller et al., 2023).

However, the implementation of the treaty is facing a lot of resistance. First, as a package deal, the BBNJ Agreement provides a framework for reaching consensus; it still lacks specifics, which needs to be discussed in future Conference of Parties (COP) (Deasy, 2023). Second, learning from the implementation of past international law (Bodansky, 2011), industry may seek to weaken implementation measures in order to reduce its adjustment costs. To solve these problems, countries, organizations, and other stakeholders need to submit implementation reports and discuss these issues in the COP. However, many of the stakeholders were not involved in the BBNJ negotiations. They needed to rapidly comprehend thousands of clauses and four interdisciplinary key knowledge points before the discussion. This presents a significant challenge to the stakeholders.

Even though stakeholders can acquire BBNJ-related knowledge through search engines, existing search engines provide information retrieval based on keywords within relevant documents. Users have to deal with the burden of browsing and filtering out results to find the candidate passages (Lau et al., 2005). Thus, providing a convenient information acquisition system is necessary, which is already called for by the BBNJ Agreement (United Nations, 2023). Knowledge question-answering (Q-A) systems take in natural language questions and provide accurate answers, which can reduce the burden of users reading a large number of irrelevant documents to obtain answers (Zhu et al., 2021). At present, it has been widely used in many fields (Zhong et al., 2020; Dai et al., 2022; Lee et al., 2023), but few Q-A systems popularize professional knowledge of international law of the sea. Therefore, this study aims to develop a Q-A system and to efficiently provide stakeholders with BBNJ-related knowledge, thereby facilitating and enhancing their comprehension and involvement with the subject matter, prompting the effective implementation of the BBNJ Agreement.

Researchers can use various methods to develop a Q-A system for BBNJ knowledge popularization. Early Q-A systems heavily relied on rule-based methods (Riloff and Thelen, 2000), in which linguistic experts needed to manually formulate rules based on the characteristics of BBNJ texts. This method lacks generalization and makes it difficult to cover all scenarios. With rapid advancements in artificial intelligence technologies, several Q-A models have been developed applying statistical language models (Rosenfeld, 2000). These models do not require manual rules, they automatically learn statistical language patterns to predict the correct answers to questions. However, this method cannot obtain semantic information. The BBNJ Agreement contains many repetitive terminologies, which makes it challenging for most statistical language models to differentiate subtle situations. Neural language models (Bengio et al., 2003) characterize the probability of word sequences generated by neural networks. These models generate a contextual representation that encodes semantic and syntactic information. However, in addition to repetition, the language of the BBNJ Agreement shows long-term dependency. Limited by the context window, these models cannot model global semantics. Pretrained language models (Devlin et al., 2019) capture context-aware word representations by fine-tuning the networks according to specific downstream tasks. Q-A systems built upon these models exhibit better performance.

Recently, researchers find that scaling pretrained language models often leads to improved model capacity on downstream tasks (i.e., following the scaling law (Kaplan et al., 2020)). With the significant success of large language models (LLMs) like ChatGPT (Ouyang et al., 2022) in tasks related to understanding and generating human-like responses (Eloundou et al., 2023), applying LLMs to Q-A systems has become a popular choice among researchers (Cui et al., 2023; Huang et al., 2023; Li et al., 2023; Vaghefi et al., 2023; Wang et al., 2023; Xiong et al., 2023; Yang et al., 2023). At present, LLMs have significantly improved their performance in open-domain Q-A (Li et al., 2023). However, when applying LLMs to the BBNJ domain, it is difficult to fully utilize its advantages (Wang et al., 2023). LLMs are trained on general corpora, such as Common Crawl (Common Crawl, 2023) and Wikipedia (Wikipedia, 2023). BBNJ-related knowledge is complex and multidisciplinary, involving legal, scientific, and international relations considerations (Humphries et al., 2021). These specialized areas differ significantly from the pre-trained data of LLMs. Therefore, efficiently adapting LLMs to the BBNJ domain, fully utilizing LLMs' understanding abilities remains a challenging problem.

Recent studies have shown (Amer-Yahia et al., 2023) that fine-tuning LLMs by using high-quality domain-specific data can improve their domain adaptation ability. However, developing a Q-A system for BBNJ knowledge popularization by fine-tuning LLMs with domain-specific data presents challenges. First, there is a lack of available Q-A datasets for fine-tuning LLMs in the BBNJ domain. Second, LLMs suffer from outdated information after fine-tuning has concluded. Ensuring stakeholders rapidly acquire the latest implementation situations and recommendations through the Q-A system is urgently needed in practice. Hence, providing accurate and up-to-date responses is paramount. Such accurate responses can help stakeholders understand the complex and dynamically updated BBNJ knowledge and prompt the implementation of the BBNJ Agreement. Thus, this study (Figure 1) aims to solve these problems with the following contributions:

(1) We proposed a data engineering method, called PDGC, to generate a higher-quality Q-A dataset for the BBNJ domain. PDGC contains two-stage data-generation and iterative correction. The two-stage data-generation method enables the model to generate higher-quality data based on BBNJ Q-A examples. Moreover, our iterative correction improves correction quality by following the human learning pattern based on easy-to-difficult.

(2) We developed a BBNJ domain language model called ChatBBNJ, which is fine-tuned by utilizing the United Nations Convention on the Law of the Sea (UNCLOS) and its annexes. BBNJ Agreement is developed under the UNCLOS. Furthermore, we introduced a domain knowledge-based prompt engineering. The domain knowledge base is constructed by utilizing the BBNJ

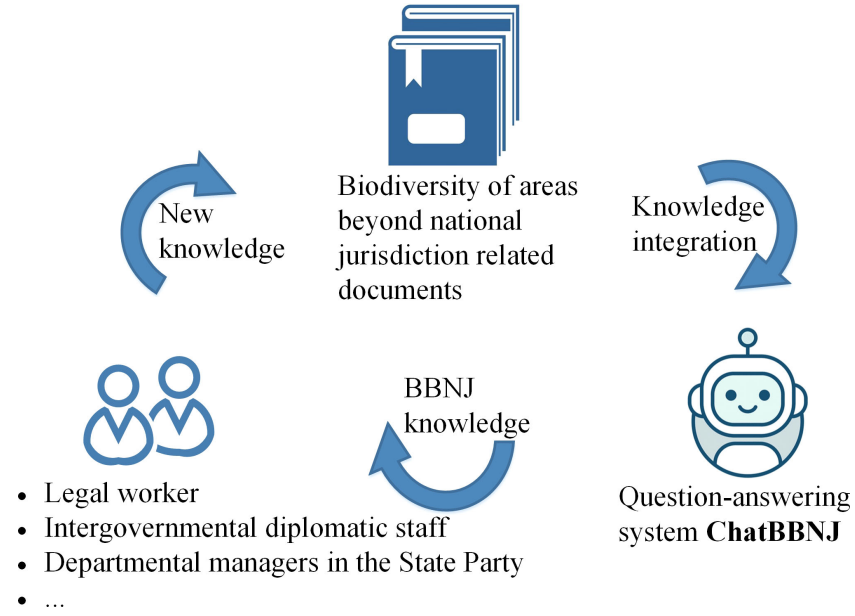


FIGURE 1
Overview of ChatBBNJ's work.

Agreement. The agreement offers the latest regulations for the management of BBNJ. It ensures that ChatBBNJ obtains the latest BBNJ domain information quickly.

2 Methods

An overview of the proposed method framework for BBNJ-related knowledge popularization is shown in Figure 2. The method framework is composed of three parts: dataset construction, model fine-tuning, and domain knowledge-based prompt engineering. At the dataset construction stage, we applied PDGC to construct a high-quality dataset for fine-tuning. Then, at the model fine-tuning stage, we applied the LoRA (Hu et al., 2021) method to fine-tune the base model, which improved the domain adaptation ability of the base model. Finally, at the domain knowledge-based prompt engineering stage, a domain knowledge base was used when constructing prompts, which ensured the timeliness of the model's answers.

2.1 Q-A dataset construction

The proposed PDGC method comprises three modules: text preprocessing, data generation, and data correction (Figure 3). During the text preprocessing, we performed reference completion as the BBNJ-related documents have many reference expressions. Then, during the data generation, since the BBNJ-related documents are multidisciplinary, involving legal, scientific, and international relations considerations (Humphries et al., 2021), single data generation will result in a significant amount of noisy data. To solve this problem, a two-stage data generation method was applied. Finally, during the data correction, existing consistency validation methods reduce data quantity and diversity. Therefore, we proposed a similarity-based data division and iterative correction method.

2.1.1 Text preprocessing

BBNJ-related documents were collected to build our dataset. The details are shown in Table 1. In our study, text preprocessing consists of two steps: (1) division of regulations; and (2) reference completion. Division of regulations divides regulations into multiple paragraphs according to their clauses. As some clauses list multiple contents when describing "requirements" and "steps", they often go beyond the input limit of the data generation model. Therefore, we took each part of the clause as a paragraph and supplemented Q-A pairs to ensure completeness. In addition, all the section titles were merged with any sentence within the corresponding section to retain semantic information. Reference completion ensures that each clause retains complete semantic information. Lots of clauses use referential terms such as "above" and "this section" in their descriptions, they lose complete semantic information after the division of regulations. Therefore, we completed the reference to the terms according to the context. Finally, 3,089 BBNJ-related paragraphs were obtained and used for Q-A data generation.

2.1.2 Data generation

Preliminary evaluation using GPT-4 as a judge shows that Vicuna-13B achieves more than 90% quality of OpenAI's ChatGPT (Chiang et al., 2023). Since ChatGPT (Ouyang et al., 2022) is in a non-open source state, we applied open source Vicuna-13B as the base model for data generation to minimize experimental costs.

Prompting is a method for guiding the LLMs toward desired outputs. To achieve the best performance of LLMs in data generation,

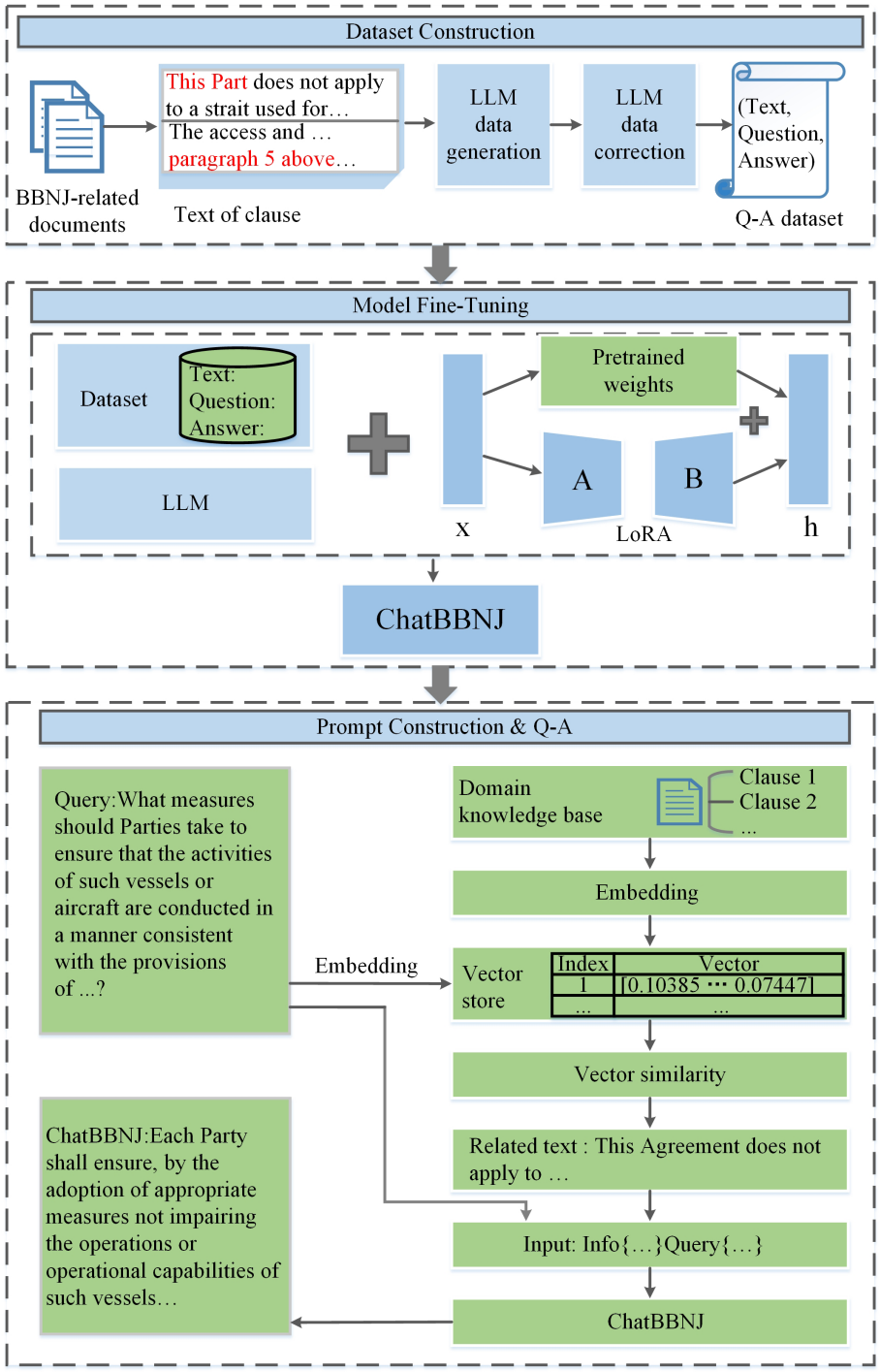


FIGURE 2
Overview of biodiversity of areas beyond national jurisdiction knowledge question–answering.

proper design of prompts is essential. We designed prompts for generating data at different stages. In the first stage, we used BBNJ-related paragraphs as input to generate Q-A pairs based on the content of the Phase 1 data generation prompt shown in Figure 4. In the second stage, following the concept of in-context learning (Dong et al., 2023), BBNJ-related paragraphs and Q-A pairs generated in Phase 1 were used as input to generate higher-quality Q-A pairs based on the content of the Phase 2 data generation prompt shown in Figure 5. Although it has been clearly stated in the prompt that LLMs need to generate new questions different from the examples, it was found that there were still occurrences of repetitive Q-A pairs during the experiment. Therefore, after the question generation process, it is necessary to carry out a deduplication operation on the generated Q-A pairs. After deduplication, we obtained 29,273 Q-A pairs, (q, a).

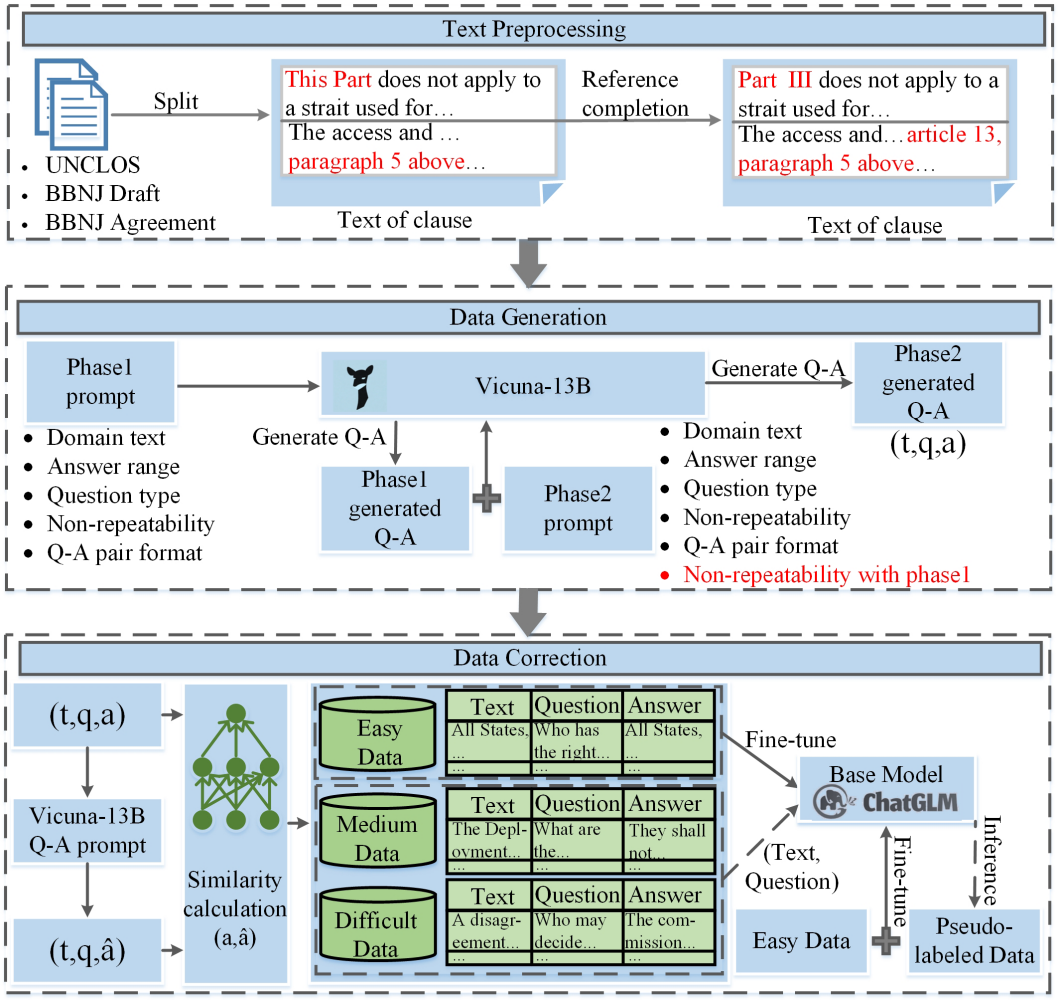


FIGURE 3
Dataset construction method framework. "UNCLOS" represents the United Nations Convention on the Law of the Sea. "BBNJ Draft" represents the draft agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction. "BBNJ Agreement" represents the agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction. "Vicuna-13B" is a large language model used to generate data. " (t, q, a) " contains three parts: " t" is the text of clause obtained in text preprocessing, " q" and " a" represent the question and answer generated by Vicuna-13B in data generation respectively. " $(t, q, \hat{a})$" contains three parts: " t" and " q" are the same as " t" and " q" in " (t, q, a)", but " $\hat{a}$" represents the new answer generated using "Vicuna-13B Q-A prompt" for data correction. "ChatGLM" is a large language model used to revise data.

2.1.3 Data correction

To further improve the quality of the generated data, the data correction module depicted in Figure 6 is applied to revise the generated Q-A pairs. Since the LLMs will generate out-of-scope answers, we obtained new model-generated answers $\hat{a}$ based on the content of the Vicuna-13B Q-A prompt shown in Figure 7. Then, we removed Q-A pairs with "no answer" and obtained new pairs $(q, \hat{a})$. The data were divided into three levels: easy, medium, and difficult by calculating the similarity between a and $\hat{a}$.

To minimize the computational resources used for model fine-tuning during the data correction, ChatGLM (Zeng et al., 2022) is used as the base model for data correction, which has only 6.2 billion parameters. Inspired by (Wang et al., 2021), we optimized the data correction model iteratively by increasing the difficulty of the Q-A pairs fed to the model gradually. First, we used easy Q-A pairs to conduct the initial fine-tuning of ChatGLM, and used the fine-tuned model to reannotate the medium Q-A pairs. Then, we further fine-tuned the model using the reannotated data and used the model obtained after this fine-tuning to reannotate the difficult Q-A pairs. Thus, the abilities of Vicuna-13B are transferred to ChatGLM for data correction in low-resource settings. Finally, 18,296 annotated Q-A pairs of BBNJ domain were obtained.

2.2 Model fine-tuning

To improve the domain adaptation ability of LLMs applied to BBNJ domain, we fine-tuned the LLMs by using the BBNJ domain Q-A dataset constructed in Section 2.1. ChatGLM is applied as the

TABLE 1 Documents contained in the dataset.

No.	BBNJ-related documents
1	Draft agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction
2	Agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction
3	United Nations Convention on the Law of the Sea
4	United Nations Convention on the Law of the Sea Annex I
5	United Nations Convention on the Law of the Sea Annex II
6	United Nations Convention on the Law of the Sea Annex III
7	United Nations Convention on the Law of the Sea Annex IV
8	United Nations Convention on the Law of the Sea Annex V
9	United Nations Convention on the Law of the Sea Annex VI
10	United Nations Convention on the Law of the Sea Annex VII
11	United Nations Convention on the Law of the Sea Annex VIII
12	United Nations Convention on the Law of the Sea Annex IX

base model. The open-source nature of the model is an important consideration.

To minimize the computational resources used for model fine-tuning, we applied the commonly used LoRA technique (Hu et al., 2021), which has been shown to effectively adapt LLMs to specific domain tasks and improve their performance (Lukichev et al., 2023). LoRA applies a simple linear design that allows the trainable matrix to be combined with frozen weights during model deployment. Compared with fully fine-tuned models, this approach does not create inference latencies, which is necessary for a knowledge Q-A system.

Data processing is necessary when fine-tuning ChatGLM. Research shows that ChatGLM and other LLMs can generalize well to unseen tasks and follow task descriptions after instruction tuning (Wei et al., 2021). However, LLMs have some weaknesses when lacking instructions, such as repetitive output and difficulty in fulfilling researchers' expected task types. Therefore, it is necessary to construct the training set based on the organization of data in instruction tuning before fine-tuning. Each training data used for instruction tuning consists of three parts: instruction, question, and answer. Table 2 shows an example of the BBNJ domain Q-A dataset.

The ChatBBNJ model was obtained by using the LoRA technique to fine-tune ChatGLM for the BBNJ knowledge Q-A task.

2.3 Domain knowledge-based prompt engineering

The training data for the ChatBBNJ model is limited to a specific time period, the model cannot provide time-sensitive knowledge. To solve this problem, we applied the framework depicted in Figure 8 to the ChatBBNJ model.

First, we create the BBNJ domain knowledge base using BBNJ Agreement and its draft. Second, we applied ERNIE 2.0 (Sun et al., 2020) to obtain vectorized representations of the domain knowledge, which was stored in our vector database. When a user poses a question, it is first embedded and then indexed using semantic similarity to find the top-k nearest vectors corresponding to the inquiry. The dot product of two vectors is utilized to analyze the similarity between vector embeddings, which is obtained by multiplying their respective components and summing the results. After identifying the nearest vectors to the query vector, we decode the numeric vectors to text and retrieve the corresponding text from the database. The textual information and user question are used to improve ChatBBNJ's prompt. This method enables users to receive reliable and up-to-date answers. The framework can be extended to other domains that require periodic knowledge updates.

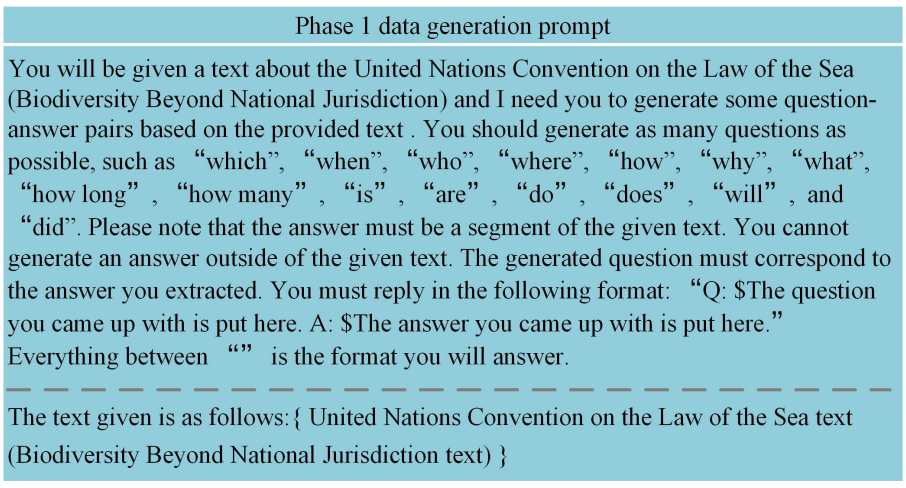


FIGURE 4
Phase 1 data generation prompt.

Phase 2 data generation prompt
You will be given a text about the United Nations Convention on the Law of the Sea (Biodiversity Beyond National Jurisdiction). The text given is as follows: { United Nations Convention on the Law of the Sea text (Biodiversity Beyond National Jurisdiction text) }
Here are some examples of the generated question-answer pairs according to the above text: { Phase 1 Generated Q&A }
I need you to generate some different question-answer pairs based on the given text and examples. You should generate as many questions as possible, such as "which", "when", "who", "where", "how", "why", "what", "how long", "how many", "is", "are", "do", "does", "will", and "did". Please note that you cannot add information beyond the provided text, the answer must be a segment of the given text. You cannot generate an answer outside of the given text. You cannot complete the given text, and the generated question-answer pairs must be different from the examples above. You must reply in the following format: "Q: $The question you came up with is put here. A: $The answer you came up with is put here." Everything between "" is the format you will answer.

FIGURE 5
Phase 2 data generation prompt.

3 Experiment

3.1 Baseline

To assess the performance of the proposed ChatBBNJ, we performed a comparative analysis using its base model ChatGLM and two additional language models.

LLaMA (Touvron et al., 2023a) is a collection of foundation language models ranging from 7 to 65 billion parameters, these models are trained using publicly available data. The experimental results demonstrate that LLaMA-7B outperforms GPT-3 in several natural language processing benchmark tests without relying on domain datasets.

Vicuna-13B (Chiang et al., 2023) is an open-source chatbot trained by fine-tuning LLaMA on user-shared conversations collected from ShareGPT. Preliminary evaluation using GPT-4 as a judge showed that Vicuna-13B achieved more than 90% quality of OpenAI's ChatGPT and Google's Bard.

3.2 Evaluation metrics

The models used in this study provide knowledge answers using a generative method. Traditional generative task evaluation metrics only consider word matching, they cannot provide a reasonable assessment for expressions with the same semantics. Thus, we applied the BERTScore (Zhang et al., 2019) to evaluate semantic equivalence. The precision, recall, and F1-scores were computed. Equations (1-3) provide the calculation methods for the evaluation metrics, where $x = \langle x_1, \ldots, x_k \rangle$ represents the ground-truth answers in the test set and $\hat{x} = \langle \hat{x_1}, \ldots, \hat{x_l} \rangle$ represents the answers from ChatBBNJ and baselines.

$$P_{BERT} = \frac{1}{|\hat{x}|} \sum_{\hat{x_h} \in \hat{x}} \max_{x_i \in x} x_i^T \hat{x_h} \tag{1}$$

$$R_{BERT} = \frac{1}{|x|} \sum_{x_i \in x} \max_{\hat{x_h} \in \hat{x}} x_i^T \hat{x_h} \tag{2}$$

$$F_{BERT} = \frac{2 * P_{BERT} * R_{BERT}}{P_{BERT} + R_{BERT}} \tag{3}$$

3.3 Results

We demonstrated the effectiveness of our method framework, the efficacy of its individual modules, and the Q-A performance of ChatBBNJ quantitatively through experiments. We divided the BBNJ domain dataset constructed in Section 2.1 into training and testing sets with ratios of 77 and 23%, respectively.

First, we compared ChatBBNJ with several other LLMs in Q-A tasks. To quantitatively evaluate the performance of ChatBBNJ, we calculated the metrics for both baselines in Section 3.1 and ChatBBNJ. The results are shown in Figure 9. The results show that ChatBBNJ achieves significantly higher precision, recall, and F1-scores, compared to baselines. The results show that ChatBBNJ achieves 0.097 precision, 0.025 recall, and 0.062 F1-scores improvement over its base model ChatGLM. These results demonstrate that ChatBBNJ exhibits superior expertise in the BBNJ domain.

Second, we conducted ablation experiments to demonstrate the efficacy of individual modules in our method framework. To

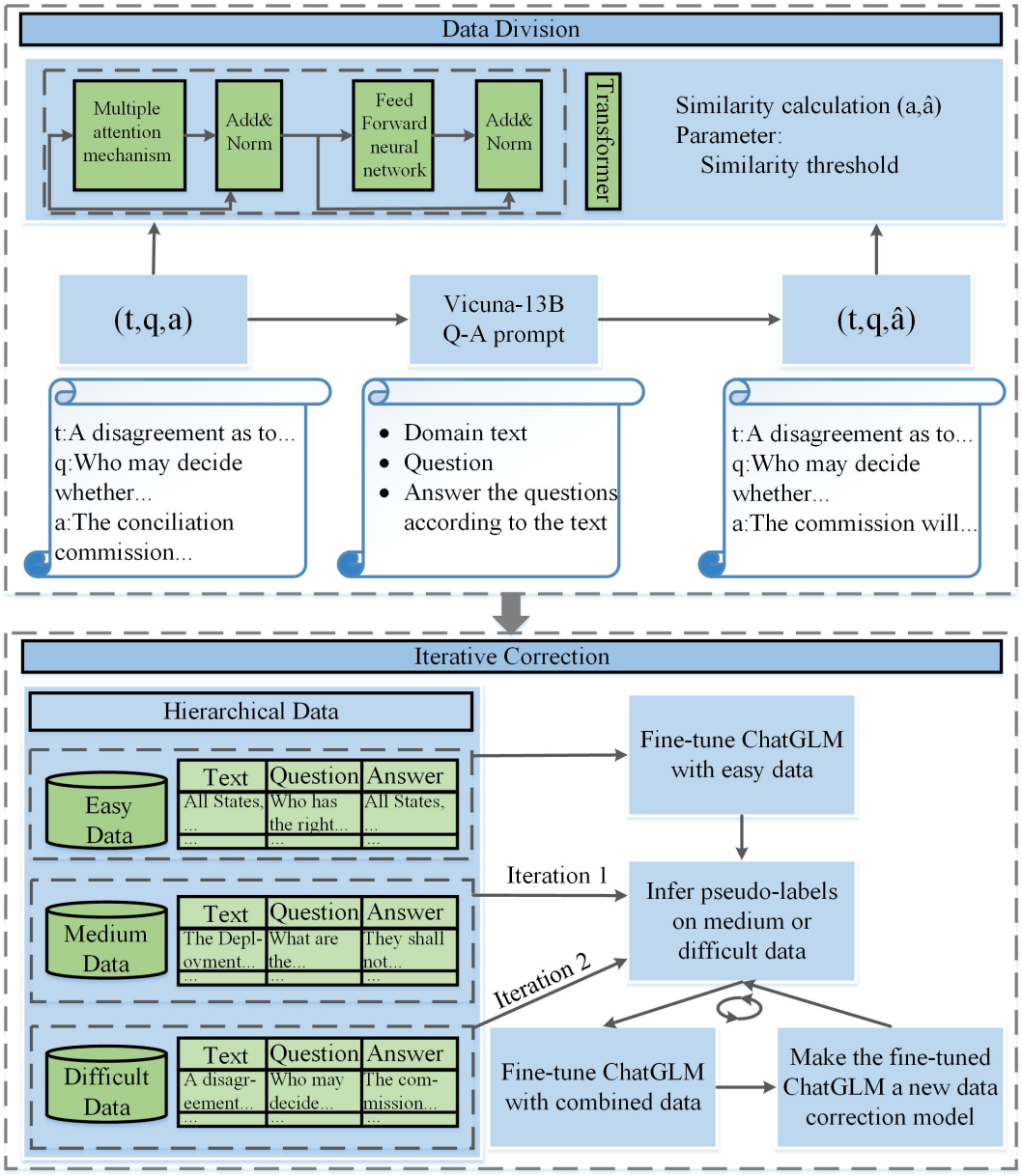


FIGURE 6
Data correction module. " (t, q, a)" is obtained from data generation. " t" and " q" in " $(t, q, \hat{a})$" are the same as " t" and " q" in " (t, q, a)", but " $\hat{a}$" is the new model-generated answer using the "Vicuna-13B Q-A prompt". During data division, first, we use the "Vicuna-13B Q-A prompt" to obtain a and $\hat{a}$; finally, we obtain the divided data including easy, medium and difficult levels. During iterative correction, first, we fine-tune the ChatGLM using only easy data; then, we use the supervised fine-tuned model to infer pseudo-labels on medium data and form the pseudo-labels in memory; then, we use the model, which accesses the pseudo-labels in memory to infer pseudo-labels on difficult data; finally, we obtain an annotated biodiversity of areas beyond national jurisdiction domain dataset.

quantitatively evaluate the effectiveness of the three proposed modules, namely PDGC for BBNJ domain dataset construction, model fine-tuning, and domain knowledge-based prompt engineering, we also calculated the metrics under different scenarios. The complete evaluation results are shown in Table 3. The quality of training data influences how well the model learns. Therefore, to evaluate the effectiveness of PDGC, we fine-tuned the model for Q-A task before and after using PDGC, then tested the model's performance. The results indicate that the model's Q-A performance improves after fine-tuning the model with data generated by PDGC. Additionally, fine-tuning the model helps enhance its performance. We find that the model achieves improvement over ChatGLM. To evaluate the effectiveness of the domain knowledge-based prompt engineering, we also compared the Q-A performance before and after using this module. The results indicate that the model performs better after using the domain knowledge-based prompt engineering when other modules are the same. The results indicate that the model incorporating with each of our module achieves higher precision, recall and F1-scores in all cases.

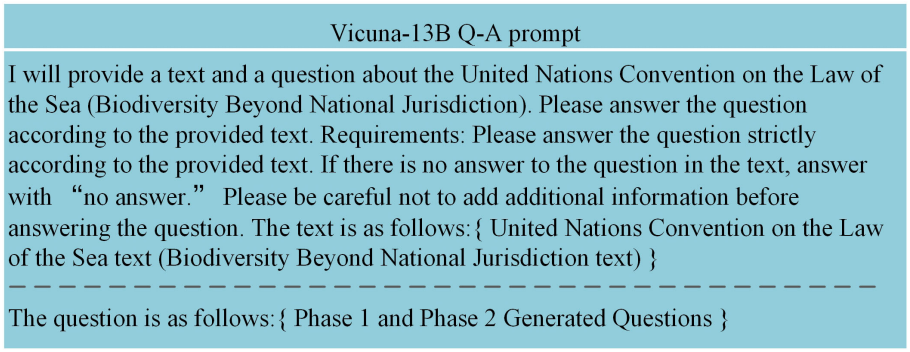


FIGURE 7
Vicuna-13B Q-A prompt.

Finally, we demonstrate the effectiveness of ChatBBNJ through specific Q-A examples. The examples generated by ChatBBNJ and baseline models are listed in Table 4, Table 5 and supplementary materials. In the tables, "Q" represents the question provided to the models. "ChatGLM", "LLaMA-7B", "Vicuna-13B", and "ChatBBNJ" represent the answers generated by the models. "Answer" represents the ground-truth answer. We underline the key points of the models' answers.

In Table 4, we provide a question related to BBNJ domain terminology. ChatGLM considers "area-based management tool" to be a software application, LLaMA-7B categorizes as manager and employee resource management, their answers deviate from the BBNJ domain. Vicuna-13B's answer is more inclusive, but it lacks domain specificity. Our ChatBBNJ provides an answer that reflects the BBNJ domain specificities and includes most of the key points from the ground-truth answer.

In Table 5, we provide a time-sensitive question related to the BBNJ domain. This question is regulated first in the BBNJ Agreement, which was formally adopted in August 2023. The answers from ChatGLM, LLaMA-7B, and Vicuna-13B are related to the COP but not to the BBNJ domain, and ChatGLM displayed language inconsistencies. It can be seen that ChatGLM's answer is a mixture of Chinese and English format, the answer includes "会议室"(conference room)、"会议设施"(conference facilities) and other Chinese format. ChatGLM's knowledge is cut off in 2022. However, ChatBBNJ, which is based on ChatGLM, provides correct BBNJ domain answers based on knowledge in 2023.

TABLE 2 Example for instruction tuning.

Instruction	The Conference of the Parties shall ordinarily meet at the seat of the secretariat or at United Nations Headquarters. Answer the following question based on the text given.
Question	Where should the Conference of the Parties meet?
Answer	At the seat of the secretariat or at United Nations Headquarters.

In Supplementary Table 1, we provide two Q-A examples for complex application scenario. The answers of ChatGLM, LLaMA-7B and Vicuna-13B use terms from the BBNJ Agreement rarely, especially ChatGLM expresses ABMT as ABM tools in Q2, which is not conform to the treaty. Besides, ChatGLM's answer is a mixture of Chinese and English format, it includes "寻求国际协作, 以解决这一问题" (seek international cooperation to solve this problem), "采取可持续的措施" (take sustainable measures) and other Chinese format. However, ChatBBNJ not only provides the original text from the Agreement in Q2, but also emphasizes the necessity of the relevant reports and the role of the United Nations in Q1, which make the answers more comprehensive. It can be seen that compared to other models, our ChatBBNJ can provide answers more aligned with the BBNJ Agreement in complex scenarios, especially in Q2, where ChatBBNJ provides almost all requirements related to ABMTs in the BBNJ Agreement.

In Supplementary Table 2, we provide two Q-A examples for the interpretation of the BBNJ Agreement under Article 31 of the Vienna Convention on the Law of Treaties (VCLT). Article 31 of the VCLT can be summarized as: be interpreted in good faith, be interpreted in the light of treaty's object and purpose, be interpreted with supplementary means of interpretation, be interpreted in accordance with the ordinary meaning and be interpreted with the terms of the treaty in their context. In Q1, ChatBBNJ's response highlights the importance of international cooperation in marine scientific research and technology development in first sentence, which complies with the principle of good faith interpretation. And the first sentence also links to the objective of the treaty. Moreover, ChatBBNJ's response provides relevant contents from Article 143 of the UNCLOS, reflecting supplementing interpretation based on external materials. In Q2, ChatBBNJ provides an ordinary explanation of "transparency", supplemented it with interpretations of the term in different contexts, and provide the role of transparency as well as the challenges it faces. This response reflects an ordinary meaning interpretation. Besides, ChatBBNJ provides some measures involved in the BBNJ Agreement, including making decisions and documents open to the public, open meeting practices, publishing and maintaining a public record of decisions and publishing decision information. These measures

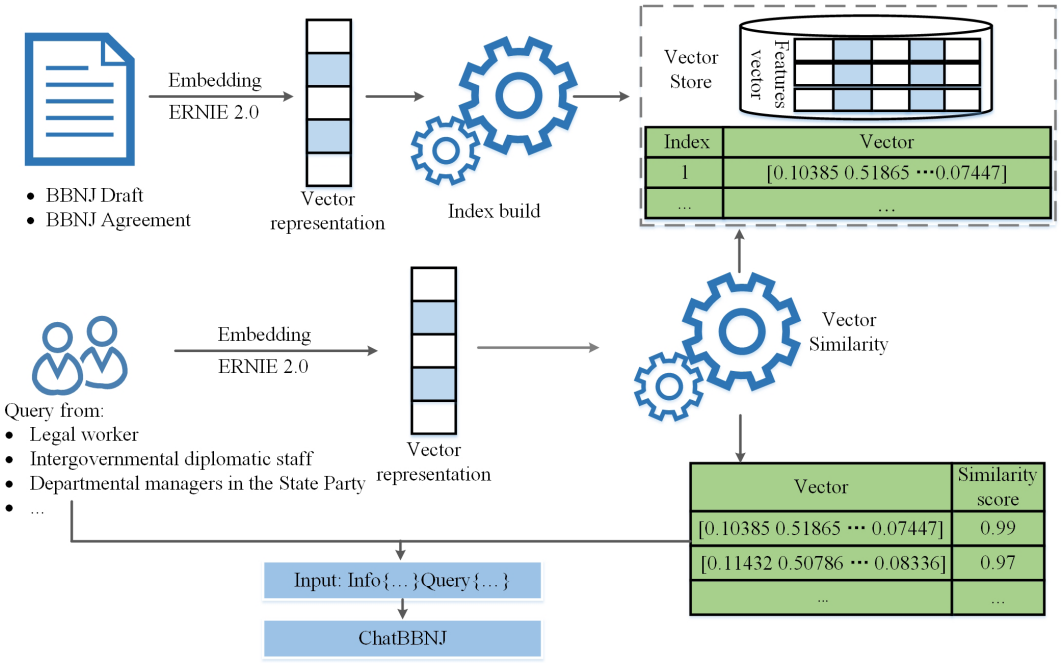


FIGURE 8
Domain knowledge-based prompt engineering framework. "BBNJ Draft" represents the draft agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction. "BBNJ Agreement" represents the Agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction.

come from different articles in the agreement, which reflects interpreting with the terms of the treaty in their context.

The latest versions of the baseline models (e.g., ChatGLM2 and LLaMA2-7B (Touvron et al., 2023b)) had improved abilities over ChatGLM and LLaMA-7B used in this study. Since we applied the ChatGLM as a base model, we compared ChatBBNJ with the latest baseline models, ChatGLM2 and LLaMA2-7B. The results are shown in Table 6. The results show that our ChatBBNJ outperforms the more advanced ChatGLM2 and LLaMA2-7B. These findings suggest that our method framework for BBNJ domain Q-A, significantly enhance the performance of the LLMs in the BBNJ domain.

4 Discussion

Over the past 50 years, the degradation of marine biodiversity in ABNJ persists, with a lack of effective governance mechanisms to

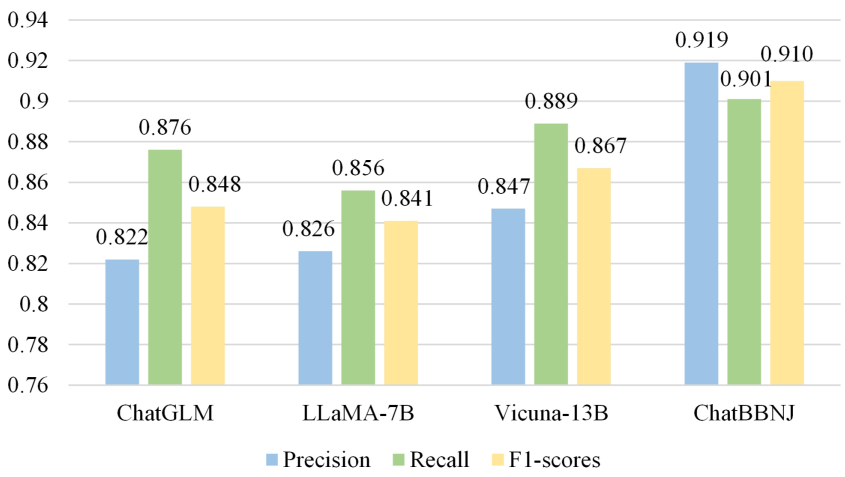


FIGURE 9
Comparison of the experimental results for ChatBBNJ.

TABLE 3 Ablation experiment results for the three modules of ChatBBNJ.

Models	Precision	Recall	F1
ChatGLM (without PDGC, model fine-tuning, and DKB prompt engineering)	0.822	0.876	0.848
ChatBBNJ (without PDGC, with model fine-tuning, without DKB prompt engineering)	0.865	0.891	0.873
ChatBBNJ (with PDGC, with model fine-tuning, without DKB prompt engineering)	0.872	0.894	0.888
ChatBBNJ (without PDGC, with model fine-tuning and DKB prompt engineering)	0.897	0.900	0.898
ChatBBNJ (with PDGC, model fine-tuning and DKB prompt engineering)	**0.919**	**0.901**	**0.910**

DKB prompt engineering represents domain knowledge-based prompt engineering.
The bold values represent the best results.

TABLE 4 Q-A example in BBNJ domain terminology.

Q: What is the purpose of area-based management tool?
ChatGLM: An area-based management tool is a software application that allows organizations to manage their resources and operations across different locations, regions, or areas. The purpose of an area-based management tool is to help organizations more effectively manage their resources, improve communication, and increase productivity. One of the main benefits of using an area-based management tool is that it allows organizations to manage their resources and operations across different locations, regions, or areas more efficiently. This can help to reduce costs by reducing the need for travel and accommodation, and improving communication by allowing for real-time collaboration between teams in different locations. Additionally, area-based management tools can help to improve productivity by allowing organizations to manage their resources and operations more effectively across different locations. This can help to reduce the time it takes for teams to work together, and improve the overall performance of the organization. Overall, area-based management tools are an important tool for organizations looking to improve their resource management, communication, and productivity across different locations.
LLaMA-7B: Area based Management Tool (ABMT) was developed to help managers and employees in making decisions about how best to manage their resources, such as people or money. It helps them identify which areas are most important for improvement by identifying what needs attention first. The ABM system can be used with any type of resource but it works particularly well when you have limited time and/or budget available so that you need to prioritize your efforts effectively. The main steps involved include: 1. Identify all possible options;2. Priority ranking each option according to its potential impact on performance goals;3. Selecting one or more priority actions from those ranked highest;4. Implement selected action(s);5. Evaluate results against original objectives;6. Repeat process if necessary until desired level of effectiveness has been achieved.
Vicuna-13B: Area-based management tools are used to help organizations and individuals manage specific areas or regions. These tools can be used for a variety of purposes, such as to track and manage resources, monitor activity, and identify trends and patterns. Some examples of area-based management tools include geographic information systems (GIS), which can be used to create maps and visualizations of an area, and resource management software, which can be used to track and manage resources such as fish stocks or forests. Area-based management tools can be useful for a wide range of applications, including natural resource management, emergency response, and urban planning.
ChatBBNJ: The purpose of an area-based management tool is to manage a Geographically defined area through which one or several sectors or activities are managed with the aim of achieving particular conservation. The tool may include a marine protected area as one of its components. The establishment of area-based management tools, including marine protected areas, is to prevent the inclusion of any areas within national jurisdiction in order to prevent asserts or denying any claims to sovereignty.
Answer: "Area-based management tool" means a tool, including a marine protected area, for a geographically defined area through which one or several sectors or activities are managed with the aim of achieving particular conservation and sustainable use objectives in accordance with this Agreement.

ChatGLM', 'LLaMA-7B', 'Vicuna-13B', and 'ChatBBNJ' represent the answers generated by the models. 'Answer' represents the ground-truth answer.
The underline words represent the key points of the models' answers.

halt this decline (Ward et al., 2022). Industrial fishing affects about 50% of oceans (Sala et al., 2018), leading to overexploitation of 31% of marine fish stocks (FAO, 2016), and ecosystem-level alterations in high seas (Ortuño Crespo and Dunn, 2017). The international maritime order is dynamic and evolving, and UNCLOS' authoritative, comprehensive, and extended nature does not imply its perfection. Due to the game of interests and compromise among countries, many UNCLOS rules are principled and articulated, creating legal ambiguities that often need to be further addressed in practice. The current international ocean order is in a state of rapid transition, necessitating a reaction to several earth system changes such as sea-level rise, plastic pollution of the seas, acidification, and destruction of marine biodiversity (Chen and Liu, 2023). BBNJ agreement is intended to serve as a governance mechanism for the protection and sustainable use of marine biodiversity in the ABNJ.

The present study introduces ChatBBNJ, a question-answering system, that designed to enhance the treaty implementation. First, we proposed PDGC, a data engineering method, that constructs a high-quality Q-A dataset specific to the BBNJ domain. Second, we applied this dataset to fine-tune the ChatGLM to obtain the BBNJ domain model, ChatBBNJ. Finally, we introduced a domain knowledge-based prompt engineering. We demonstrated improvements by testing ChatBBNJ on Q-A data related to the BBNJ Agreement and its draft. Experiment results demonstrate that ChatBBNJ outperforms baseline LLMs across three Q-A metrics. Additionally, hybrid ChatBBNJ, which introduces a domain knowledge-based prompt framework outperforms standalone ChatBBNJ. The main findings of our work are summarized as follows:

(1) The quality of LLMs text generation can be enhanced through appropriate prompt engineering and data correction. The effectiveness of model training is to some extent related to the quality of training data. Therefore, Table 3 compares the Q-A performance of ChatBBNJ before and after using PDGC. It can be seen that the Q-A performance of ChatBBNJ improves when the model is fine-tuned with data generated by PDGC.

(2) The domain adaptation ability of LLMs in Q-A tasks can be improved by fine-tuning the model on domain-specific Q-A datasets. Analyzing the experimental results in Table 3, regardless of the method used for data generation, ChatBBNJ's Q-A performance improves after model fine-tuning.

TABLE 5 Time-sensitive Q-A example in the BBNJ domain.

Q: Where should the Conference of the Parties meet?
ChatGLM: The Conference of the Parties (CP) is an international organization that致力于 developing and implementing policies to reduce climate change. It meets regularly, usually in locations that are convenient for its members. TheCP's current meeting, which took place in Madrid, Spain in 2020, was the 11th meeting of theCP since its formation in 1995. The next meeting of theCP will take place in late 2021 or early 2022, and the location of the meeting will be announced at a later date. TheCP's meetings are held in a variety of locations, including 会议室 (会议室是指会议所需的会议室、会议桌、椅子等会议设施), which are designed to provide a comfortable and productive environment for conference attendees. The location of theCP's next meeting will be determined by the needs and preferences of its members, as well as the availability of会议室 and other 会议设施. TheCP meets regularly to discuss and develop policies to reduce climate change, including policies to reduce carbon emissions, promote renewable energy, and protect the environment. The organization is committed to working towards a goal of reducing climate change by 2C by the end of the century.
LLaMA-7B: The conference will be held in Paris, France because it has been suggested by many countries and they have agreed to host this meeting there for 2 weeks starting on December 1st until January 3rd at Hotel de Ville (City Hall). This location was chosen due to its centrality within Europe which makes traveling easier as well as being able to accommodate all delegates from around the world with ease. The city also offers great food options such as baguettes or crepes along with other delicious cuisines making sure everyone's taste buds are satisfied! It would not only benefit those who attend but also help boost tourism throughout the country bringing more money into their economy.
Vicuna-13B: The Conference of the Parties (COP) is a meeting of the parties to the United Nations Framework Convention on Climate Change (UNFCCC). The COP is the supreme decision-making body of the UNFCCC, and it is responsible for reviewing the implementation of the Convention and taking decisions to further its objectives. The COP is typically held annually, and it is attended by representatives from the governments of the parties to the Convention, as well as experts, civil society organizations, and the media. The location of the COP is typically decided by the UNFCCC secretariat and the government of the host country. The COP has been held in a variety of locations, including developed and developing countries, and it has typically been hosted by countries that are parties to the Convention and have the capacity to host a large international meeting. In the past, the COP has been held in countries such as Germany, France, and South Africa. The next COP is scheduled to be held in Glasgow, Scotland in 2021.
ChatBBNJ: At the seat of the secretariat or at United Nations Headquarters.
Answer: The Conference of the Parties shall ordinarily meet at the seat of the secretariat or at United Nations Headquarters.

ChatGLM', 'LLaMA-7B', 'Vicuna-13B', and 'ChatBBNJ' represent the answers generated by the models. 'Answer' represents the ground-truth answer.
The underline words represent the key points of the models' answers.

(3) The outdated issues of LLMs can be refined by giving the model access to the knowledge beyond its fine-tuning phase time and instructing LLMs on how to utilize that knowledge. In Table 5, the model was asked a time-sensitive question, with relevant information not within the model's training data. However, our ChatBBNJ, equipped with the domain knowledge-based prompt engineering, accessed external knowledge and provided the correct answer.

(4) This study not only demonstrates the feasibility of BBNJ knowledge acquisition by using Q-A system but also provides a method framework to apply Q-A system in BBNJ domain. The method framework has three parts. Firstly, domain datasets are acquired using data engineering method. Secondly, LLMs are fine-tuned for Q-A task based on the generated datasets. Finally, a domain knowledge-based prompt engineering is employed to assist the model in accessing the latest information, ensuring the timeliness of its responses.

TABLE 6 Supplementary comparisons of experimental results for ChatBBNJ.

Models	Precision	Recall	F1
ChatGLM2	0.846	0.883	0.864
LLaMA2-7B	0.852	0.889	0.870
ChatBBNJ	**0.919**	**0.901**	**0.910**

The bold values represent the best results.

In the future, the successful application of ChatBBNJ can bring several benefits. From the perspective of the representatives who have not participated in BBNJ negotiations, they can acquire BBNJ knowledge and avoid reading a large number of irrelevant documents. Simultaneously, governments can benefit from the Q-A system. The BBNJ Agreement calls for parties to take the necessary legislative measures to ensure the implementation of this agreement (United Nations, 2023). ChatBBNJ can provide popularization and interpretation of the agreement, which is helpful to assist governments in enacting implementation legislation. The successful implementation of the proposed ChatBBNJ will make a substantial contribution towards prompting the effectie implementation of the BBNJ Agreement, which will hopefully result in the conservation and sustainable use of marine biodiversity in ABNJ.

However, the limitations of this study remain. First, the accuracy of ChatBBNJ needs to be improved. The present system has achieved reasonable accuracy in the current research field, but there is still room for improvement. Second, the sources of knowledge need to be expanded. The present study mainly focused on promoting the implementation of the BBNJ Agreement, but the methods can be applied to more implementation in international agreements in the law of the sea domain. In future research, more international law of the sea data will be added to the study to obtain richer knowledge and expand the scope of applications.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

XW: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. MZ: Data curation, Formal analysis, Writing –

review & editing. HL: Conceptualization, Resources, Supervision, Writing – review & editing. XM: Project administration, Validation, Writing – original draft. YL: Project administration, Writing – original draft. YC: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Resources, Supervision, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was funded by the National Social Science Fund of China, Grant No. 20CFX082.

Acknowledgments

We would like to thank the computing resources and the professional technical guidance provided by Hao Liu. Thanks to Mittens and Panda.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2024.1368356/full#supplementary-material

References

Amer-Yahia, S., Bonifati, A., Chen, L., Li, G. L., Shim, K., Xu, J. L., et al. (2023). From large language models to databases and back: A discussion on research and education. *SIGMOD Rec.* 52, 49–56. doi: 10.1145/3631504.3631518

Bengio, Y., Ducharme, R., Vincent, P., and Jauvin, C. (2003). A neural probabilistic language model. *JMLR* 3, 1137–1155. doi: 10.1162/153244303322533223

Bodansky, D. (2011). Implementation of international environmental law. *Jpn. Yearb. Int. Law.* 54, 62–96.

Chen, Y. T., and Liu, H. R. (2023). Critical perspectives on the new situation of global ocean governance. *Sustainability* 15, 10921. doi: 10.3390/su151410921

Chiang, W.-L., Li, Z., Lin, Z., Sheng, Y., Wu, Z., Zhang, H., et al. (2023) *Vicuna: an open-source chatbot impressing GPT-4 with 90%* chatGPT quality*. Available online at: https://lmsys.org/blog/2023-03-30-vicuna/ (Accessed November 4, 2023).

Common Crawl (2023). Available online at: https://commoncrawl.org/ (Accessed November 4, 2023).

Cui, J. X., Li, Z. J., Yan, Y., Chen, B. H., and Yuan, L. (2023). ChatLaw: open-source legal large language model with integrated external knowledge bases. *arXiv*. doi: 10.48550/arXiv.2306.16092

Dai, F., Zhao, Z., Sun, C., and Li, B. (2022). "Intelligent audit question answering system based on knowledge graph and semantic similarity," in *2022 11th International Conference of Information and Communication Technology (ICTech)*, Wuhan, China: IEEE. 125–132. doi: 10.1109/ICTech55460.2022.00033

Deasy, K. (2023). What we know about the new high seas treaty. *NPJ Ocean Sustain.* 2, 7. doi: 10.1038/s44183-023-00013-x

Devlin, J., Chang, M.-W., Lee, K., and Toutanova, K. (2019). BERT: pretraining of deep bidirectional transformers for language understanding. *arXiv*. doi: 10.48550/arXiv.1810.04805

Dong, Q. X., Li, L., Dai, D. M., Zheng, C., Wu, Z. Y., Chang, B. B., et al. (2023). A survey on in-context learning. *arXiv*. doi: 10.48550/arXiv.2301.00234

Eloundou, T., Manning, S., Mishkin, P., and Rock, D. (2023). GPTs are GPTs: an early look at the labor market impact potential of large language models. *arXiv*. doi: 10.48550/arXiv.2303.10130

FAO (2016) *The state of world fisheries and aquaculture 2016. contributing to food security and nutrition for all* (Rome, Italy: Food and Agriculture Organization of the United Nations). Available online at: https://www.fao.org/3/i5555e/i5555e.pdf (Accessed March 4, 2024).

Hu, E. J., Shen, Y. L., Wallis, P., Allen-Zhu, Z., Li, Y. Z., Wang, S. A., et al. (2021). LoRA: low-rank adaptation of large language models. *arXiv*. doi: 10.48550/arXiv.2106.09685

Huang, Q. Z., Tao, M. X., An, Z. W., Zhang, C., Jiang, C., Chen, Z. B., et al. (2023). Lawyer LLaMA technical report. *arXiv*. doi: 10.48550/arXiv.2305.15062

Humphries, F., and Harden-Davies, H. (2020). Practical policy solutions for the final stage of BBNJ treaty negotiations. *Mar. Policy.* 122, 104214. doi: 10.1016/j.marpol.2020.104214

Humphries, F., Rabone, M., and Jaspars, M. (2021). Traceability approaches for marine genetic resources under the proposed ocean (BBNJ) treaty. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.661313

Kaplan, J., McCandlish, S., Henighan, T., Brown, T. B., Chess, B., Child, R., et al. (2020). Scaling laws for neural language models. *arXiv*. doi: 10.48550/arXiv.2001.08361

Lau, G. T., Law, K. H., and Wiederhold, G. (2005). "Legal information retrieval and application to e-rulemaking," in *Proceedings of the 10th International Conference on Artificial Intelligence and Law, ICAIL'05* (Association for Computing Machinery, New York, NY), 146–154. doi: 10.1145/1165485.1165508

Lee, S.-H., Choi, S.-W., and Lee, E.-B. (2023). A question-answering model based on knowledge graphs for the general provisions of equipment purchase orders for steel plants maintenance. *Electronics* 12, 2504. doi: 10.3390/electronics12112504

Li, Y. X., Li, Z. H., Zhang, K., Dan, R. L., Jiang, S., and Zhang, Y. (2023). ChatDoctor: A medical chat model fine-tuned on a large language model meta-AI (LLaMA) using medical domain knowledge. *Cureus* 15, e40895. doi: 10.7759/cureus.40895

Li, J. L., Zhang, Z. S., and Zhao, H. (2023). Self-prompting large language models for zero-shot open-domain QA. *arXiv*. doi: 10.48550/arXiv.2212.08635

Lukichev, D., Kryanina, D., Bystrova, A., Fenogenova, A., and Tikhonova, M. (2023). "Parameter-efficient tuning of transformer models for Anglicism detection and substitution in Russian," in *Proceedings of the International Conference "Dialogue 2023."* Available at: https://www.dialog-21.ru/media/5911/lukichevdplusetal042.pdf (Accessed April 3, 2024).

Ortuño Crespo, G., and Dunn, D. C. (2017). A review of the impacts of fisheries on open-ocean ecosystems. *ICES J. Mar. Sci.* 74, 2283–2297. doi: 10.1093/icesjms/fsx084

Ouyang, L., Wu, J., Jiang, X., Almeida, D., Wainwright, C., Mishkin, P., et al. (2022). Training language models to follow instructions with human feedback., in Advances in Neural Information Processing Systems. Curran Associates, Inc., 27730–27744. Available at: https://proceedings.neurips.cc/paper_files/paper/2022/file/b1efde53be364a73914f58805a001731-Paper-Conference.pdf (Accessed April 3, 2024).

Riloff, E., and Thelen, M. (2000). "A rule-based question answering system for reading comprehension tests," in *ANLP-NAACL 2000 workshop: reading comprehension tests as evaluation for computer-based language understanding systems*, (Seattle, WA, USA: ACL). Vol. 6. 13–19. doi: 10.3115/1117595.1117598

Rosenfeld, R. (2000). Two decades of statistical language modeling: where do we go from here? *Proc. IEEE* 88, 1270–1278. doi: 10.1109/5.880083

Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M. L. D., Pauly, D., et al. (2018). The economics of fishing the high seas. *Sci. Adv.* 4, eaat2504. doi: 10.1126/sciadv.aat2504

Sun, Y., Wang, S. H., Li, Y. K., Feng, S. K., Tian, H., Wu, H., et al. (2020). "ERNIE 2.0: a continual pre-training framework for language understanding," in *Proceedings of the AAAI Conference on Artificial Intelligence*, (New York, USA: AAAI). Vol. 34. 8968–8975. doi: 10.1609/aaai.v34i05.6428

Tessnow-von Wysocki, I., and Vadrot, A. B. M. (2020). The voice of science on marine biodiversity negotiations: a systematic literature review. *Front. Mar. Sci.* 7. doi: 10.3389/fmars.2020.614282

Tiller, R., Mendenhall, E., De Santo, E. D., and Nyman, E. (2023). Shake it off: negotiations suspended, but hope simmering, after a lack of consensus at the fifth intergovernmental conference on biodiversity beyond national jurisdiction. *Mar. Policy*. 148, 105457. doi: 10.1016/j.marpol.2022.105457

Touvron, H., Lavril, T., Izacard, G., Martinet, X., Lachaux, M.-A., Lacroix, T., et al. (2023a). LLaMA: open and efficient foundation language models. *arXiv*. doi: 10.48550/arXiv.2302.13971

Touvron, H., Martin, L., Stone, K., Albert, P., Almahairi, A., Babaei, Y., et al. (2023b). Llama 2: open foundation and fine-tuned chat models. *arXiv*. doi: 10.48550/arXiv.2307.09288

United Nations (2023) *Agreement under the united nations convention on the law of the sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction*. Available online at: https://undocs.org/en/A/77/L.82 (Accessed August 10, 2023).

Vaghefi, S. A., Stammbach, D., Muccione, V., Bingler, J., Ni, J. W., Kraus, M., et al. (2023). ChatClimate: Grounding conversational AI in climate science. *Commun. Earth Environ.* 4, 480. doi: 10.1038/s43247-023-01084-x

Wang, X., Chen, Y., and Zhu, W. (2021). A survey on curriculum learning. *Proc. IEEE* 44, 4555–4576. doi: 10.1109/TPAMI.34

Wang, H. C., Liu, C., Xi, N. W., Qiang, Z. W., Zhao, S. D., Qin, B., et al. (2023). HuaTuo: tuning LLaMA model with Chinese medical knowledge. *arXiv*. doi: 10.48550/arXiv.2304.06975

Wang, Z. Z., Yang, F. K., Zhao, P., Wang, L., Zhang, J., Garg, M., et al. (2023). Empower large language model to perform better on industrial domain-specific question answering. *arXiv*. doi: 10.48550/arXiv.2305.11541

Ward, D., Melbourne-Thomas, J., Pecl, G. T., Evans, K., Green, M., McCormack, P. C., et al. (2022). Safeguarding marine life: conservation of biodiversity and ecosystems. *Rev. Fish Biol. Fisheries*. 32, 65–100. doi: 10.1007/s11160-022-09700-3

Wei, J., Bosma, M., Zhao, V. Y., Guu, K., Yu, A. W., Lester, B., et al. (2021). Finetuned language models are zero-shot learners. *arXiv*. doi: 10.48550/arXiv.2109.01652

Wikipedia (2023). Available online at: https://en.wikipedia.org/wiki/MainPage (Accessed November 4, 2023).

Xiong, H. L., Wang, S., Zhu, Y. T., Zhao, Z. H., Liu, Y. X., Huang, L. L., et al. (2023). DoctorGLM: fine-tuning your Chinese doctor is not a herculean task. *arXiv*. doi: 10.48550/arXiv.2304.01097

Yang, H. Y., Liu, X.-Y., and Wang, C. D. (2023). FinGPT: open-source financial large language models. *arXiv*. doi: 10.2139/ssrn.4489826

Zeng, A. H., Liu, X., Du, Z. X., Wang, Z. H., Lai, H. Y., Ding, M., et al. (2022). GLM-130B: an open bilingual pre-trained model. *arXiv*. doi: 10.48550/arXiv.2210.02414

Zhang, T. Y., Kishore, V., Wu, F. L., Weinberger, K. Q., and Artzi, Y. (2019). BERTScore: evaluating text generation with BERT. *arXiv*. doi: 10.48550/arXiv.1904.09675

Zhong, B., He, W., Huang, Z., Love, P. E. D., Tang, J., and Luo, H. (2020). A building regulation question answering system: a deep learning methodology. *Adv. Eng. Inform.* 46, 101195. doi: 10.1016/j.aei.2020.101195

Zhu, F. B., Lei, W. Q., Wang, C., Zheng, J. M., Poria, S., and Chua, T.-S. (2021). Retrieving and reading: a comprehensive survey on open-domain question answering. *arXiv*. doi: 10.48550/arXiv.2101.00774

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 22 April 2024
DOI 10.3389/fmars.2024.1388975

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
José Joel Peña Llanes,
National Autonomous University of Mexico, Mexico
Nitin Agarwala,
Centre for Joint Warfare Studies, India

*CORRESPONDENCE
Shuli Han
hanshuli@jnu.edu.cn

RECEIVED 20 February 2024
ACCEPTED 01 April 2024
PUBLISHED 22 April 2024

CITATION
Xu Q, Zhang M and Han S (2024) Reflections on the European Union's participation in negotiations of the global plastic pollution instrument under international environmental law. *Front. Mar. Sci.* 11:1388975. doi: 10.3389/fmars.2024.1388975

COPYRIGHT
© 2024 Xu, Zhang and Han. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Reflections on the European Union's participation in negotiations of the global plastic pollution instrument under international environmental law

Qi Xu, Mingyang Zhang and Shuli Han*

School of Law, Jinan University, Guangzhou, China

Increasing plastic pollution is looming worldwide, damaging biodiversity, marine ecosystems, and human health. At the global level, no overarching normative framework sets out the specific rules and principles of general application in international environmental law, leading to difficulties in compliance and enforcement of plastic pollution governance. Developing an effective and legally binding instrument to tackle this emerging issue is imperative. The United Nations Environment Assembly (UNEA) has called for developing an international legally binding instrument on plastic pollution, including in the marine environment, based on plastic's full lifecycle approach. As one of the active participants in the negotiations, the European Union (EU) has discussed various aspects of the instrument in detail and sought to introduce the EU governance experience at the international level. This article develops a framework that considers contextual, actor, and process factors to assess the extent of achieving EU targets. On this basis, we argue that the EU's objectives for the international instrument may be achieved at a high level. However, how the EU responds to challenges will also impact subsequent development, which may require the EU to adopt a more moderate stance and compromise on some controversial issues.

KEYWORDS

global plastic pollution, international instrument, European Union, international environmental law, full lifecycle approach

1 Introduction

The impacts of plastic pollution are becoming increasingly palpable – forcing ecosystems to reduce their ability to adapt to climate change, threatening people's livelihoods, food production capabilities and social well-being, and the health of humans and other living organisms (UNEP, 2022a; Varvastian, 2023). It is estimated that between 1.15 and 2.41 million tons of plastic waste enters the ocean every year from rivers (Lebreton et al., 2017). Plastics

account for at least 85 percent of marine waste (UNEP, 2022a). The mismanagement of plastic waste on shorelines and at the sea surface from pole to pole has damaged the entire marine environment (Woodall et al., 2014). The worldwide community should be aware of the urgent global issue since it will unavoidably cause harm to all nations directly and indirectly (Nellyana et al., 2023).

United Nations (UN) mechanisms played an increasingly important role in making the environmental concerns genuinely global from Stockholm to Paris, notably the United Nations Environment Programme (UNEP) and the 1992 United Nations Framework Convention on Climate Change (UNFCCC) (Kumar, 2020; Chen and Xu, 2022b). According to the United Nations Environment Assembly (UNEA) resolution 5/14, it is required that the executive Director should convene an Intergovernmental Negotiating Committee (INC) to develop an internationally legally binding instrument[1] on plastic pollution, including marine plastic pollution, henceforth referred to as "the instrument," which could include both binding and voluntary approaches, based on a comprehensive approach that addresses the full lifecycle[2] of plastics (UNEP, 2022c; UNEP, 2023a). In September 2023, the essential "Zero Draft" [3]was launched with an alternative scenario for an overall target year of 2040. The revised version, including most of the proposed text submissions from global actors, will be discussed in April 2024 (Xu et al., 2023; IISD, 2023a).

1 Legally binding instrument: According to the Organization for Economic Co-operation and Development (OECD) and United Nations Treaty Collection, international instruments binding at international law are treaties, agreements, conventions, charters, protocols, declarations (declarations are not always legally binding), memoranda of understanding, modus vivendi and exchange of note. They can be adopted by intergovernmental organizations' governing or decision-making bodies or by ad hoc negotiating groups (e.g., negotiating conferences) specifically set up for this purpose. They are addressed to states, who - if any necessary procedures to become parties to them have been completed - will have an obligation under international law to implement them. See https://www.oecd.org/gov/regulatory-policy/IO-Rule-Based%20System.pdf.

2 Full lifecycle: According to UNEP, the full lifecycle approach of plastics may be simplified into upstream, midstream, and downstream activities. Upstream activities include obtaining raw materials from crude oil, natural gas, or recycled and renewable feedstock and polymerization. Midstream activities involve the design, manufacture, packaging, distribution, use (and reuse), and maintenance of plastic products and services. Downstream activities involve end-of-life management–including segregation, collection, sorting, recycling, and disposal. See https://wedocs.unep.org/bitstream/handle/20.500.11822/40767/K2221533%20-%20%20UNEP-PP-INC.1-7%20-%20ADVANCE.pdf.

3 Zero Draft: The Zero Draft text is proposed to facilitate and support the intergovernmental negotiating committee's work towards developing the international legally binding instrument on plastic pollution, including in the marine environment, called for by United Nations Environment Assembly (UNEA) resolution 5/14. It does not prejudge the committee's decisions on the content of the future instrument. See https://wedocs.unep.org/bitstream/handle/20.500.11822/43239/ZERODRAFT.pdf.

As the INC meetings progressed, discussions in the academic literature increased proportionately. Some studies emphasize the need for an instrument that could fill the regulatory and governance gaps in international environmental law and provide concrete recommendations for a solid and effective agreement and the interaction between the instrument and other agreements, such as the United Nations Convention on the Law of the Sea (UNCLOS) (Beltran et al., 2023; Vidar et al., 2023; Mendenhall, 2023a, b). Some discuss the fundamental elements of this instrument (Wang, 2023), while others analyze the main drivers behind the global wave of plastic pollution cases and the prospect of plastic treaty negotiations (Stöfen-O'Brien, 2022).

The European Union (EU), as one of the most active global negotiation actors, promotes and implements ambitious environmental policies worldwide (European Commission, 2019b). The EU's foreign policy agenda and the forward-looking European strategy on plastics (2018) show its ambition and leadership on global marine litter by shifting waste leakage from a linear model to a circular one (Penca, 2018; Iverson, 2019). The EU has enforced the directives to reduce the impact of certain plastic products on the environment (Da Costa et al., 2020). It also develops a more robust "green deal diplomacy" focused on convincing and supporting others to take on their share of promoting more sustainable development (European Commission, 2019b).

Despite the research on the instrument and the EU's plastic governance already validated in the literature, this article provides a more comprehensive analysis. Through theoretical and practical discussion on the EU's participation in negotiations of the global plastic pollution instrument under international environmental, we predict the extent to which EU policy objectives are reflected in the outcome of the international negotiations and shed new light on how the EU will contribute to the negotiation of the instrument. We developed a comprehensive assessment framework to guide our analysis. We distinguish here four categories of factors related to (1) global ocean governance and pollution control, (2) the EU's leadership role in the governance of plastic pollution, (3) the EU's positions on the instrument elements during INC meetings, (4) the EU's diplomacy strategy during the negotiations. Finally, we summarize the findings and analyze the challenges and outlook of the EU's future participation in the plastic pollution instrument.

2 Global ocean governance and pollution control

This section reviews and analyzes the framework of the existing international agreements and international political efforts on plastic pollution, as well as the governance gaps and deficiencies that impede the current efforts to address the issue.

2.1 The existing international agreements and international political efforts

As a branch of international law, international environmental law addresses States and international organizations concerning protecting

the environment. Global plastic pollution governance represents a multidimensional governance landscape at international, regional, and national levels (Wysocki and Billon, 2019), with UNCLOS as the core, formal binding legal forms such as environment-related international conventions, agreements, and protocols as the mainstay, and international political efforts as the complement.

The Stockholm Declaration (1972) was one of the first attempts to get States to agree on environmental protection goals (Fritz, 2020) as the conceptual cornerstone to shape five decades of environmental action. Principle 7[4] was further supported by the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (The London Convention of 1972), which regulates the dumping of waste at sea at a global level. Annex V of the International Convention for the Prevention of Pollution from Ships 1973 (MARPOL) is the complete ban imposed on the disposal into the sea of all plastics (Wysocki and Billon, 2019). Further, the 1982 United Nations Law of the Sea Convention (UNCLOS) provides general obligations to prevent or to reduce marine pollution from land- and ocean-based sources through domestic laws (Wang, 2023). The UNCLOS defines "pollution of the marine environment" [5] in Article 1 and regulates related aspects in other articles.[6] However, the framework is rather general, and there are no concrete solutions to address the full lifecycle of plastic and prevent ongoing marine plastic pollution (Raubenheimer et al., 2018; Nagtzaam, 2023). Other binding international instruments also address specific issues of plastic wastes, such as the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes (1989) and the Stockholm Convention on Persistent Organic Pollutants (2004) (Wysocki and Billon, 2019). The Basel Convention (1989) aims to protect human health and the environment by reducing waste at the source and disposing of hazardous waste in an environmentally sound manner (Guggisberg, 2024). Its amendment in 2019 further strengthened the regulation of transboundary movements of plastic waste, minimizing the potential for new plastic pollution of the oceans. The Stockholm Convention (2004) addressed persistent organic pollutants and was a new milestone in the international community's response to plastic pollution (Hagen and Walls, 2005).

Since marine environmental matters differ from region to region, implementing differentiated regional legal regimes for protecting the environment is a viable option where global laws cannot be applied uniformly to specific marine areas. At the level of regional regulations, significant agreements such as the Convention on the Protection of the Marine Environment of the Baltic Sea Area (1974), the Convention for the Protection of the Mediterranean Sea against Pollution (1976), and the Convention for the Protection of the Marine Environment of the North-East Atlantic (1992), exist to address these concerns. Although the scope of application of these regional action plans or mechanisms varies, the proliferation of relevant international instruments and improved cooperation and coordination among regions enormously fortified the legal foundation for preventing and controlling marine microplastic pollution.

International political efforts have played a complementary role in global governance. In addition to The Stockholm Declaration (1972) mentioned above, the Global Program of Action to Protect the Marine Environment from Land-Based Activities (1995) and the Honolulu Strategy (2012) provided a guiding framework for action to combat plastic pollution (UNEP, 2012). The five resolutions of the UN Environmental Assembly on plastic waste and microplastics in the sea after 2014 signaled the beginning of concrete measures by the international community against plastic waste in the sea (IISD, 2021). Furthermore, regional and global political initiatives also operate voluntarily without a legally binding nature, such as the G20 Implementation Framework for Action on Marine Plastic Litter (2017), the Ocean Plastic Charter (2018), and the Association of Southeast Asian Nations (ASEAN) Framework of Action on Marine Debris (2019) (Wang, 2023).

2.2 Governance gaps and deficiencies

In this section, "gaps" refers to implementation gaps in the international legal framework and substantive/normative gaps (including procedural and institutional gaps (UNEP, 2018b). While there are comprehensive international legal frameworks to regulate marine plastic pollution at global and regional levels, the amount of plastic waste continues to increase, and plastic continues to leak into rivers and oceans (Wysocki and Billon, 2019; Nagtzaam, 2023).

Current regulations need to be revised to address plastic pollution's damage effectively. First, legally binding international instruments are primarily directed at the oceans and are less concerned with land-based sources of pollution. Second, the resource-inefficient and linear plastics economy is the biggest culprit in the plastic pollution crisis (Fritz, 2020). Only a tiny fraction of plastics can be recycled from raw plastic production to

4 Principle 7 of the Stockholm Declaration (1972): "States shall take all possible steps to prevent pollution of the seas by substances that are liable to create hazards to human health, to harm living resources and marine life, to damage amenities, or to interfere with other legitimate uses of the sea."

5 In accordance with Article 1 of UNCLOS, "Pollution of the marine environment" means the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities.

6 Article 207 of the UNCLOS provides that States shall adopt laws and regulations to prevent, reduce, and control pollution of the marine environment from land-based sources, including rivers, estuaries, pipelines, and outfall structures, taking into account internationally agreed rules, standards, and recommended practices and procedures. Articles 210 and 211 regulate pollution prevention, reduction, and control by dumping and pollution from vessels. In addition, articles 213 to 222 provide for the implementation by States of measures necessary to prevent, reduce, and control pollution in all its aspects, as well as applicable international rules and standards established through competent international organizations or international conferences.

waste and spills. Third, The emerging plastics governance regime only contains "downstream" (Mendenhall, 2023a) while not offering any solutions to the "upstream" production of plastic as a cause of marine plastic pollution (Nagtzaam, 2023).

Moreover, principles of general international law can also govern matters if the convention does not regulate them. No overarching normative framework sets out the concrete rules and principles of general application in international environmental law (UNEP, 2018b). These principles of the Rio Declaration on Environment and Development (1992) deserve attention, such as precaution[7], polluter pay [8]and common but differentiated responsibilities[9]. However, not all principles are well-recognized through international instruments and international courts. The principle of not being content-wise, status-wise, and having a lack of clarity makes it hard to reach a global consensus.

The current piecemeal and reactive framework led to a deficit in coordination at the legislation and implementation level due to the lack of coherence and synergy (UNEP, 2018b). The gaps between states should also be considered regarding financial resources, environmentally sound technologies, and capacities, which contribute to the implementation at the national and international levels. States and the United Nations should work together to address the gaps and deficiencies. Therefore, It is necessary to develop an internationally legally binding instrument on plastic pollution, including marine plastic pollution, with the clarification and reinforcement of regulations and principles, the international legally binding force, and robust compliance and enforcement procedures to ensure effective implementation of States' commitments.

7 Principle 15 of the Rio Declaration on Environment and Development (1992): "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

8 Principle 16 of the Rio Declaration on Environment and Development (1992): "National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment."

9 Principle 7 of the Rio Declaration on Environment and Development (1992): "States shall cooperate in a spirit of global partnership to conserve, protect, and restore the health and integrity of the Earth's ecosystem. In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities. The developed countries acknowledge the responsibility that they bear in the international pursuit of sustainable development in view of the pressures their societies place on the global environment and of the technologies and financial resources they command."

3 EU's leadership role in the governance of plastic pollution

An actor is qualified as a leader in global governance because it has more ambitions than others in pursuing the common good (Oberthür and Dupont, 2021). In past environmental negotiations and issues, the EU, as a critical contributor to advancing and revising global and regional conventions while amassing considerable negotiation experience, has been found to exert leadership with varying degrees of success (Kilian and Elgstrom, 2010; Bäckstrand and Elgström, 2013; Iverson, 2019; Oberthür and Dupont, 2021). To assess the EU's ambition in plastic pollution governance, we first put the analytical effort on the EU's participation in previous international negotiations as the basis for understanding EU marine plastic pollution governance stances. Then, we analyze the EU's policies and legislation to assess whether they could significantly shape and condition EU leadership.

3.1 Positive actor in international marine plastic pollution governance

The EU Integrated Maritime Policy (2007) extensively delineates the future vision and planning for ocean utilization and protection. It highlights the EU's crucial role in regional and global ocean governance, signifying the externalization of the EU's maritime policy. Following this, the EU has actively participated in extraterritorial maritime affairs and promoted European programs globally (European Commission, 2008b). As a role model in environmental protection for its effective path for eliminating marine plastic pollution, the EU has transposed international agreements into its internal legal order through legislation and policies. After the United Nations Environment Assembly (UNEA) issued the first resolution on marine litter emphasizing the urgency to take concrete action (UNEP, 2014), the EU initiated the Marine Safety Strategy (2014), followed by the adoption of the EU Action Plan for the Circular Economy (2015). In 2016, the EU presented its first global ocean governance strategy (European Commission, 2016), suggesting taking marine plastic litter as one of the 50 actions of international ocean governance. Along with the UNEP resolution 3/7 on marine litter and microplastic (2018), the EU adopted the European strategy (2018) for plastics, which highlighted the need to harness global action on plastic (European Commission, 2018) and embraced A new Circular Economy Action Plan (2020), underscoring the global plastic agreement as a global priority (European Commission, 2020).

The EU has contributed to integrating the global plastic waste governance system. Primarily, the EU actively engages in revising established conventions, such as being the vocal and active supporter of the Basel amendments (Environmental Investigation Agency, 2019). Another aspect is to strengthen international cooperation on marine research and data. The European Commission confirmed its commitment to improved ocean governance in the recent Joint communication on the EU's

International Ocean Governance agenda (2022) to build international ocean knowledge for evidence-based decision-making that leads to actions to protect and sustainably manage the ocean, which requires promoting marine research, data, and science to develop comprehensive, reliable, comparable, and accessible knowledge about the oceans (Dañobeitia et al., 2023). Funded by the European Commission (EC), the Copernicus Maritime Service Center provides a comprehensive, scientifically assessed, and regularly updated product portfolio to understand how plastic pollution spreads and reliable inputs for specific plastic applications with free and open access to all stakeholders (Copernicus Marine Service, 2017, 2020). In addition, the EU also provided funding for research and innovation work, such as Horizon 2020, which was succeeded by Horizon Europe. Some programs focus on tackling the problem of marine plastic waste by tracking the amount of plastic in the sea and producing high-quality products from marine plastic waste (European Union External Action, 2021).

3.2 Addressing the gap: EU internal plastic pollution policies and legislation

We include the EU's internal policies and legislation as one of the factors in assessing its leadership, which underpins the EU's ambitions. First, the EU has an elaborate policy framework to face the governance of plastic pollution. Critical decisions on the ambition of EU policies have regularly been taken in the context of specific policies. Additionally, almost 26 million tons of plastic waste are generated annually in Europe, and land-based sources represent nearly 80% of plastic inputs to the ocean (Lavers and Bond, 2017; European Commission, 2023b). Therefore, its policies on significant plastic consumption and production can substantially impact the worldwide plastic lifecycle (Eckert et al., 2024). As a framework policy to address the challenges, the European Commission officially launched the European Strategy for Plastics in a Circular Economy (2018) to ensure that plastic materials last longer, can be collected more easily after use, and can be reused or recycled more easily (European Commission, 2018). The transition to higher recycled plastics in Europe increases significantly between 2018 and 2022. The content of recycled plastics in new products reached a new record high of 13.5%. Compared with the nearly 15% European plastics recycling rate in 2018 (with almost 62 million tonnes plastics production and 9.4 million tonnes recycling), it has increased to 26.9% in 2022. It remarks as a crucial circularity milestone and stands as a model for other actors (Plastics Europe, 2019; Plastics Europe, 2024).

The Marine Strategy Framework Directive (2008) is a critical horizontal legislative pillar, providing a cross-sector framework covering all the primary pollution sources. It shows a new approach to EU environmental policy, in which different polluters and sources of pollution are not addressed independently but integrated into a comprehensive legal act. The regulatory framework for marine plastic pollution ranges from water and marine policy to waste and product policy to measures under the common fisheries policy.

In the upstream phase, most monomers used to make plastics, such as ethylene and propylene, are derived from fossil hydrocarbons. None of the commonly used plastics are biodegradable. As sunlight and other elements degrade plastics, they break into thousands of tiny pieces called microplastics, accumulating in the environment and polluting marine ecosystems, causing environmental degradation and health problems for humans and animals alike (Earth Day, 2023). The EU is taking bioplastics as a possible alternative to plastic packaging. There isn't a comprehensive EU legislation but a non-legal binding policy framework on sourcing, labeling, and using biobased biodegradable and compostable plastics (European Commission, 2023a), and the European Commission adopted a REACH restriction (2023) on microplastics intentionally added to products. In the midstream, the EU Plastic Bags Directive (2015) addresses the unsustainable consumption and use of lightweight plastic carrier bags through consumption limitation (European Commission, 2015). Directives on single-use plastics (2019) aim to reduce the volume and impact of certain plastic products on the environment and introduce waste management and clean-up obligations for producers, including Extended Producer Responsibility (EPR) schemes (European Commission, 2019a). EU rules on packaging and packaging waste cover both packaging design and packaging waste management and set additional waste prevention and reuse obligations for EU countries and packaging EPR schemes (European Commission, 1994). In the downstream, the EU launched the Waste Framework Directive (2008) in response to challenges associated with illegal dumping and insufficient downstream waste management (European Commission, 2008a). This policy strives to decrease waste generation at its source by enhancing product design and advocating for the recycling and reuse of waste. The Polluter Pays Principle is a fundamental guiding principle in achieving this objective, ensuring that product manufacturers assume the costs of combating environmental pollution.

Additionally, measures have been taken to establish a fisheries management regulation (2009), which requires marking fishing gear and recovering fishing gear when fishermen unintentionally lose or intentionally discard fishing in the sea (European Council, 2009). The EU is also grappling with downstream shipments of plastic waste through Delegated Regulation (EU) 2020/2174 amending the Waste Shipments Regulation, which establishes different entries for the classification of hazardous, non-hazardous, or special plastic waste to be taken into account has been changed, ending the export of plastic waste to third countries that lack the capacity and standards for sustainable disposal. To better understand the EU legislation, we compare the national-level

regulatory challenges identified by UNEP (UNEP, 2022b) with the EU legislation[10] in (Table 1).

(The two leftmost columns of Table 1 are based on UNEP/PP/INC.1/11-*Priorities, needs, challenges, and barriers to ending plastic pollution at the national level* (UNEP, 2022b). We have compiled the legislation and policies from the official website of the European Union and analyzed how they could address the regulatory challenges and barriers at the national level.)

The EU has generally established a relatively comprehensive system to prevent and control marine plastic pollution through policies and legislation. It could address the regulatory challenges and barriers at the national level. However, EU legislation still has limitations in the full lifecycle approach (Steensgaard et al., 2017). Many measures focus on downstream activities (Milios, 2018), while only a non-legally binding framework is effective at the upstream stage to reduce the overall consumption of primary fossil-based materials. Policy action mostly leaves the upstream material input stage unaddressed (Eckert et al., 2024). The downstream limiting the number of plastics currently disposed of in landfills, which could further optimize resource efficiency, still needs to be regulated in the EU (Steensgaard et al., 2017). In addition, the EU has yet to give a specific response to the lack of integration in the informal waste sector.

In summary, we argue that the EU has played a leading role in international marine plastic pollution governance. It has actively participated in developing relevant international instruments and shared free and open-access knowledge, providing technical support and financial backing for innovation and development. It also transposed international agreements into its internal legal order through legislation and policies. The EU legislation and policies could address the most challenges at the national level, which underpins the feasibility of pursuing EU goals at the international level. However, the EU must focus on improving policy and legislation at each life cycle stage and increase regulation and enforcement if it wants to gain leadership in global governance.

10 According to the European Commission, EU legislation is divided into two classes: Primary legislation consists of treaties between EU member countries. They set out EU objectives, rules for EU institutions, how decisions are made, and the relationship between the EU and its member countries. Every action taken by the EU is founded on treaties. Treaties are comparable to constitutional law in many countries. Secondary legislation consists of regulations, directives, decisions, recommendations, and opinions used to implement the policies set out in the treaties. Regulations are binding legislative acts that apply directly to all member states. They often concern trade issues. Directives are legislative acts that set out goals that all EU countries must achieve. However, it is up to the individual countries to devise their own laws to reach these goals. Decisions are binding on those it addresses (e.g., an EU country or an individual company) and are directly applicable. Recommendations allow EU institutions to make their views known and to suggest a line of action without imposing any legal obligation on those to whom it is addressed. They are not legally binding. Opinions are issued by the main EU institutions (Commission, Council, Parliament), the Committee of the Regions and the European Economic and Social Committee. They are not legally binding.

4 The EU's positions on the instrument elements during INC meetings

Ahead of the negotiations, the European Commission issued a justification for the EU's participation in the negotiations on an international agreement on plastic pollution, ensuring that the EU's positions in the instrument are consistent with existing EU policy provisions, which suggested that the agreement should be based on the precautionary principle, the polluter pays principle, and source government (European Commission, 2022b). As discussed earlier, the EU's position in the instrument negotiations will likely continue the EU's policy and legislative preferences. However, it also depends on whether the EU pursues conservatism to stick to its goals in the negotiations or adopts reformism to compromise. The following section discusses the EU's positions on the more controversial elements of the instrument and analyzes the opinions through international environmental law.

4.1 Principles of the instrument

According to the requirements mentioned in resolution 5/14, the instrument should be based on the principles of the Rio Declaration on Environment and Development, as well as national circumstances and capabilities. In the third session of the Intergovernmental Negotiating Committee (INC-3) contact group 3 In-session Submissions, 25 countries submitted written comments on the principles. According to Table 2, the principles that received high support are the precautionary principle/precautionary approach, the common but differentiated responsibility, and the polluter pays principle[11]. It is worth noting that there is a wide divergence of views on the precautionary principle and common but differentiated responsibilities. The position of the EU and the majority of HAC members remains consistent in favor of the precautionary principle and the polluter pays principle. It is also worth noting that the positions of China, Iran, and India on these

11 The High Ambition Coalition to End Plastic Pollution (HAC) is committed to developing an ambitious international legally binding instrument based on a comprehensive and circular approach that ensures urgent action and effective interventions along the full lifecycle of plastics. According to HAC Member States Ministerial Joint Statement INC-3, there are 63 members. They are Antigua & Barbuda, Armenia, Australia, Austria, Azerbaijan, Belgium, Bulgaria, Burkina Faso, Cabo Verde, Canada, Chile, Colombia, Cook Island, Costa Rica, Denmark, Dominican Republic, Ecuador, Estonia, European Union, Federated States of Micronesia, Finland, France, Gabon, Georgia, Germany, Ghana, Greenland, Guinea, Iceland, Ireland, Israel, Japan, Jordan, Luxembourg, Malawi, Maldives, Mali, Mauritius, Mexico, Moldova, Monaco, Montenegro, Netherlands, New Zealand, Nigeria, Norway, Palau, Panama, Peru, Portugal, Republic of Korea, Romania, Rwanda, Senegal, Seychelles, Slovenia, Solomon Islands, Spain, Sweden, Switzerland, Togo, United Kingdom of Great Britain and Northern Ireland, and Uruguay.

TABLE 1 Applicable EU Legislation along the full lifecycle approach.

Lifecycle phase	Regulatory challenges and barriers at the national level	Applicable EU Legislation along the full lifecycle approach		
		Sources	Legislations and policies	Applicability
Upstream	1. Lack of legislation (e.g., planning, environmental impact assessments, licensing regulations) for sustainable material sourcing (virgin or recycled materials). 2. Lack of legislation to phase out harmful chemicals and intentionally added microplastics. 3. Lack of inclusion of environmental criteria in public procurement decision-making.	Biobased, biodegradable, and compostable plastics	Currently, there is no comprehensive EU law but two specific laws with partial objectives: 1. **Directive on single-use plastics (**Directive EU 2019/904) 2. **Plastic Bags Directive** (Directive EU 2015/720)	**Challenge 1:** EU adopted a non-legal binding policy framework on sourcing, labeling, and using biobased biodegradable and compostable plastics. The framework clarifies biobased, biodegradable, and compostable plastics and sets out the conditions to ensure that the overall environmental impact of their production and consumption is positive. **Challenge 3:** The European Commission encourages citizens, public authorities, and businesses to use this framework in policy, investment, or purchasing decisions. In addition, Directive 2014/24/EU on public procurement and Directive 2014/25/EU on procurement by entities seek to ensure greater inclusion of common societal goals, including environmental protection.
		Microplastics	Currently, there is no comprehensive EU law but several specific laws with partial objectives: 1. **Marine Strategy Framework Directive** (Directive 2008/56/EC) 2**. Fertilizing Products Regulation (**Regulation EU 2019/1009) 3. **A European Strategy for Plastics in a Circular Economy** 4. **Waste Framework Directive (**Directive 2008/98/EC) 5. **Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)** Regulation (EC) No 1907/2006 6. **European Pollutant Release and Transfer** (Regulation EC No 166/2006) 7. **Directive on the quality of water intended for human consumption** (Directive EU 2020/2184)	**Challenge 2:** In 2023, the European Commission adopted a REACH restriction on microplastics intentionally added to products and a proposal for a Regulation on preventing plastic pellet losses to the environment (2023).
Midstream	1. Lack of legislation on the design of plastic products to reduce the production of unnecessary, disposable, and difficult-to-recycle plastics and the need for greater stimulation for upstream innovative solutions. 2. Lack of legislation and policy to support reuse. 3. Lack of legislation to encourage the use of recycled content by setting mandatory targets for packaging and durable goods containing plastics. 4. Lack of public procurement policies favoring sustainability.	Plastic bags	**Plastic Bags Directive** (Directive EU 2015/720)	**Challenge 2:** EU rules on single-use plastics (SUPs) introduced mandatory recycled content for beverage bottles manufactured from PET as the major component. **Challenge 4:** EU green public procurement criteria for food, catering services (2019), and vending machines regulate that if disposable items are used, they must be recyclable, made of either recyclable plastic or compostable material.
		Single-use plastic products and fishing gear	1. **Directive on single-use plastics** (Directive EU 2019/904) 2**. Implementing Decision** (EU) 2021/1752 3. **Implementing Regulation** (EU) 2020/2151 4. **Packaging Directive (**Directive 94/62/EC)	
		Packaging and packaging waste	1. **Packaging Directive (**Directive 94/62/EC) 2. **Plastic Bags Directive** (Directive EU 2015/720)	**Challenge 1:** EU rules on packaging and packaging waste cover packaging design and waste management. **Challenge 2:**

(Continued)

10.3389/fmars.2024.1388975

TABLE 1 Continued

Lifecycle phase	Regulatory challenges and barriers at the national level	Applicable EU Legislation along the full lifecycle approach		
		Sources	Legislations and policies	Applicability
				Article 6 of the Package Directive regulated the recovery and recycling of packages. **Challenge 3:** The packaging amendment provides mandatory setting up of packaging Extended Producer Responsibility (EPR) schemes as part of the legislative proposals adopted under the circular economy package in 2018. Another amendment added sustainable consumption reduction measures for plastic carrier bags in 2015.
Downstream	1. Lack of repair and waste management regulation and policies and their enforcement. 2. Lack of effectively implemented extended producer responsibility and lack of eco-modulation to stimulate the reduction of problematic and unnecessary packaging and plastic products. 3. Lack of integration of the informal sector in decision-making. 4. Lack of effective enforcement of regulations against open burning and dumping.	Waste management	1. **Waste Framework Directive** (Directive 2008/98/EC) 2. **Directive on the Landfill of Waste** (1999/31/EC) 3. **Urban Waste Water Treatment Directive** (91/271/EEC)	**Challenge 1:** EU countries must report to the European Commission on implementing the EU waste laws, including achieving targets for waste collection, reuse, recycling, and recovery every year or every two years. **Challenge 2:** The proposal for amending Directive 2008/98/EC on waste (2023) suggests establishing harmonized Union extended producer responsibility rules for textiles with eco-modulation fees. **Challenge 4:** The Landfill of Waste Directive (1999) regulates the incineration of municipal and non-hazardous waste and takes appropriate measures to avoid the abandonment, dumping, or uncontrolled disposal of waste.
		Sea-based marine litter	1. **Common fisheries policy** (Regulation EC No 1224/2009) 2. **Directive on single-use plastics** (Directive EU 2019/904) 3. **Port State control** (Directive 2009/16/EC)	
		Plastic waste shipments	1. **Delegated Regulation (EU) 2020/2174 amending the Waste Shipments Regulation** 2. **Basel Convention amendments on plastic waste**	

10.3389/fmars.2024.1388975

TABLE 2 In-session submissions of principles from members in INC-3.

		Precautionary approach/ Prevention principle	Common but differentiated responsibility	Polluter pays principle
1	GRULAC	○	○	○
2	**Costa Rica**	○	○	○
3	India	○	√	○
4	Indonesia	√	√	○
5	AOSIS	√	√	√
6	Brazil	√	√	√
7	**Chile**	√	√	√
8	Iran	○	√	○
9	Jamaica	√	√	√
10	Kenya	√	√	√
11	**Mexico**	√	√	○
12	**EU**	√	×	√
13	**Cook Islands**	√	○	√
14	Fiji	√	√	√
15	**Norway**	○	○	○
16	**Panama**	○	○	√
17	Singapore	○	○	○
18	**Japan**	√	×	○
19	Africa	○	○	○
20	Vietnam	√	√	√
21	China	○	√	○
22	Philippines	√	√	○
23	Argentina	○	√	○
24	Qatar	√	√	○
25	**Korea**	○	○	○
Number of supports		16	15	10

√: The member supported the principle in the submission.
○: The member did not explicitly identify the principles or do not mention the principle in the submission.
×: The member objected to the principle in the submission.
The boldface of members: They are the members of HAC.
(Table 2 is based on the in-session submissions of principles from members in INC-3, see https://www.unep.org/inc-plastic-pollution/session-3/documents/in-session#NonPapers).

three principles are the same, stressing the importance of the common but differentiated responsibility. The EU's positions on the precautionary principle, common but differentiated responsibilities, and the polluter pays principle will be scrutinized below.

4.1.1 The precautionary principle

At the international level, the definition of the precautionary principle in Rio Declaration Principle 15 of 1992 is widely accepted. The precautionary principle is enshrined in many previous plastic pollution control instruments. International organizations and conference resolutions have also contributed to developing the precautionary principle. The 1992 United Nations Conference on Environment and Development, regarded as a landmark in national environmental law, further strengthened the precautionary principle in the Rio Declaration and Agenda 21 (UNGA, 1992). In numerous cases, plaintiffs have frequently invoked the precautionary principle, but the International Court of Justice has not responded positively (ICJ, 1996, 1997, 2010).

Through a series of laws, policy documents, and extensive application, the precautionary principle has evolved into the foundation for policy formulation and implementation within the EU. Article 191 of the Treaty on the Functioning of the European Union (1958) states that union policy on the environment should be

based on the precautionary principle. The environmental damage should be a priority rectified at the source, and the polluter should pay. In addition, the precautionary principle remains a fundamental tenet of successive EU environmental action plans and substantive legislation on environmental pollution. For example, the Industrial Emissions Directive (2010) requires operators to follow the principles of "taking all necessary precautions," "best available techniques," and "the principle of avoiding pollution" (European Commission, 2010). In the Waste Framework Directive (2008), prevention was defined as the measures taken before a substance, material, or product became waste and was prioritized in the waste hierarchy. The customary international law status of the precautionary principle is now undisputed, particularly within the EU region (Schröder, 2014). In the EC measures countering meat and meat products Case, the precautionary principle is already, in the view of the European Communities, a general customary rule of international law or at least a general principle of law (WTO, 2014).

Without full scientific certainty, the precautionary principle should require Parties to increase the standard of proof of the safety of plastic polymers, additives, and chemicals, thereby helping to prevent future environmental injustices and irreversible harm (Dauvergne, 2023; Vidar et al., 2023). The EU made a similar proposal during the first session of INC. Furthermore, the EU insisted that the precautionary principle should take precedence to prevent the spread of potentially unsustainable alternatives or substitutes in the second session of INC. In the third session, the EU's pre-submission reaffirmed this principle's fundamental and established status, and all the economic sectors must take responsibility that any plastic y plastic material, product, or component they intend to place on the market will not (or is very unlikely to) result in significant harm. It also suggested a technical review committee to assess the application of this principle (European Union, 2023d). The EU's adherence to the precautionary principle extends from its domestic policy to this negotiation. As we can see from Table 2, its advocacy has progressed relatively smoothly with a relatively high level of support (56%). This principle is supported by most HAC members (Mexico, Cook Islands, Panama, and Japan) and by developing countries (such as Vietnam, Indonesia, and the Philippines).

4.1.2 The common but differentiated responsibilities principle

Throughout INC meetings, there was much discussion about the responsibilities of developed and developing countries and the common but differentiated responsibilities principle that will most likely play a significant part in this instrument (Stöfen-O'Brien, 2023). According to UNEP Resolution 5/14, plastic pollution needs to be tackled under the consideration of national circumstances and capabilities. It was formalized in international law at the 1992 United Nations Conference on Environment and Development (UNCED), the concept of which was enshrined as Principle 7 of the Rio Declaration and also strengthened in Article 3(1) of the 1992 UNFCCC, together with Article 2(2) of the Paris Agreement (2015) and the Preamble to the Kyoto Protocol (1997). However, it is hard to determine whether it has legally binding status as a principle since there is no explicit element in the Multilateral Environmental Agreements (MEAs). In general international law, however, the concept of common but differentiated responsibilities is likely to be regarded as an international environmental policy or a far-reaching soft law (Hey and Paulini, 2021).

The establishment of the principle was regarded as a compromise between developed and developing countries during the international climate negotiations and thus has been the target of controversy between them. According to the Rio Declaration, the basic idea of CBDR applied to marine plastic pollution could be that given the different contributions to global environmental degradation, States have common but differentiated responsibilities. Thus, developed countries with advanced technologies and sufficient financial resources have an immense contribution to global plastic waste and thus should carry a larger responsibility in the international pursuit of sustainable development (Wang, 2023). Conversely, developing countries that make a minor contribution to plastic waste should take less responsibility. The EU has accepted its responsibility as a developed country to significantly contribute to reducing global emissions in compliance with the CBDR principle and respecting the capacities of developing countries in the UNFCC, Kyoto Protocol, and Paris Agreement (Gayon, 2023). However, the EU's position on plastic pollution changed. Most developing countries supported the principle of common but differentiated responsibilities, but Japan and the EU raised clear objections. EU stressed there was no relevance for the general application of the CBDR principle in the agreement and further insisted that it did not support individual principles (European Union, 2023d).

The principle is not always effective and was suspected of impeding the implementation of other international treaties in the climate change regime (Stöfen-O'Brien, 2023). Considering the complexity of plastics' full life cycle approach, how to equitably allocate responsibility will also pose a significant challenge. On the one hand, this principle has the potential to push high-income plastic producers, consumers, and polluters in Europe and the United States to accept extra global responsibilities, including funding, cleaning up pollution, preventing illegal dumping, and ending the practice of exporting plastic waste to low-income countries (Dauvergne, 2023). On the other hand, the EU's disagreement with CBDR may be related to its proposed polluter pays principle, which emphasizes that the costs of damages and remediation caused by environmental pollution are borne by the polluter rather than passed on to other groups and individuals.

4.1.3 The polluter pays principle

As complementary to the precautionary principle, the polluter pays principle to blame the polluter who causes environmental damage for the costs of remediation and compensation, ensuring the fair allocation of expenses for preventive and remedial measures (Wang, 2023; Zhu, 2023). In addition, it also acts as an incentive to encourage the polluters who bear the burdensome remediation costs to decrease the pollution. The principle first appeared in a legal context in a document prepared by the International Organization for Economic Cooperation and Development (OECD) to encourage

rational use of scarce environmental resources and to avoid distortions in international trade and investment (Larson, 2005). The principle has been adopted into many pollution-related multilateral conventions, as detailed in the 1992 Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) and the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter. The polluter pays principle has not been uniformly recognized in international law regarding legal status and specific content. However, its significance in environmental liability regimes worldwide could not be ignored. In the Rhine Chlorides Arbitration case (2014), the tribunal stated that although it did not view this principle as part of general international law, it admitted its importance in treaty law (PCA, 2014).

The Polluter Pays Principle has been widely recognized in EU environmental policies and legislation. The EU articulated the application of the polluter pays principle progressively. After being adopted in 1973, the polluter pays principle also appeared in the 1975 Recommendation 75/436 and further developed in the 1986 Single European Act (OCED, 2022). In addition, the European Commission adopted a white paper on environmental liability, stating that the Polluter Pays Environmental Liability regime should prevent further damage and allow polluters to internalize the environmental costs themselves, which means that the costs of preventing and restoring environmental damage will be paid by the parties responsible for the damage rather than being financed by society in general (European Commission, 2000). The European Court of Justice also supported this principle in protecting waters against pollution caused by nitrates from agricultural sources Case (CJEU, 1999), indicating that polluters are only liable for actions that impact environmental pollution. This principle has been utilized as an economic tool by implementing legislation such as the Waste Framework Directive (2008), Landfill Directive (1999), and Water Framework Directive (2000).

The EU's position on the Polluter Pays Principle certainly extends to plastic pollution negotiations, which have been standing pat from the beginning (European Union, 2022a). During the second session, the EU emphasized the role and responsibilities of the private sector in ending plastic pollution, following the polluter pays principle. The responsibility of producers and manufacturers who introduce the raw material/product into the market are required to be accountable for financing collection in the third session (European Union, 2023d). In the latest revised draft, there are various options for providing funding, such as adopting the EU's proposed polluter pays principle, which suggests that resource mobilization should include all sources, national and international, public and private. Parties should endeavor to mobilize additional private resources, including by aligning public and private investments and financing with the objectives and provisions of the instrument. Other options suggested that developed countries should provide new and additional financing to enable developing countries and Parties with economies in transition to cover the agreed full costs of measures to implement their commitments under this instrument (UNEP, 2023b). It may be one of the reasons why the EU and other Member States have different views on common but differentiated responsibilities. So far, many members stated that EPR was crucial, and there was broad support for the Polluter Pays Principle as a core instrument in contacting Group 1 of the third session.

4.2 Core obligations, control measures, and voluntary approaches

Control measures are clauses in a treaty specifically designed to prevent, minimize, or resolve the problems that prompted the instrument's adoption. The problem of plastics in the ocean reflects very complex patterns of global ownership, production, and consumption and is thus an example of structural inequality among States (Fritz, 2020). The setback between two different "like-minded" groups—High Ambition, which the EU joined before the first session of INC, and Big Oils, representing the global petrochemical industry and plastic-producing countries, jeopardized a more robust agreement (Environmental Investigation Agency, 2023a). There is an apparent dichotomy between the countries that are the source of the pollution and the countries that are the victims. With High Ambition Coalition countries blaming oil- and plastics-producing countries for the production of plastics and oil- and plastics-producing countries blaming the former for ineffective waste management capacity, there is a greater divergence in the discussion of core obligations that focus on upstream production reduction or downstream waste management.

4.2.1 Reducing the supply of, demand for, and use of primary

At the present growth rate, plastic production is estimated to double within the next 20 years (Lebreton and Andrady, 2019). Global municipal plastic waste generation is projected to triple by 2060 (*v.* 2015 values) (UNEP, 2018a). To prevent the creation of plastic waste at the source, it is possible, on the one hand, to reduce or limit the production of plastics (polymers) based on fresh fossil fuels, i.e., Gas and petrochemical companies (Busch, 2022b). Another way to prevent plastic waste is by improving the design of plastic products to increase their reusability and recyclability (Simon et al., 2021). Moreover, the 5/14 resolution also stressed the importance of the resources they are made of and of minimizing waste generation, which can significantly contribute to sustainable production and consumption of plastics. The enormous global rate of plastic production, which has surpassed carbon emissions, is the primary cause of the plastic pollution crisis (Varvastian, 2023).

The EU adopted a non-legal binding policy framework on sourcing, labeling, and using biobased biodegradable and compostable plastics. The framework clarifies biobased, biodegradable, and compostable plastics and sets out the conditions to ensure that the overall environmental impact of their production and consumption is positive. It is estimated that the EU's recycling target of 55 percent for 2025 will double the demand for reusable and recycled plastics to 10 million tons (European Commission et al., 2019). Suppose plastic producers decrease their reliance on fossil fuels and actively shift toward a sustainable, circular plastics economy in both production methods and consumption patterns. In that case, they can harness economic

prospects while mitigating the potential for plastics to become waste in landfills, dumps, or environmental pollutants (Busch, 2022a). Preventing waste and pollution at source is less expensive than remediation (UNEP, 2022a). The high costs of both landfilling and energy from waste in the EU promote the circular economy of separation and recycling plastics in the EU because the disposal costs are greater than the combined sorting and recycling costs (Ackerman and Levin, 2023). Therefore, the EU aims to promote the principles of plastic reduction, recycling, and recovery in global governance and reduce the cost of governance by harnessing new technologies and boosting the capacity to produce alternatives.

The High Ambition Coalition to End Plastic Pollution is led by Rwanda and Norway, suggesting restraining and reducing the consumption and production of primary plastic polymers to sustainable levels (High Ambition Coalition to End Plastic Pollution, 2023). As a member of HAC, the EU also stressed the need for all Parties to use the future instrument to reduce the overall production of primary plastics to make production and consumption sustainable.

4.2.2 Waste management

A like-minded group, including Iran, Russia, India, Cuba, and some Western Asian countries, advocated for a legally binding instrument focusing on waste management rather than controlling production to limit the damage to plastic-producing countries. Cuba urged not to go beyond resolution 5/14 by focusing on eliminating plastic pollution and not including the production and commercialization of plastics. Reducing polymer production will significantly impact developing countries, producers, and importers (Cuba, 2023). Concerning waste management, the EU generates more plastic waste than its recycling capacity ((European Commission, 2018). In 2015, only 9% of the plastics ever produced were recycled. Most plastics have accumulated in landfills or the natural environment (Geyer et al., 2017). European Union member states are the top plastic-consuming and plastic waste-exporting countries (Environmental Investigation Agency, 2023b). In 2020, of the top 10 plastic waste exporting countries, six were EU Member States (Environmental Investigation Agency, 2021). The EU produces large quantities of non-recyclable plastic waste exported to other countries, causing significant environmental damage.

In the context of weak downstream waste management, the EU has strongly urged that the instrument be based on the waste hierarchy as a guiding principle or overall target for waste management obligations. The waste hierarchy considers the entire life cycle of plastics, focusing on upstream waste prevention and preparation for reuse, followed by recycling (European Commission, 2008b). This proposal could be linked to the Basel Convention (1989), which has the principle of environmentally sound management (ESM), taking all practicable measures to ensure that hazardous waste or other waste is managed to protect human health and the environment from harmful effects. In addition, the EU and its MS consider the principle of Extend Producer Responsibility (EPR) as an essential tool to operationalize the polluter pays principle and one way for countries to strengthen waste management. The EU also suggests promoting waste prevention by incentivizing producers to develop sustainable products and putting the cost of collection, sorting, recycling, and littering on the private sector (European Union, 2023e). Generally speaking, the EU proposal on the waste hierarchy encouraging decisions that achieve the best overall environmental outcome rather than being bound by rigid rules aligns with the EU Waste Framework Directive (2008).

4.2.3 Extended producer responsibility

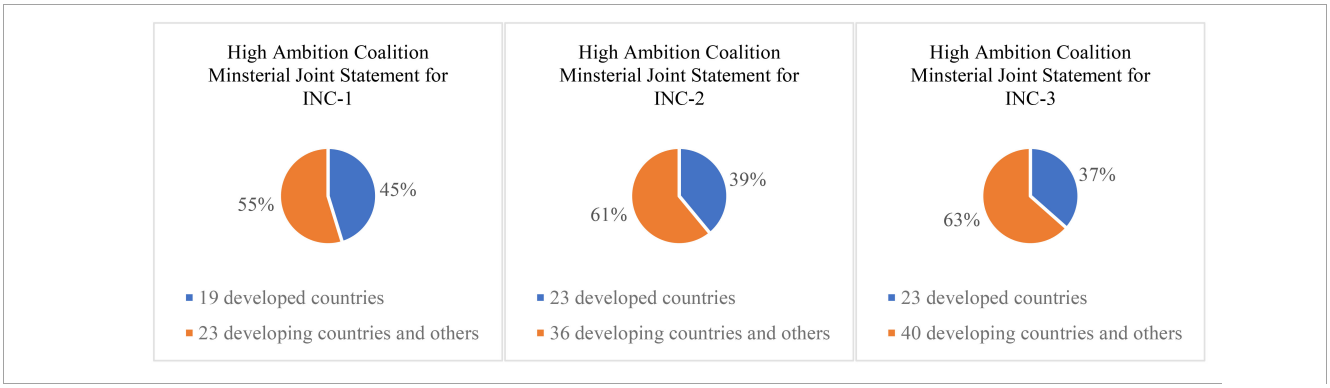
As a common legislative practice of the EU (Wang, 2023), the extended producer responsibility is regulated in the Waste Framework Directive (2008), which requires manufacturers to have and take appropriate measures to promote the design of products in a way that reduces their impact on the environment and the generation of waste during their manufacture and subsequent use can be minimized. Likewise, the Waste Electrical and Electronic Equipment Directive (2012) transfers responsibility for collecting, reusing, and recycling electronic waste to the manufacturer (European Commission, 2012). The extended producer responsibility is based on the polluter pays principle—Principle 16 of the 1992 Rio Declaration, assigning long-term environmental responsibility for products (Sachs, 2006). It influences the production and discharge stages in the full lifecycle approach. During production, the plastic producer should ensure the reparability and reusability of products. They are also responsible for retrieving the plastic products they use during the discharge. It differs from the polluter pays principle, which only requires the polluter to shoulder the cost of pollution. The customers and people who discharge the pollution can also be the polluters. If so, the legal basis for EPR would disappear.

Extended producer responsibility is not only taken up in the alternative principles of the latest revised version. It is also controversial whether its implementation should be mandatory for each contracting party or according to their national circumstances. The EPR is a proven policy tool that has gained global support, not only in Europe. In recent years, Vietnam, the Philippines, and India have started implementing an EPR (UNEP, 2023c). However, there exists an unjust imbalance between developing countries that manufacture plastic production (Wang, 2023) and developing countries without advanced recycling technologies. Mandatory EPR responsibilities may be impractical and increase the burden on developing countries. The EU did not include it in the principles but presented the EPR proposal as one of the core commitments, control measures, and voluntary approaches. It suggests that each party shall establish and regulate EPR systems on a sector or product basis based on the modalities for the products in Annex D (European Union, 2023a). In addition, the EU supports a harmonized EPR system at the regional or global level and avoids a single EPR model, whereby each party would have to set up an EPR system adapted to its national circumstances.

4.3 National plans

The EU's position on national plans, one of the main arguments for the implementation measure, is also worth analyzing. Whether

TABLE 3 Developing and developed countries in HAC Ministerial Joint Statement Joint Statement.



(Table 3 is based on the three HAC Ministerial Joint Statement Joint Statements (accessed February 1, 2024). The distinction between developing and developed countries is based on the United Nations Conference on Trade and Development classification. Other groups include least developed countries, landlocked developing countries, and small island developing States.)

to take a bottom-up (based on voluntary nationally-set commitments) or a top-down approach (based on binding globally-made commitments) remains one of the conflicts that impede the development of negotiations (Ballerini, 2023). Some States support voluntary programs and commitments based on national circumstances and capacities. In particular, each member designs the national plan according to its national circumstances and decides on the content of the engagement by establishing country-specific programs to combat plastic pollution. The goals are achieved jointly, based on the implementation of the commitments made by each party. Many countries may support this bottom-up mechanism because it gives the parties greater autonomy and flexibility and allows them to capitalize on their strengths in national circumstances. However, it could also have a narrow scope, focusing only on downstream issues such as waste management (IISD, 2023b).

Some members have different opinions due to their interests. The countries of the High Ambition Coalition to End Plastic Pollution (HAC) supported binding national plans with mandatory reporting requirements that included a top-down approach and advocated for a global standard of "mandatory Top-down division" (HAC, 2022). The implementation of the "top-down" mechanism is reflected in the adoption of a unified international agreement that sets specific goals and paths of action for the parties involved. Conversely, the "bottom-up" approach passively implements established programs and pathways. This model has a solid international legal binding force and includes strict compliance mechanisms, uniform accounting rules, and strict measurement, reporting, and verification protocols in its implementation framework. Such provisions guide countries' actions based on scientific evidence and ensure the effectiveness of measures related to legal responsibilities. However, building consensus between all parties in this model proves difficult, leading to generally slow progress in the overall process.

The EU takes a relatively moderate stance on national plans. In the pre-session document of the first session of INC, the European Union referred to the 5/14 Resolution, acknowledging national plans as a plausible foundation. However, creating a global common indicator and monitoring is also significant, which could leverage established monitoring protocols from various regional seas conventions and other pertinent regional and international instruments (e.g., the Minamata Convention), along with the sustainable development goals' monitoring framework for effective implementation. In the pre-session submission in the second session of INC, the EU stresses that national plans that could harmonize templates and guidance are not the only tool and insists that the core obligations or control measures, the design of recycling standards, the technical guidelines and requirements for transparency, information, and labeling, as well as the provisions for monitoring and reporting, should be global, regional or broadly formulated to allow for further implementation at the national level (European Union, 2023b, c). Overall, it suggested that the implementation should be based on national reporting (bottom-up) and environmental monitoring (top-down) (European Union, 2022b).

Resolution 5/14 and Zero Draft advocated a bottom-up mechanism that would promote more flexible national plans, taking into account national circumstances and capacities. But after several rounds of negotiations, Zero Draft also leaves more room for international monitoring, suggesting that "a combination of nationally and internationally agreed approaches can provide the necessary flexibility in implementing the prevention, reduction, and elimination of plastic pollution," showing the possibility, of adding mandatory requirements. In general, the position of the EU is consistent with Zero Draft, reflecting the likelihood that international instruments on plastic pollution will further discuss a compromise between a top-down global framework and bottom-up voluntary national action.

4.4 Remarks on the EU's position in the negotiations of the instrument

In light of our discussion above, the EU's position on some key instrument elements continues the trend of its internal policies and legislation, such as the positive recommendation of the precautionary principle, the polluter pays principle, and extended producer responsibility. Regarding core obligations and control measures, the EU and HAC support a focus on upstream governance, which focuses on reducing the supply of, demand

for, and use of primary. For the implementation measure, the EU has taken a more moderate and compromising stance on national plans, recognizing their importance but also stressing the necessity of regulation at the global level.

The EU's proposals have made some progress. Firstly, the minimum elements proposed by the EU are partly supported by the Zero draft, such as covering the entire life cycle of plastics, extended producer responsibility, and recycled plastic content. Whether these elements are mandatory is controversial, as the Zero draft uses the term "relevant elements," which the EU later introduced with a proposal to change to "necessary measures" to make it more binding. Second, among nearly 180 attendees, 135 explicitly call for binding global rules that apply equally to all countries rather than a voluntary agreement (World Wide Fund for Nature, 2023). Therefore, the compromise between a top-down global framework and bottom-up voluntary national action proposed by the EU may get high support in the future. In addition, the EU's proposal calling for the Treaty to prioritize banning or phasing out problematic polymers, chemicals, and high-risk plastic products is likely reflected in the final instrument because more countries are joining the HAC, and more than half of the attendees favor this obligation (World Wide Fund for Nature, 2023).

5 The EU's diplomacy strategy during the negotiations

As an international leader, the EU would be expected to pursue highly ambitious policy objectives and realize them to a high degree through its activities (Oberthür and Rabitz, 2014). In addition to assessing the EU's proposals on instrument elements during the negotiations, we also consider that its diplomacy strategy may translate its weight into actual impact in the negotiations. The EU may promote its goal achievement by building different coalitions or alliances, which may require concessions and compromises. It may also focus on building bridges between other negotiating parties and coordinating between them to maximize their interests (Oberthür and Groen, 2018).

The EU has demonstrated high diplomatic activity inside and outside the plastic instrument negotiations. It utilizes regional and bilateral dialogues and ocean-related development cooperation. As one of the active participants in the negotiations on the plastics instrument, the EU has continued to make written submissions to the conference, and its resolution underscoring the need for concerted action to address the interconnected challenges was adopted by UNEA (European Commission, 2024). Beyond the conferences, the EU engaged very actively in other forums to actively cooperate and communicate with other countries, such as the Ministerial Meeting on Environment and Climate Change between the Ministers of the Environment of Latin America and the Caribbean (LAC) and the European Union and G7 Hiroshima 2023. Its diplomacy also involved the highest political levels, such as the Joint Statement of the EU-Japan Summit, EU-Canada Summit, and EU- Republic of Korea 2023 on plastic pollution.

Second, it actively participates in coalition building to increase negotiating influence and expand consensus. The EU joined the HAC Coalition before the first session of INC. So far, according to the INC-3 Ministerial Statement, more developing countries joined the High Ambition Coalition (Table 3). Moreover, the least developed country - Guinea - joined the INC-2 Statement, followed by Solomon Islands and Togo in the INC-3 Joint Statement, which means that in addition to developed countries, the position of HAC, such as the reduction of plastic production and environmentally sound management may be supported by more developing countries and least developed countries.

Third, the EU shows its leadership through example. To reduce shipments of problematic waste outside the EU, it reached a preliminary political agreement in 2023 to amend the Waste Shipment Regulation (2006), meaning that countries in the global south will no longer serve as landfills for European developed countries. In response to the increasing total amount of packaging waste, the EU Parliament has decided to increase the reduction targets for plastic packaging, setting specific targets for reducing plastic packaging (10% by 2030, 15% by 2035, and 20% until 2040) (European Parliament, 2023). The EU also contributes to technical support and funding for developing countries. As one of the most important donors of ocean-related development aid and voluntary contributors to international organizations and processes (European Commission, 2022a), it committed €1 million to Blue Mediterranean to catalyze sustainable blue economy investments in plastic waste reduction in the non-EU countries of the Mediterranean region (EU Blue Economy Observatory, 2023). In addition, the EU is also committed to working with UNEP until 2026 on deploying appropriate technologies, waste recycling systems, and institutional and human capacity.

6 The challenges in the future negotiations

The last but most important aspect of assessing the achievement of the EU's objectives is to analyze the challenges that the EU now faces. Although most countries call for an ambitious agreement covering the entire life cycle of plastics, the High Ambition Coalition and the EU must confront the conflicts between fossil fuel and petrochemical exporters. It is calculated that 43 chemical and fossil fuel industry lobbyists have signed up for the third round of negotiations, 36 percent more than the last round (Center for International Environmental Law, 2023). Notably, the U.S. – one of the world's top generators of plastic waste – has been slow to endorse ambitious goals. It showed a wavering attitude towards the plastics instrument, given its previous experience in climate negotiations. The Biden administration recently agreed that national plans should be based on a globally agreed target for reducing plastic rather than simply calling on countries to act individually (Morath, 2023), which may promote the proposal of the EU. Japan opposes the EU's approach of demanding uniform measures internationally and favors greater national autonomy. In this respect, Japan's position may not be conducive to

implementing the instrument, as it may weaken its unity and binding force (Xu et al., 2023).

The EU needs to adopt more moderate positions, such as the national plans, if it wants to achieve a higher level of achievement of its objectives. In multilateral negotiations, extreme positions have less chance of success than moderate ones, as agreements between several key actors/coalitions require compromises (Oberthür and Groen, 2018). How to seek more consensus in future negotiations while striving for more national interests is a challenge the EU will always need to face in subsequent negotiations. Developing countries may not support the stance against the CBDR principle because this policy preference will reduce the historical responsibility of developed countries in plastic pollution control and reduce the obligation of developed countries to help developing countries in plastic pollution control. The EU should consider the diverse stages of development in developing countries to show greater inclusiveness in future negotiations and share technology, finance, and experience with all parties to support plastic reduction actions on a global scale. Capacity-building and the transfer of marine technology (CBTMT) are key elements for developing countries to fulfill their obligations under the agreement. It remains controversial whether capacity-building and transfer should be limited to assisting states meet their treaty obligations or include realizing broader social and economic objectives (Mendenhall, 2023b).

Moreover, it may gain wider acceptance by sharing best practices, scientific research, and policy experiences from different countries to understand the balance between different interests better. In addition, the EU needs to realize the importance of establishing a transparent information-sharing mechanism. Monitoring and surveillance capabilities are vital for detecting and addressing marine pollution, which includes investing in technology, improving data collection and analysis, and enhancing cooperation among countries for information sharing (Vidar et al., 2023).

7 Conclusion

In conclusion, due to a lack of adequate and concrete rules and principles, the current fragmented and reactive framework for global ocean governance and pollution control has resulted in a coordination gap at the legislative and implementation levels. As a leader in plastics governance, the EU has positively shaped its preferences and role in the plastic pollution governance process. At the global governance level, the EU promoted consolidating the global plastic waste governance system and introduced several relevant initiatives and programs in response to United Nations standards. The internal policies and legislation also address the regulatory challenges and obstacles at the national level with positive and tangible results that could set an example for other states and give credibility to the EU proposal in the negotiations. Given the current negotiation process, the EU made recommendations on instrument elements and tried to integrate EU programs such as the environmentally sound management policy, the waste hierarchy, the precautionary principle, the polluter pays principle, and extended producer responsibility into international rules. The EU's persistence and coordination of its position, as well as its focus on multilateral cooperation and strong environmental standards, continue the EU's long-standing commitment to promoting international cooperation and ensuring environmentally sustainable development.

Furthermore, the EU's diplomatic engagement beyond the negotiations can also contribute to achieving the EU's proposals to reach a broader consensus with different countries. Our analyses demonstrate the assessment framework's usefulness, combining multiple factors to reveal the EU's influence before and after the negotiation process. We therefore assume that the EU's objectives will be achieved at a high level in future negotiations due to the interaction of the above favorable situations. However, the challenges the EU faces and how it responds will also affect realizing its objectives, which may require the EU to adopt a more moderate stance and compromise on some issues.

States may enjoy a differentiated status in the international law-making of the law of the sea due to differences in their geographical situation (Chen and Xu, 2022a). The matter of plastics goes beyond a mere environmental concern, and the intricacies in negotiating a global legal instrument on plastics pose challenges akin to those encountered in climate negotiations. Plastic's full life cycle approach holds relevance across various industries. The plastic economy is a fundamental pillar for some chemical and plastics-producing countries, and plastics are also undoubtedly indispensable consumer products for most countries. Thus, it is clear that there will be different positions, concerns, and strategies in this value chain that take time to reconcile. After all, international negotiations are often accompanied by insistence and concession, confrontation and cooperation, unilateralism and multilateralism. The importance and urgency of this global environmental issue and the prioritization of the rights and interests of all parties will influence the direction of this global convention and the effectiveness of the solution to the plastics problem. It remains to be seen whether the EU will seek balance and cooperation in future negotiations and continue to play a leading role by introducing a more comprehensive program that considers all parties' interests and addresses existing challenges.

Finally, we acknowledge the limitations of this paper. We have constructed an assessment framework by integrating key and process-related factors, providing a more comprehensive analysis than a single-round negotiation analysis. However, there is more room for progress in this framework. Other factors, such as motivation to participate in negotiations and other key instrumental elements, have yet to be discussed. Furthermore, the framework could be better applied by including comparisons with other countries. We will address these gaps in future research and conduct further research to test and refine the framework.

Author contributions

QX: Writing – review & editing, Methodology, Funding acquisition, Conceptualization. MZ: Writing – original draft, Formal analysis. SH: Writing – review & editing, Supervision, Formal analysis.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. Fundamental Research Funds for the Central Universities Project No. 23JNQN04; National Social Science Foundation Project No. 23VHQ016.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Ackerman, J., and Levin, D. B. (2023). Rethinking plastic recycling: A comparison between North America and Europe. *J. Environ. Manage.* 340, 117859. doi: 10.1016/j.jenvman.2023.117859

Bäckstrand, K., and Elgström, O. (2013). The EU's role in climate change negotiations: From leader to 'leadiator'. *J. Eur. Public Policy* 20, 1369–1386. doi: 10.1080/13501763.2013.78178

Ballerini, T. (2023). *Global plastics treaty: upsides and downsides of the second round of negotiations.* Available online at: https://www.renewablematter.eu/articoli/article/Global-Plastics-Treaty-the-second-round-of-negotiations-plastic-pollution (Accessed 1/12/2024).

Beltran, M., Tjahjono, B., Suoneto, T. N., Tanjung, R., and Julião, J. (2023). Rethinking marine plastics pollution: Science diplomacy and multi-level governance. *Int. Rev. Adm. Sci.* 90 (1), 237–258. doi: 10.1177/00208523231183909

Busch, P. O. (2022a). *Analysis of Upstream Economic Opportunities from change in the plastics lifecycle*. Available online at: https://adelphi.de/system/files/mediathek/bilder/GPA_Economic_Opportunities.pdf (Accessed 1/10/2024).

Busch, P. O. (2022b). *Small Island Developing States and plastic pollution- Challenges and opportunities of a global agreement on plastic pollution for SIDS*. Available online at: https://adelphi.de/en/publications/small-island-developing-states-and-plastic-pollution (Accessed 1/12/2024).

Center for International Environmental Law. (2023). *Fossil Fuel and Chemical Industries Registered More Lobbyists at Plastics Treaty Talks than 70 Countries Combined.* Available online at: https://www.ciel.org/news/fossil-fuel-and-chemical-industries-at-inc-3/ (Accessed 1/12/2024).

Chen, X., and Xu, Q. (2022a). Mitigating effects of sea-level rise on maritime features through the international law-making process in the Law of the Sea. *Front. Mar. Sci.* 9, 1072390. doi: 10.3389/fmars.2022.1072390

Chen, X., and Xu, Q. (2022b). Reflections on international dispute settlement mechanisms for the Fukushima contaminated water discharge. *Ocean Coast. Manage.* 226, 106278. doi: 10.1016/j.ocecoaman.2022.106278

CJEU. (1999). The Queen v Secretary of State for the Environment and Ministry of Agriculture, Fisheries and Food, ex parte H.A. Standley and Others and D.G.D. Metson and Others. In *Judgment of the Court (Fifth Chamber) of 29 April 1999, European Court Reports 1999.* (CJEU, 1999).

Copernicus Marine Service. (2017). *Copernicus Marine Service Side Event at the UN Ocean Conference on June 8th.* Available online at: https://marine.copernicus.eu/news/copernicus-marine-service-side-event-un-ocean-conference-june-8th (Accessed 1/16/2024).

Copernicus Marine Service. (2020). *Marine Plastic Pollution: New content on Copernicus Marine website.* Available online at: https://marine.copernicus.eu/news/marine-plastic-pollution-new-content-copernicus-marine-website (Accessed 1/19/2024).

Cuba. (2023). *In-session Submissions on Primary Plastic Polymers INC-3*. Available online at: https://resolutions.unep.org/resolutions/uploads/cubaprimaryplasticpolymers.pdf (Accessed 12/1/2023).

Da Costa, J. P., Catherine, M., Mónica, M., Armando, C. D., and Teresa, R. S. (2020). The role of legislation, regulatory initiatives and guidelines on the control of plastic pollution. *Front. Env. Sci.* 8. doi: 10.3389/fenvs.2020.00104

Dañobeitia, J. J., Pouliquen, S., Pade, N., Arvanitidis, C., Sanders, R., Stanica, A., et al. (2023). The role of the marine research infrastructures in the European marine observation landscape: present and future perspectives. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1047251

Dauvergne, P. (2023). The necessity of justice for a fair, legitimate, and effective treaty on plastic pollution. *Mar. Policy* 155, 105785. doi: 10.1016/j.marpol.2023.105785

Earth Day. (2023). *From fossil fuels to plastic addiction: unveiling the hidden link impacting our world*. Available online at: https://www.earthday.org/from-fossil-fuels-to-plastic-addiction-unveiling-the-hidden-link-impacting-our-world/ (Accessed 1/1/2024).

Eckert, S., Karassin, O., and Steinebach, Y. (2024). A policy portfolio approach to plastics throughout their life cycle: Supranational and national regulation in the European Union. *Environ. Policy Gov.* 1–15. doi: 10.1002/eet.2092

Environmental Investigation Agency. (2019). *Basel Convention scores a major victory in the war on plastic pollution*. Available online at: https://eia-international.org/news/basel-convention-scores-a-major-victory-in-the-war-on-plastic-pollution/ (Accessed 1/12/2024).

Environmental Investigation Agency. (2021). *The Truth Behind Trash: The scale and impact of the international trade in plastic waste*. Available online at: https://eia-international.org/wp-content/uploads/EIA-The-Truth-Behind-Trash-FINAL.pdf (Accessed 1/15/2024).

Environmental Investigation Agency. (2023a). *Big Oil influence at UN talks thwarts progress towards reaching an effective Global Plastics Treaty*. Available online at: https://eia-international.org/news/big-oil-influence-at-un-talks-thwarts-progress-towards-reaching-an-effective-global-plastics-treaty/ (Accessed 1/16/2024).

Environmental Investigation Agency. (2023b). *Plastic Waste Power Play*. Available online at: https://eia-international.org/wp-content/uploads/EIA_UK_Plastic_Waste_Trade_Report_0123_FINAL_SPREADS.pdf (Accessed 1/12/2024).

EU Blue Economy Observatory. (2023). *COP28: Commission commits €1 million to Blue Mediterranean Partnership*. Available online at: https://blue-economy-observatory.ec.europa.eu/news/cop28-commission-commits-eu1-million-blue-mediterranean-partnership-2023-12-12_en?prefLang=el (Accessed 1/12/2024).

European Commission. (1994). *Directive 94/62/EC*. Available online at: https://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31994L0062:EN:HTML (Accessed 11/11/2023).

European Commission. (2000). *Commission adopts White Paper on Environmental Liability*. Available online at: https://ec.europa.eu/commission/presscorner/detail/en/IP_00_137 (Accessed 12/11/2023).

European Commission. (2008a). *Directive 2008/98/EC*. Available online at: http://data.europa.eu/eli/dir/2008/98/oj (Accessed 12/11/2023).

European Commission. (2008b). *Integrated Maritime Policy of the European Union*. Available online at: https://www.europarl.europa.eu/RegData/docs_autres_institutions/commission_europeenne/com/2007/0575/COM_COM(2007)0575_EN.pdf (Accessed 12/11/2023).

European Commission. (2010). *Directive 2010/75/EU*. Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32010L0075 (Accessed 12/11/2023).

European Commission. (2012). *Directive 2012/19/EU*. Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0019 (Accessed 12/12/2023).

European Commission. (2015). *Directive 2015/720*. Available online at: https://eur-lex.europa.eu/legal-content/EN/NIM/?uri=CELEX:32015L0720 (Accessed 12/11/2023).

European Commission. (2016). *International ocean governance: an agenda for the future of our oceans*. Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52016JC0049 (Accessed 9/11/2023).

European Commission. (2018). *A European Strategy for Plastics in a Circular Economy*. Available online at: https://www.europarc.org/wp-content/uploads/2018/01/Eu-plastics-strategy-brochure.pdf (Accessed 10/11/2023).

European Commission. (2019a). *Directive 2019/904*. Available online at: https://eur-lex.europa.eu/eli/dir/2019/904/oj (Accessed 11/11/2023).

European Commission. (2019b). *The European Green Deal*. Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0640 (Accessed 1/1/2024).

European Commission. (2020). *A new Circular Economy Action Plan For a cleaner and more competitive Europe*. Available online at: https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF (Accessed 11/11/2023).

European Commission. (2022a). *Questions and Answers on International Ocean Governance*. Available online at: https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_3744 (Accessed 1/1/2024).

European Commission. (2022b). *Recommendation for a COUNCIL DECISION authorizing the opening of negotiations on behalf of the European Union for an international agreement on plastic pollution*. Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0342&qid=1692253213990 (Accessed 11/11/2023).

European Commission. (2023a). *Biobased, biodegradable, and compostable plastics*. Available online at: https://environment.ec.europa.eu/topics/plastics/biobased-biodegradable-and-compostable-plastics_en (Accessed 1/1/2024).

European Commission. (2023b). *Plastics*. Available online at: https://environment.ec.europa.eu/topics/plastics_en (Accessed 1/1/2024).

European Commission. (2024). *UN Environmental Assembly adopts a resolution to strengthen action for the ocean*. Available online at: https://oceans-and-fisheries.ec.europa.eu/news/un-environmental-assembly-adopts-resolution-strengthen-action-ocean-2024-03-01_en (Accessed 1/3/2024).

European Commission, Directorate-General for Research and Innovation, De Smet, M., Linder, M., Koopmans, R. (2019). *A circular economy for plastics: insights from research and innovation to inform policy and funding decisions*. Available online at: https://data.europa.eu/doi/10.2777/269031 (Accessed 1/1/2024).

European Council. (2009). *Regulation (EC) No 1224/2009*. Available online at: http://data.europa.eu/eli/reg/2009/1224/oj (Accessed 1/1/2024).

European Parliament. (2023). *Packaging: new EU rules to reduce, reuse and recycle*. Available online at: https://www.europarl.europa.eu/news/sv/press-room/20231023IPR08128/packaging-new-eu-rules-to-reduce-reuse-and-recycle (Accessed 1/1/2024).

European Union and 1/1/2024. (2023e). *Statements on Behalf of Group of States in INC-2*. Available online at: https://resolutions.unep.org/resolutions/uploads/eu_0.pdf.

European Union. (2022a). *EU+MS opening statement at INC-1*. Available online at: https://resolutions.unep.org/resolutions/uploads/all_statements_made_by_eu_during_inc1.pdf (Accessed 12/11/2023).

European Union. (2022b). *Written submission from the European Union and its 27 Member states on recommendations for the organization of work of the INC*. Available online at: https://resolutions.unep.org/resolutions/uploads/eums_written_submission_inc_organization_of_work.pdf#overlay-context=node/344%3Fq%3Dnode/344 (Accessed 1/1/2024).

European Union. (2023a). *EU Drafting proposals for Zero Draft*. Available online at: https://resolutions.unep.org/resolutions/uploads/eu_part1.pdf (Accessed 1/1/2024).

European Union. (2023b). *In-session Submissions on national plans*. Available online at: https://resolutions.unep.org/resolutions/uploads/eu_nationalplans.pdf (Accessed 1/1/2024).

European Union. (2023c). *Pre-session Submission before INC-2*. Available online at: https://wedocs.unep.org/bitstream/handle/20.500.11822/41793/EUsubmission.pdf?sequence=1&isAllowed= (Accessed 1/1/2024).

European Union. (2023d). *Proposed response template on written submissions prior to INC-3 (part a)*. Available online at: https://resolutions.unep.org/resolutions/uploads/eums_14092023_a.pdf (Accessed 1/1/2024).

European Union External Action. (2021). *EU and ASEAN foster innovative approaches in managing Plastic Waste in the Marine Environment*. Available online at: https://www.eeas.europa.eu/eeas/eu-and-asean-foster-innovative-approaches-managing-plastic-waste-marine-environment_en (Accessed 1/1/2024).

Fritz, J. S. (2020). Governing plastics pollution in the ocean: from anarchy to mission orientation. *Ocean Yearb.* 34, 231–254. doi: 10.1163/9789004426214_010

Gayon, C. A. A. (2023). *The EU's CBAM, Complying with the CBDR Principle Could Also Mean Compliance with WTO Law*. Available online at: https://minnjil.org/article/the-eus-cbam-complying-with-the-cbdr-principle-could-also-mean-compliance-with-wto-law/ (Accessed 1/1/2024).

Geyer, R., Jambeck, J. R., and Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Sci. Adv.* 3, e1700782. doi: 10.1126/sciadv.1700782

Guggisberg, S. (2024). Finding equitable solutions to the land-based sources of marine plastic pollution:Sovereignty as a double-edged sword. *Mar. Policy* 159, 105960. doi: 10.1016/j.marpol.2023.105960

Hagen, P. E., and Walls, M. P. (2005). The Stockholm convention on persistent organic pollutants. *Nat. Resour. Environ.* 19, 49–52. Available at: https://www.jstor.org/stable/40924611

Hey, E., and Paulini, S. (2021). "Common but differentiated responsibilities," in *The Max Planck Encyclopedia of Public International Law (MPEPIL)* (Oxford University Press, New York).

High Ambition Coalition to End Plastic Pollution. (2022). *HAC Member States Joint Statement INC-1*. Available online at: https://resolutions.unep.org/resolutions/uploads/high_ambition_coalition_to_end_plastic_pollution_joint_statement_inc-1_.pdf (Accessed 1/1/2024).

High Ambition Coalition to End Plastic Pollution. (2023). *HAC Member States Joint Statement INC-3*. Available online at: https://hactoendplasticpollution.org/wp-content/uploads/2023/11/Approved-Final-HAC-Ministerial-Joint-Statement-INC-3-for-publication-63-members.pdf (Accessed 1/1/2024).

ICJ. (1996). Legality of the Threat or Use of Nuclear Weapons. *Advisory Opinion, I.C.J. Reports 1996* . (ICJ, 1996).

ICJ. (1997). "Gabčíkovo-nagymaros project (Hungary/Slovakia)," in *Judgment, I.C.J. Reports 1997*. (ICJ, 1997).

ICJ. (2010). "Pulp mills on the river Uruguay, (Argentina v Uruguay)," in *Judgment, I.C.J. Reports 2010*. (ICJ, 2010).

IISD. (2021). *International Legally Binding Instrument on Plastics Pollution, including in the Marine Environment*. Available online at: https://enb.iisd.org/negotiations/international-legally-binding-instrument-plastics-pollution-including-marine (Accessed 1/1/2024).

IISD. (2023a). *Plastic Treaty Negotiators Request Revised Zero Draft for INC-4*. Available online at: https://sdg.iisd.org/news/plastic-treaty-negotiators-request-revised-zero-draft-for-inc-4/ (Accessed 1/1/2024).

IISD. (2023b). *Summary of the Third Session of the Intergovernmental Negotiating Committee to Develop an International Legally Binding Instrument on Plastic Pollution*. Available online at: https://enb.iisd.org/sites/default/files/2023-11/enb3620e.pdf (Accessed 1/1/2024).

Iverson, A. R. (2019). The United States requires effective federal policy to reduce marine plastic pollution. *Conserv. Sci. Pract.* 1, e45. doi: 10.1111/csp2.45

Kilian, B., and Elgstrom, O. (2010). Still a green leader? The European Union's role in international climate negotiations. *Coop. Confl.* 45, 255–273. doi: 10.1177/0010836710377392

Kumar, R. (2020). The United Nations and global environmental governance. *Strate. Anal.* 44, 479–489. doi: 10.1080/09700161.2020.1824462

Larson, E. T. (2005). Why environmental liability regimes in the United States, the European community, and Japan have grown synonymous with the polluter pays principle. *Vanderbilt J. Transnatl. Law* 38, 542–575. Available at: https://scholarship.law.vanderbilt.edu/vjtl/vol38/iss2/6

Lavers, J. L., and Bond, A. L. (2017). Exceptional and rapid accumulation of anthropogenic debris on one of the world's most remote and pristine islands. *Proc. Natl. Acad. Sci.* 114, 6052–6055. doi: 10.1073/pnas.1619818114

Lebreton, L., and Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. *Palgrave Commun.* 5, 6. doi: 10.1057/s41599-018-0212-7

Lebreton, L. C. M., van der Zwet, J., Damsteeg, J. W., Slat, B., Andrady, A., and Reisser, J. (2017). River plastic emissions to the world's oceans. *Nat. Commun.* 8, 15611. doi: 10.1038/ncomms15611

Mendenhall, E. (2023a). Building a regime complex for marine plastic pollution. *Cambridge Prisms: Plastics* 1, e12. doi: 10.1017/plc.2023.12

Mendenhall, E. (2023b). Making the most of what we already have: Activating UNCLOS to combat marine plastic pollution. *Mar. Policy* 155, 105796. doi: 10.1016/j.marpol.2023.105786

Milios, L. (2018). Advancing to a circular economy: Three essential ingredients for a comprehensive policy mix. *Sustain. Sci.* 13, 861–878. doi: 10.1007/s11625-017-0502-9

Morath, S. J. (2023). *As plastic production grows, treaty negotiations to reduce plastic waste are stuck in low gear*. Available online at: https://www.caledonianrecord.com/opinion/conversation/as-plastic-production-grows-treaty-negotiations-to-reduce-plastic-waste-are-stuck-in-low-gear/article_1c58a47f-4945-52d2-a547-6e73e7a8c38b.html (Accessed 1/1/2024).

Nagtzaam, D. G. (2023). A fraying patchwork quilt: international law and plastic pollution. *Vill. Envtl. L.J.* 34, 133–182. Available at: https://digitalcommons.law.villanova.edu/elj/vol34/iss2/1

Nellyana, R., Listriani, S., Mahfud, M., Rivaldi, A., Chaliluddin, M. A., and Bustami, B. (2023). Law enforcement in plastic waste management in Aceh waters: transboundary marine pollution concern. *IOP Conf. Ser.: Earth Environ. Sci.* 1221, 012074. doi: 10.1088/1755-1315/1221/1/012074

Oberthür, S., and Dupont, C. (2021). The European Union's international climate leadership: towards a grand climate strategy? *J. Eur. Public Policy* 28, 1095–1114. doi: 10.1080/13501763.2021.1918218

Oberthür, S., and Groen, L. (2018). Explaining goal achievement in international negotiations: the EU and the Paris Agreement on climate change. *J. Eur. Public Policy* 25, 708–727. doi: 10.1080/13501763.2017.1291708

Oberthür, S., and Rabitz, F. (2014). On the EU's performance and leadership in global environmental governance: the case of the Nagoya Protocol. *J. Eur. Public Policy* 21, 39–57. doi: 10.1080/13501763.2013.834547

Organization for Economic Cooperation and Development. (2022). *Background note: The implementation of the Polluter Pays Principle*. Available online at: https://www.oecd.org/water/background-note-polluter-pays-principle-29-20-march-2022.pdf.

PCA. (2014). *Award (Unofficial English Translation) of the rhine chlorides arbitration concerning the auditing of accounts (The Netherlands/France)*. Available online at: https://pcacases.com/web/sendAttach/78.

Penca, J. (2018). European plastics strategy: What promise for global marine litter? *Mar. Policy* 97, 197–201. doi: 10.1016/j.marpol.2018.06.004

Plastics Europe. (2019). *Plastics—The facts 2019. An analysis of European plastics production, demand and waste data*. Available online at: https://plasticseurope.org/wp-content/uploads/2021/10/2019-Plastics-the-facts.pdf (Accessed 1/1/2024).

Plastics Europe. (2024). *Circular Economy for Plastics – A European Analysis*. Available online at: https://plasticseurope.org/knowledge-hub/the-circular-economy-for-plastics-a-european-analysis-2024 (Accessed 3/26/2024).

Raubenheimer, K., McIlgorm, A., and Oral, N. (2018). Towards an improved international framework to govern the life cycle of plastics. *Rev. Eur. Comp. Int. Environ. Law* 27, 210–221. doi: 10.1111/reel.12267

Sachs, N. (2006). Planning the funeral at the birth: extended producer responsibility in the European Union and the United States. *Harvard Environ. Law Rev.* 30, 51–98. Available at: https://scholarship.richmond.edu/cgi/viewcontent.cgi?article=1495&context=law-faculty-publications

Schröder, M. (2014). "Precautionary approach/principle," in *The Max Planck Encyclopedia of Public International Law (MPEPIL)* (Oxford University Press, New York).

Simon, N., Raubenheimer, K., Urho, N., Unger, S., Azoulay, D., Farrelly, T., et al. (2021). A binding global agreement to address the life cycle of plastics. *Science* 373, 43–47. doi: 10.1126/science.abi9010

Steensgaard, I. M., Syberg, K., Rist, S., Hartmann, N. B., Boldrin, A., and Hansen, S. F. (2017). From macro- to microplastics - Analysis of EU regulation along the life cycle of plastic bags. *Environ. pollut.* 224, 289–299. doi: 10.1016/j.envpol.2017.02.007

Stöfen-O'Brien, A. (2022). The prospects of an international treaty on plastic pollution. *Int. J. Mar. Coast. Law* 37, 727–740. doi: 10.1163/15718085-bja10108

Stöfen-O'Brien, A. (2023). The second session of the intergovernmental negotiating committee to develop an international legally binding instrument on plastic pollution, including the marine environment. *Int. J. Mar. Coast. Law* 38, 821–832. doi: 10.1163/15718085-bja10153

UNEP. (2012). *The Honolulu Strategy: A Global Framework for Prevention and Management of Marine Debris*. Available online at: https://wedocs.unep.org/bitstream/handle/20.500.11822/10670/Honolulu%20strategy.pdf?sequence=1&isAllowed=y (Accessed 1/1/2024).

UNEP. (2014). *Proceedings of the United Nations Environment Assembly of the United Nations Environment Programme at its first session*. Available online at: https://documents.un.org/doc/undoc/gen/k14/024/81/pdf/k1402481.pdf?token=g7tYpB18dg0m8XPiIf&fe=true (Accessed 1/1/2024).

UNEP. (2018a). *Combating marine plastic litter and microplastics: an assessment of the effectiveness of relevant international, regional and subregional governance strategies and approaches*. Available online at: https://documents.un.org/doc/undoc/gen/k18/003/47/pdf/k1800347.pdf?token=eh7R99ZssrBko3kAPD&fe=true (Accessed 1/1/2024).

UNEP. (2018b). *Gaps in international environmental law and environment-related instruments: towards a global pact for the environment*. Available online at: https://wedocs.unep.org/handle/20.500.11822/27070?show=full (Accessed 1/1/2024).

UNEP. (2022a). *Plastics science*. Available online at: https://wedocs.unep.org/bitstream/handle/20.500.11822/40767/K2221533%20-%20%20UNEP-PP-INC.1-7%20-%20ADVANCE.pdf (Accessed 1/1/2024).

UNEP. (2022b). *Priorities, needs, challenges and barriers relating to ending plastic pollution at the national level*. Available online at: https://wedocs.unep.org/bitstream/handle/20.500.11822/40721/K2221859%20-%20UNEP-PP-INC.1-11%20-%20ADVANCE.pdf (Accessed 1/1/2024).

UNEP. (2022c). *Resolution adopted by the United Nations Environment*. Available online at: https://wedocs.unep.org/bitstream/handle/20.500.11822/39640/K2200733%20-%20UNEP-EA-5-RES-14%20-%20ADVANCE.pdf (Accessed 1/1/2024).

UNEP. (2023a). *Potential options for elements towards an international legally binding instrument, based on a comprehensive approach that addresses the full life cycle of plastics as called for by United Nations Environment Assembly resolution 5/14*. Available online at: https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/42190/UNEP-PP-INC.2-4%20English.pdf?sequence=13&isAllowed=y (Accessed 1/1/2024).

UNEP. (2023b). *Revised draft text of the international legally binding Instrument on plastic pollution, including in the marine environment*. Available online at: https://wedocs.unep.org/bitstream/handle/20.500.11822/44526/RevisedZeroDraftText.pdf (Accessed 1/1/2024).

UNEP. (2023c). *Topic Sheet Extended Producer Responsibility*. Available online at: https://wedocs.unep.org/bitstream/handle/20.500.11822/42235/producer_responsibility_sheet.pdf?sequence=3&isAllowed=y (Accessed 1/1/2024).

UNGA. (1992). *Report of The United Nations Conference on Environment and Development*. Available online at: https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf (Accessed 1/1/2024).

Varvastian, S. (2023). The role of courts in plastic pollution governance. *Int. Comp. Law Q.* 72, 635–669. doi: 10.1017/S0020589323000179

Vidar, A., Ella, E., and Göte, I. (2023). International environmental law and marine pollution in the Pacific islands: promoting sustainable ocean governance. *Law Economy* 2, 6–14. doi: 10.56397/LE.2023.11.02

Wang, S. (2023). International law-making process of combating plastic pollution: Status Quo, debates and prospects. *Mar. Policy* 147, 105376. doi: 10.1016/j.marpol.2022.105376

Woodall, L. C., Sanchez-Vidal, A., Canals, M., Paterson, G. L. J., Coppock, R., Sleight, V., et al. (2014). The deep sea is a major sink for microplastic debris. *R. Soc Open Sci.* 1, 140317. doi: 10.1098/rsos.140317

World Wide Fund for Nature. (2023). *UN Plastic Pollution Treaty' one step closer' to being realized, as negotiators in Paris agree to start developing a draft treaty with global rules to curb plastic pollution*. Available online at: https://wwf.panda.org/wwf_news/press_releases/?8901966/UN-Plastic-Pollution-Treaty-one-step-closer-to-being-realised-as-negotiators-in-Paris-agree-to-start-developing-a-draft-treaty-with-global-rules-to-curb-plastic-pollution (Accessed 1/11/2024).

WTO. (2014). *Measures Concerning Meat and Meat Products (Hormones) - Joint communication from the European Union and the United States*. Available online at: https://docs.wto.org/dol2fe/Pages/SS/directdoc.aspx?filename=q:/WT/DS/26-29.pdf&Open=True.

Wysocki, I. T., and Billon, P. L. (2019). Plastics at sea: Treaty design for a global solution to marine plastic pollution. *Environ. Sci. Policy* 100, 140317. doi: 10.1016/j.envsci.2019.06.005

Xu, Q., Zhang, M., and Guo, P. (2023). Reflections on Japan's participation in negotiations of the global plastic pollution instrument under international environmental law. *Front. Mar. Sci.* 10, 1323748. doi: 10.3389/fmars.2023.1323748

Zhu, L. (2023). Some thoughts on application of the polluter pays principle for controlling marine greenhouse gas emissions. *Mar. Policy* 158, 106877. doi: 10.1016/j.marpol.2023.105877

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 02 May 2024
DOI 10.3389/fmars.2024.1362554

Check for updates

OPEN ACCESS

EDITED BY
Wen-Hong Liu,
National Kaohsiung University of Science and Technology, Taiwan

REVIEWED BY
Yi-Che Shih,
National Cheng Kung University, Taiwan
Wei Xing,
China University of Petroleum (East China), China

*CORRESPONDENCE
Jifeng Cao
13305321132@163.com

RECEIVED 08 January 2024
ACCEPTED 17 April 2024
PUBLISHED 02 May 2024

CITATION
Dai B, Cao J, Chen G and Ma C (2024) Study on the relationship between informatization and marine eco-efficiency in China—taking 11 coastal provinces as examples. *Front. Mar. Sci.* 11:1362554. doi: 10.3389/fmars.2024.1362554

COPYRIGHT
© 2024 Dai, Cao, Chen and Ma. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Study on the relationship between informatization and marine eco-efficiency in China—taking 11 coastal provinces as examples

Baodong Dai, Jifeng Cao*, Gonghang Chen and Cheng Ma

School of Business, Qingdao University, Qingdao, China

This article focuses on 11 coastal provinces in China and selects relevant data from 2008 to 2021. The improved entropy method is used to calculate the level of informationization development in each province. The Malmquist index is used to calculate the marine ecological efficiency of each province. The panel vector autoregression (PVAR) model is established to study the dynamic relationship between informationization and marine ecological efficiency. The results show that: (1) There is a long-term equilibrium relationship between informationization and marine ecological efficiency, and informationization is a Granger cause of marine ecological efficiency at the 5% significance level. (2) Overall, informationization has a promoting effect on marine ecological efficiency, but with a certain lag; the improvement of marine ecological efficiency also benefits the development of informationization. (3) There is a bidirectional relationship between informationization and marine ecological efficiency, and informationization has become the main influencing factor of marine ecological efficiency.

KEYWORDS

informatization, marine eco-efficiency, Malmquist index, panel vector autoregressive model, entropy method

1 Introduction

In the 21st century, the ocean's "territorialization" trend is on the rise, with rapid advancements in marine science and technology and intensifying competition for resources [Zeyu et al. (2016); Zeyu et al. (2017)]. The development of the marine economy plays a pivotal role in grasping more resources and space, occupying a strategic position in the growth of the national economy. China's gross marine product exceeded 9 trillion yuan in 2021, marking a significant milestone with a total of 9038.5 billion yuan [Ministry of Natural Resources (2022)]. This represents an 8.3% increase compared to 2020,

contributing 8.0% to national economic growth, and accounting for 15.0% of coastal GDP. However, China's early crude approach to marine economic development has resulted in substantial consumption of marine resources. Simultaneously, the excessive discharge of waste has caused a deterioration in the marine environment, further impeding the sustainable development of the marine economy [Lin et al. (2016)].

Following the era of reform and opening up, China has placed a renewed emphasis on the sustainable utilization of marine resources and the protection of the marine ecological environment. As part of this effort, the country has embraced the "Ocean Power" strategy [Yanqun and Peng (2017)] and the concept of "Expanding Blue Economic Space", with a focus on integrating land and sea resources, promoting the coordinated development of economy, society, and the ecological environment, and establishing a marine ecological civilization [Aimin (2016)]. Amidst the dual pressures of human activities and climate change, the task of ecological protection is both complex and arduous. In recent years, with the rapid advancement of big data, cloud computing, and the Internet, informatization has played a pivotal role in the process of ecological civilization construction, providing key technical support for all facets of the construction effort. For example, China has implemented a series of ocean construction programs to develop intelligent application services for ocean information using advanced technologies such as real-time information transmission over the Internet, big data, and cloud computing. The Daya Bay Station, in particular, has always adhered to the purpose of long-term ecological monitoring, research, demonstration, and service, providing important theoretical and technical support for China's offshore ecological protection and sustainable development of biological resources. The Jiaozhou Bay Marine Ecological Protection Information Platform provides a key service for the comprehensive remediation and restoration of Jiaozhou Bay [Qingyun et al. (2020)]. In conclusion, informatization holds the potential to contribute significantly to the establishment of an ecological civilization.

Most of the current research on informatization and eco-efficiency has been conducted from the perspective of theory and policy recommendations, and there is a lack of research on the impact mechanisms between the two, as well as no empirical research on the impact of informatization on more specific marine eco-efficiency. Therefore, this study focuses on the relationship between marine eco-efficiency in China and its main influencing factor, informatization. The improved entropy method and Malmquist index were used to measure and analyze the level of informatization and marine eco-efficiency in China, and then the PVAR model was proposed to study the dynamic impact of informatization on marine eco-efficiency from an empirical perspective [Ji and Li (2021)], and finally policy-oriented recommendations were proposed based on the research findings.

The concept of eco-efficiency was initially introduced in the context of sustainable development. In line with China's commitment to the core principle of sustainable development, which emphasizes the harmonious integration of economy, resources, and the environment, there has been a shift from sole focus on economic efficiency to a greater emphasis on eco-efficiency [Xiaodi (2015)]. Eco-efficiency takes into account the complex interplay between economic, environmental, resource, and ecological interests, providing a comprehensive measure of resource and environmental utilization, as well as its coordination with economic efficiency and environmental impact [Yufei et al. (2017)]. Therefore, it is of significant practical importance to investigate marine eco-efficiency and its influencing factors in China. Such research can facilitate the promotion of marine ecological civilization and expedite the construction of a robust marine state [Mei and Yarong (2019)].

Due to the past focus on the economy at the expense of the environment, the problem of pollution has gradually become a major problem that hinders social development. Therefore, the assessment of the eco-efficiency of the corresponding areas and the adoption of measures according to the specific situation have become the main tasks of the new period [Chen et al. (2021)]. After a series of studies, it was found that the eco-efficiency of different regions varies to some extent even in the neighboring regions, which makes it difficult for national-level policies to solve the ecological problems at the regional level sometimes or the effects are not obvious, which demands the study of the spatial and temporal dynamic characteristics of eco-efficiency [Wang et al. (2018)]. In order to investigate the impact of environmental regulation on eco-efficiency, Qin quantified the environmental regulation policies and found that mandatory policies can significantly reduce negative environmental effects, and then proposed policy recommendations such as strengthening policy control and enacting environmental laws and regulations according to local conditions [Qin et al. (2021)].

As research on eco-efficiency has progressed, both the research methods and models as well as the research objects have become increasingly specific and diverse. The development of the concept of ecoeconomic output efficiency [Defeng et al. (2018)], the use of the non-desired output SBM model [Biao and Yeteng (2016)] that can exclude more confounding factors to make the results more accurate, the proposal of new methods to assess eco-efficiency scores based on multi-intelligence simulations instead of relying on field survey data [Ma et al. (2021); Qin and Sun (2021); Xiao et al. (2021)], and even the shift from regional to specific government and sector, agriculture [Defeng et al. (2018)], tourism [Liu et al. (2017)], and coal mining [Liu et al. (2019)] perspectives on eco-efficiency, and Matheus even applied eco-efficiency to the field of apparel design to assess environmental impacts and costs at the early design stage, providing informed advice to designers, manufacturers, and policy makers [Belucio et al. (2021)]. Research on eco-efficiency in marine aspects has mostly focused on the eco-efficiency of mariculture and its influencing factors [Carauta et al. (2022)], eco-efficiency evaluation of marine pastures [Xu et al. (2022)], and efficiency calculation of complex marine systems [Sun et al. (2017)], providing theoretical basis and suggestions for the development of specific marine industries.

The integration of information technology such as the Internet of Things, digital technology [He et al. (2022)], industrial big data [Qiao et al. (2021)], and the "5G+Industrial Internet" [Taleb et al. (2019)] has significantly contributed to the sustainable development of social economy and culture, offering a new model for the global economic

landscape. Examining the role of information and communication technologies and other technological tools [Aldakhil et al. (2019); Ahmed et al. (2021); Ma et al. (2022)], it becomes evident that the advancement of informatization provides a wealth of resources and opportunities for the development of diverse industries, particularly in enhancing tourism. It is more conducive to industry transformation and upgrading; however, the level of development between the two may not always be congruous [Yuanyuan (2016)]. Therefore, several scholars have lately endeavored to examine the development of informatization in the context of its integration with various other factors. Niu delved into the synergistic evolution mechanism between top management support, employees' technical abilities, and informatization performance in the course of "informatization and industrialization integration" in manufacturing enterprises [Niu et al. (2021)]. Wu and Zhu [Wu and Zhu (2020)], on the other hand, unraveled the dynamic process of integration between manufacturing technology and informatization, informatization and industrialization, and employed technical efficiency as a metric for gauging the extent of integration between informatization and industrialization [Zhu et al. (2020)]. The utilization of informatization in the oceanic realm is primarily visible in its role in propelling the ocean economy's informatization and amassing data and information through informatization, which is subsequently applied to coastal management [Xiaozhong and Qingjun (2016); Zeyu and Ganggang (2019); Ma et al. (2023)]. By combining the aforementioned literature studies, we can infer that the correlation between informatization and marine eco-efficiency has not been previously investigated solely in terms of eco-efficiency and informatization itself or the correlation between the two and other factors.

The main contributions of this study to the literature are as follows: firstly, the necessity of informatization for the construction of marine ecological civilization is clarified from the perspective of policy and text, and the construction of informatization can promote the improvement of marine eco-efficiency; secondly, the study was conducted from the perspective of empirical proof. A system of indicators was established to measure and comprehensively evaluate China's informatization and marine eco-efficiency, and it was found that the level of informatization and marine eco-efficiency showed a fluctuating upward trend, and the change curves of both were roughly the same. The dynamic relationship between informatization and marine eco-efficiency is examined, demonstrating that informatization can significantly improve marine eco-efficiency, and enriching the literature with corresponding development suggestions based on the main findings.

2 Informatization level measurement and evaluation

2.1 Study area, data sources and processing

The study area of this study is the 11 coastal provinces of Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi and Hainan. The indicator data of this study are obtained from China Statistical Yearbook, China Tertiary Industry Statistical Yearbook, China Regional Economic Statistical Yearbook, China Social Statistical Yearbook, China Science and Technology Statistical Yearbook, China Marine Statistical Yearbook, China Marine Yearbook and the official website of the National Bureau of Statistics (www.stats.gov.cn) [National Bureau of Statistics of China (2021b); National Bureau of Statistics of China (2021c); National Bureau of Statistics of China (2021d); National Bureau of Statistics of China (2021e); National Bureau of Statistics of China (2021f); National Bureau of Statistics of China (2021g); China Ocean Yearbook Editorial Committee (2021)]. Some years with missing data were filled in by linear interpolation.

2.2 Measurement method

In this study, the improved entropy method is used to calculate the information level indicators [Zeyu and Ganggang (2019)]. The entropy method is an objective weighting method. Compared with the subjective weighting method, the weight value of the index obtained has higher credibility and accuracy, and is widely applicable and has the advantages of dealing with multi-indicator problems. The weighted summation of various indicators in the supply chain resilience index system can achieve the purpose of reducing the number of indicators and more accurate empirical results [Guo (1998)]. We choose n objects and m indicators to form the initial matrix, and $x_{ij}$is the value of the j^{th} indicator of object i, where (i = 1,2,…,n;j = 1,2,…,m). The specific steps are as follows.

- Data standardization Positive indicators:

$$\text{Positive indicators}: \quad x_{ij}^{*} = \frac{x_{ij} - \min\ (x_j)}{\max\ (x_j) - \min\ (x_j)} + \epsilon$$

$$\text{Negative indicators}: \quad x_{ij}^{*} = \frac{\max\ (x_j) - x_{ij}}{\max\ (x_j) - \min\ (x_j)} + \epsilon$$

Where $\min(x_j)$ denotes the minimum value of the j^{th} index of object i and $\max(x_j)$ denotes the maximum value of the j^{th} index of object i. Since this step of the calculation process will produce zero normalized value, which is meaningless when using logarithm to find the entropy value, this study takes ϵ as 0.0001 in the calculation process to avoid this problem without affecting the calculation results. The normalized value of the j^{th} indicator of object i can be defined as: $y_{ij} = \frac{x_{ij}^{*}}{\sum_{i=1}^{n} x_{ij}^{*}}$.

- Second, the entropy value e and the coefficient of variation d of the j^{th} indicator are calculated.

$$\text{Entropy value}: \quad e_j = -k\sum_{i=1}^{n} y_{ij} \ln\ (y_{ij}), k = \frac{1}{\ln\ (n)}$$

$$\text{Variance factor}: \quad d_j = 1 - e_j$$

- Calculate the weight of the j^{th} indicator.

$$\text{Weigh}: \quad w_j = \frac{{}_d j}{\sum_{j=1}^{m} d_j}$$

- Finally, the comprehensive evaluation index of object i is calculated.

$$\text{Indicator}: \quad s_i = \sum_{j=1}^{m} w_j x_{ij}$$

2.3 Evaluation index of informatization level

In this study, the selection of indicators was carried out in a scientific and reasonable manner, adhering to the four principles of scientificity, practicality, operability, and representativeness.

Based on the connotation of informatization and the interaction mechanism between marine eco-efficiency and informatization, this study selects four primary indicators of informatization infrastructure level, social application level, scientific research environment level, and industry operation level and further subdivides them into eight secondary indicators to comprehensively and objectively evaluate the informatization development level of 11 coastal provinces in China from 2006 to 2018 [Wang et al. (2014)]. The indicator system is shown in the Table 1.

2.4 Evaluation of informatization level

The weights of each index were calculated by the improved entropy method, and the results were averaged as shown in the Table 2.

In terms of indicators, the weights of informatization infrastructure level, social application level, scientific research environment level, and industrial operation level are 0.2304, 0.2100, 0.3130, and 0.2466. This indicates that the scientific research environment level is the primary factor influencing informatization and providing more effective support for informatization development, and the informatization infrastructure implementation level, social application level, and industry operation level have equal importance in relative terms.

The average informatization level of the 11 coastal provinces each year is presented in the form of a line graph as shown in the figure to observe the change trend more clearly. The average level of informatization in each province is shown in the Figure 1.

From 2008 to 2016, the level of informatization in China's coastal provinces showed a significant upward trend, with an increase of 0.0520% compared to 2008. Due to the transformation of China's economic growth mode in 2017 and the pressure brought by the money market, as well as the outbreak of the COVID-19 in 2019, all walks of life were affected, and the level of informatization also declined. However, from 2020, the level of informatization began to rise. Overall, the level of informatization development is constantly improving.

The level of informatization in each province and the average and ranking of the four primary indicators during 2008-2021 are shown in the Table 3.

The informatization level of Guangdong is 0.9407 and that of Hainan is only 0.0601, indicating significant provincial disparities. The overall average level of informatization stands is 0.3786, and only four provinces, namely Guangdong, Jiangsu, Zhejiang and Shandong, are above the average level. This indicates that the overall level of informatization in China's coastal provinces is not high.

In terms of infrastructure level, the average level is 0.0978, Guangdong is 0.2306, which is much higher than the average, ranking the first, Hainan is 0.0009, ranking the last; In terms of social application level, the average level is 0.0838, Guangdong, Jiangsu and other provinces are higher than the national average level, and other provinces are lower than the national average level; In terms of the level of scientific research environment, Jiangsu, Guangdong and Zhejiang ranked at the top, while Hainan lagged behind. In terms of industrial operation level, the average level is

TABLE 1 Informatization level evaluation index system.

First-level indicators	Secondary indicators	Variable
Level of infrastructure, A1	Long distance fiber optic cable line length Cell phone exchange capacity	A11 A12
Social application level, A2	Cell phone penetration rate Number of people with Internet access	A21 A22
Scientific research environment level, A3	R&D personnel full time equivalent Number of patent applications	A31 A32
Industrial operation level, A4	Total telecommunication business Seaside observation stations	A41 A42

TABLE 2 Entropy weight of each evaluation index.

First-level indicators	Entropy weight	Secondary indicators	Entropy weight
Level of infrastructure, A1	0.2304	Long distance fiber optic cable line length A11 Cell phone exchange capacity A12	0.1159 0.1145
Social application level, A2	0.2100	Cell phone penetration rate A21 Number of people with Internet access A22	0.0996 0.1104
Scientific research environment level, A3	0.3130	R&D personnel full time equivalent A31 Number of patent applications A32	0.1295 0.1835
Industrial operation level, A4	0.2466	Total telecommunication business A41 Seaside observation stations A42	0.1357 0.1109

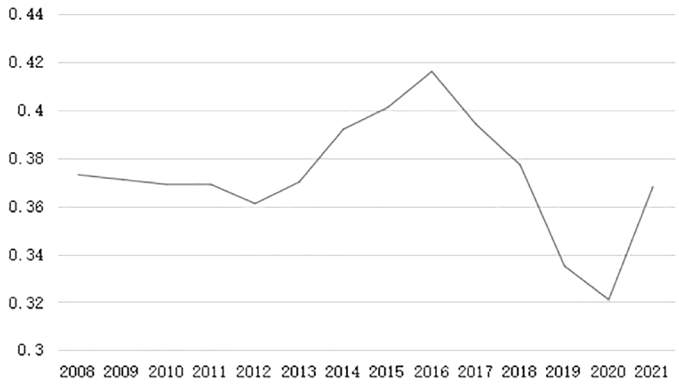


FIGURE 1
2008-2021 informatization level average.

0.0884, with Guangdong, Zhejiang and Shandong ranking top, and Tianjin ranking last. It can be seen that the development of information technology in China's coastal provinces is not balanced, and there are still big gaps in the level of economic development, policy support, talent reserve and innovation ability of the coastal provinces.

3 Measurement and analysis of marine eco-efficiency level

3.1 Data source and processing

The indicator data in this study were obtained from the China Statistical Yearbook and the official website of the National Bureau of Statistics [Dataset National Bureau of Statistics of China, 2021; National Bureau of Statistics of China (2021a); National Bureau of Statistics of China (2021g)]. Some years with missing data were completed by linear interpolation method.

3.2 Measurement method

In this study, by using the software DEAP2.1. Calculate marine eco-efficiency indicators using the Malmquist index. The Malmquist index is proposed based on Data Envelopment Analysis (DEA) and is suitable for evaluating the production efficiency and technological progress of organizational units in different periods or regions. It can reflect the dynamic changes in eco-efficiency of each province during the current period and one lagging period, and make up for the shortcomings of DEA models in studying dynamic data.

3.3 Marine eco-efficiency input-output index system

In this study, in order to accurately assess the actual situation of marine eco-efficiency in 11 coastal provinces, a scientific and reasonable marine eco-efficiency evaluation index system is constructed in terms of both inputs and outputs in the selection of indicators [Qingfeng and Zhuchang (2014)], as shown in the Table 4.

According to the characteristics of the production and operation of the marine economy, the statistical indicators of resource consumption related to economic activities such as marine fisheries, marine salt industry and marine oil and gas industry are selected as resource inputs; because marine economic production activities do not depend directly on current investments, but more on the fixed capital stock of the region, marine fixed capital stock is used as a capital input; use of marine-related practitioners as human input; using the gross marine product of the 11 coastal provinces as the desired output; with the increase of marine economic activities on land, but a large part of the resulting wastewater and waste gas pollution treatment costs are still transferred to the marine economy, so chemical oxygen demand and ammonia nitrogen emissions from industrial wastewater discharge in coastal areas and sulfur dioxide and soot emissions from industrial waste gas discharge in coastal areas are selected as non-desired outputs.

In order to minimize the number of input-output indicators, we use an improved entropy method to synthesize various marine resource inputs and industrial emissions from coastal areas into resource indicators and non-desired output indicators, respectively. Marine fixed capital stock is calculated using the equal capital production ratio method Zhang et al. (2004): $\frac{K_N}{Y_N} = \frac{K}{Y} \rightarrow K = Y \times \frac{K_N}{Y_N}$, K_N is the sum of capital stock of 11 coastal provinces, and Y_N is the sum of gross marine product of 11 coastal provinces. Capital stock is calculated using the perpetual inventory method $K_{it} = (1-\delta)K_{it-1} + I_{it}$, K_{it} is the capital stock in year t in region i, δ is the depreciation rate (9.6%) Zhang et al. (2004), and I_{it} denotes the total capital formation in year t in region i (deflated by the fixed asset investment price index using 2006 as the base period). The initial capital stock is obtained by dividing the total fixed capital formation in the base year by 10%, using Young's estimation method [Young (2003)]. The calculation of marine GDP is deflated by the GDP deflator of each province and region using 2006 as the base period.

TABLE 3 Informative evaluation results.

Provinces	Information level		Infrastructure level		Social application level		Research environment level		Industry 0peration level	
	U	Ranking	A1	Ranking	A2	Ranking	A3	Ranking	A4	Ranking
Guangdong	0.9407	1	0.2306	1	0.1993	1	0.2702	2	0.2406	1
Jiangsu	0.6217	2	0.1379	3	0.0953	4	0.2881	1	0.1004	5
Shanghai	0.3165	6	0.0249	9	0.1101	3	0.0954	5	0.0861	6
Zhejiang	0.5672	3	0.1173	5	0.1298	2	0.1956	3	0.1245	2
Shandong	0.4780	4	0.1444	2	0.0815	5	0.1384	4	0.1137	3
Hebei	0.2770	8	0.1301	4	0.0587	8	0.0367	9	0.0515	8
Fujian	0.3265	5	0.0845	8	0.0757	6	0.0542	6	0.1121	4
Liaoning	0.2871	7	0.0858	7	0.0704	7	0.0491	7	0.0818	7
Tianjin	0.1132	10	0.0086	10	0.0482	9	0.0484	8	0.0080	11
Hainan	0.0601	11	0.0009	11	0.0315	10	0.0003	11	0.0274	9
Guangxi	0.1767	9	0.1106	6	0.0212	11	0.0181	10	0.0268	10
Average value	0.3786	–	0.0978	–	0.0838	–	0.1086	–	0.0884	–

10.3389/fmars.2024.1362554

TABLE 4 Marine eco-efficiency input-output indicator system.

Target layer	Guideline layer	Indicator layer
Inputs	Resources	Marine fishing production Mariculture production Sea salt production Offshore gas production
	Capital	Marine fixed capital stock
	Manpower	Maritime-related Practitioners
Outputs	Expected output	Gross Ocean Product
	Non-desired outputs	Chemical oxygen demand (COD)discharged from industrial wastewater in coastal areas Ammonia nitrogen emissions from industrial wastewater in coastal areas Sulfur dioxide emissions from industrial waste gas in coastal areas Fume and dust emissions from industrial waste gas in coastal areas

3.4 Marine eco-efficiency analysis

Through calculation, the marine eco-efficiency of each province during 2008-2021 was obtained in this study as shown in the Table 5.

The results show that the marine eco-efficiency of Guangdong, Jiangsu, Shanghai, and Shandong provinces is higher than the average level, with Shanghai having the highest marine eco-efficiency. China's marine ecological environment policies consist of four categories of policies: marine pollution prevention and control, marine ecological protection, marine resource development, and land source planning related to the sea. Due to the shift of policy focus to deepening the construction of the rule of law in the ocean in 2016, and the large-scale adjustment of China's administrative structure in 2018, there were many discontinuous phenomena in the number and distribution of policy subjects. As for the various links of the marine ecological environment policy chain, the number and functional allocation of policy subjects in their distribution showed discontinuity. Therefore, the marine eco-efficiency of various coastal provinces decreased after 2015, After 2018, there has been a slight rebound. Overall, the marine eco-efficiency of 11 coastal provinces showed an upward trend.

4 The impact of informatization on marine eco-efficiency

4.1 Theoretical mechanism of informatization on marine ecological efficiency

Marine informatization is a means of enhancing marine resource management and protecting the marine ecological environment through modern information technology. It includes the collection, processing, and analysis of marine data, as well as the application of this data, in order to improve the efficiency of marine ecology. The following are some key theoretical mechanisms that illustrate how ocean informatization affects marine ecological efficiency:

Data collection and monitoring: Ocean informatization achieves continuous monitoring of the marine environment through technologies such as satellite remote sensing, underwater drones, and sensor networks. This comprehensive data collection helps scientists better understand the state of marine ecosystems and develop more effective protection measures [Han and Zhang (2015); Bai et al. (2020)]. Resource management optimization: By utilizing information technology tools, it is possible to more accurately assess the distribution and sustainability of marine resources. This helps to develop reasonable development plans, reduce damage to marine ecology, and improve the efficiency of resource utilization [Gilman et al. (2020); Schwing (2023)]. Early warning and disaster prevention and control: Marine information technology can predict natural disasters in advance, such as tsunamis, hurricanes, etc., issue timely warnings, and reduce the damage of disasters to marine ecosystems [Schwing (2023)]. Environmental protection and restoration:

TABLE 5 Marine eco-efficiency values in 11 coastal provinces from 2008-2021.

Provinces	2009	2011	2013	2015	2017	2019	2021
Guangdong	0.3819	0.5413	1.0290	1.1635	0.7416	0.7814	0.7746
Jiangsu	0.4751	0.5770	0.7884	1.0466	1.712	1.0028	1.0381
Shanghai	0.6825	0.8274	1.7034	1.0153	0.8488	0.9733	1.2109
Zhejiang	0.3771	0.3635	0.4546	0.4879	0.2481	0.3431	0.4332
Shandong	0.4600	0.4177	0.5751	0.6302	0.5170	0.6735	0.5691
Hebei	0.3294	0.3300	0.4412	0.4598	0.2636	0.3683	0.4450
Fujian	0.3269	0.3189	0.3898	0.4694	0.2984	0.3209	0.4182
Liaoning	0.3293	0.3235	0.4070	0.4124	0.1933	0.3398	0.4217
Tianjin	0.3691	0.3998	0.5138	0.5693	0.3140	0.4481	0.3917
Hainan	0.2517	0.2410	0.2895	0.3000	0.1045	0.1981	0.2031
Guangxi	0.2631	0.2485	0.3087	0.3366	0.1259	0.4291	0.2873

Due to space limitation, only odd-numbered years' informational values are shown.

Information technology supports the implementation of environmental protection actions, such as precise positioning and management of polluted areas. At the same time, informatization can also monitor the effectiveness of ecological restoration work, ensuring the correct implementation and effectiveness of ecological restoration measures [Lange et al. (2023)]. Policy formulation and implementation monitoring: Marine informatization provides a real-time and dynamic decision support system, allowing policy makers to formulate or adjust policies based on the latest scientific data. At the same time, information tools can also monitor policy implementation to ensure the achievement of policy objectives [Zou (2012); Ma (2020)].

Through the above mechanisms, ocean informatization can not only improve the efficiency of marine resource development and utilization, but more importantly, effectively protect and improve the marine ecological environment. This is a key way to achieve sustainable development of the ocean.

4.2 Methods

PVAR model is a model method for empirical analysis of panel data developed on the basis of VAR model [Love and Zicchino (2006)]. It not only has the advantages of VAR model, but also allows the lag coefficient to change with time, and has less stringent requirements on the time stationarity of data than other models. Because there are certain deviations in the availability and accuracy of the display data, this also highlights the advantages of the PVAR model for the higher possibility of obtaining empirical results, and will not be unable to obtain results due to excessive data requirements.The endogeneity issues is effectively solved by introducing lag terms [Ye et al. (2023)]. The empirical analysis in this paper uses panel data, which contains more time dimensions and information. This also makes panel data increase the reliability of empirical results and reduce data generation errors when analyzing the dynamic relationship between variables because there are more observations. Therefore, this study used the PVAR model to analyze the data, and investigated the endogenous dynamic effects of informatization and Marine eco-efficiency. The model is constructed as follows:

$$y_{i,t} = \sum_{j=1}^{k} \alpha_j y_{i,t-1} + \beta_i + \mu_t + \epsilon_{i,t}$$

where i denotes province and t denotes year; $y_{i,t}$ denotes two variables, informatization (fi) and marine eco-efficiency (mar), respectively; k represents the lag order; j represents a lag term; α_j represents the parameter matrix of order j after; β_i denotes individual fixed effects, reflecting differences across provinces; μ_t denotes the time effect, reflecting the characteristics of the variable in time; $\epsilon_{i,t}$ denotes the random perturbation term.

4.3 Analysis of the dynamic impact of informatization on marine eco-efficiency

Given the complexity of macroeconomic variables and the possible non-stationarity of the data, four-unit root tests: LLC, IPS, Fisher-ADF, and Fisher-PP, were chosen to test the stability of the panel data in order to ensure the validity of the model. To solve the heteroscedasticity problem, we took logarithmic treatment of the raw data, but it could not pass the smoothness test. After further first-order differencing of the data, as shown in the Table 6, the data results all reject the original hypothesis of the existence of a unit root at the 1% significance level, indicating that both informatization and marine eco-efficiency are stable series.

Since the data are single integer of the same order at 1% level of significance, in order to avoid the phenomenon of pseudo-regression, three methods of kao test, Pedroni test, and Westerlund test are used in this study to test the cointegration of variables. The original hypothesis of the three tests is that there is no cointegration relationship between the variables. As shown in the Table 7, the results reject the original hypothesis at the 1% significance level, so there is a cointegration relationship in the panel data, indicating that there is a long-term equilibrium relationship between informatization and marine eco-efficiency, which can be estimated by regression on the panel data.

The optimal lag order of the model must first be determined to estimate the PVAR model. The optimal lag order of the panel vector autoregressive model for 11 provinces is shown in the Table 8, and the PVAR model is estimated by selecting lag 5 according to the AIC, BIC, and HQIC criteria.

To ensure the accuracy of subsequent model estimation, impulse response, and variance decomposition, it is imperative to assess the robustness of the model by determining whether the eigenvalues of the dynamic matrix are less than 1 (confined within the unit circle). Figure 2 illustrates that the PVAR model employed in this research is trustworthy and appropriate for estimation, impulse response, and variance decomposition.

After determining the optimal lag order, granger causality tests were done on the panel data to analyze the relationship between informatization and marine eco-efficiency. As shown in the Table 9, informatization is the Granger cause of marine eco-efficiency at 5% significance level, while marine eco-efficiency is not the Granger cause of informatization, and the two are univariate causality.

Further GMM estimation of the model was performed. The variables h_D_lnmar and variable h_D_lnfi were obtained after performing the helmert transformation to eliminate individual fixed effects, and the following results (Table 10) were obtained by GMM estimation.

When h_D_lnmar is the explanatory variable, L5. h_D_lnmar and L5. h_D_lnfi at a 1% level of significance has a significant positive impact on h_D_lnmar. The impact of five lagging periods of informatization on the current marine eco-efficiency is 0.2960,

TABLE 6 Panel unit root test.

Variables	LLC	IPS	Fisher-ADF	Fisher-PP
D_lnmar	-6.3377 (0.0000)	-5.6577 (0.0000)	44.5604 (-0.0030)	178.2433 (0.0000)
D_lnfi	-6.5515 (0.0000)	-5.767 (0.0000)	47.2272 (-0.0014)	145.4454 (0.0000)

The p-values are reported in parentheses.

TABLE 7 Panel cointegration test.

Variables	Kao-ADF	Pedroni-ADF	Westerlund-VR
D_lnmar D_lnfi	-5.5543 (0.0000)	-13.2535(0.0000)	-3.5971(0.0002)

The p-values are reported in parentheses.

TABLE 8 Lag order test of informatization - marine eco-efficiency.

Lag	AIC	BIC	HQIC
1	-0.2465	0.2922*	-0.0276
2	-0.2317	0.4235	0.0345
3	-0.0571	0.7284	0.2619
4	-0.2299	0.7030	0.1485
5	-0.4886*	0.6122	-0.0433*

*The optimal lag order.

indicating that informatization can significantly promote the improvement of marine eco-efficiency. When h_D_lnfi is the explanatory variable, at the 1% significance level, L4. h_D_lnmar has a significant positive impact on h_D_lnfi. The impact of four periods of lagging marine eco-efficiency on current informatization is 0.1135, indicating that marine eco-efficiency has a promoting effect on the development of informatization.

The impulse response function describes the impact and effect of one endogenous variable in the model on the other endogenous variables in the model in the current and future periods after being subjected to a standard deviation of orthogonalized impulses. The interaction between the variables can be analyzed with the help of impulse response functions. Impulse response analysis was performed separately for the variables in the model, and in order to observe the long-term trend of the impulse response, the observation period was set to six periods, and a separate positive pulse of one unit was performed for the variables in the base period, respectively, and the impulse response plots with 95% confidence intervals were obtained after 200 random simulations of the Monte Carlo model (Figure 3).

The Figure 3 shows that the impact of informatization on itself reaches its maximum in the current period, and then shows a rapid downward trend with gradually weakening fluctuations; the impact of marine eco-efficiency on itself reaches its maximum in the current period, followed by a rapid downward trend, and then produces a positive fluctuation; the pulse shock of informatization has a negative effect on marine eco-efficiency in the current period and lasts until the third period, and produces positive fluctuations in the fourth period, which indicates that informatization has some inhibitory effect on marine eco-efficiency in the short term, but the overall effect of informatization on marine eco-efficiency is promoted; the pulse shock of marine eco-efficiency has a significant positive effect on informatization, indicating that the improvement of marine eco-efficiency is beneficial to the development of informatization.

The variance decomposition is utilized to further evaluate the significance of different structural shocks by analyzing the contribution of each structural shock to the changes in endogenous variables. The variance decomposition analysis based on the impulse response function yields the following results (Table 11).

The variance decomposition shows the predicted results for the 10th, 20th, and 30th periods. The results show that the contribution

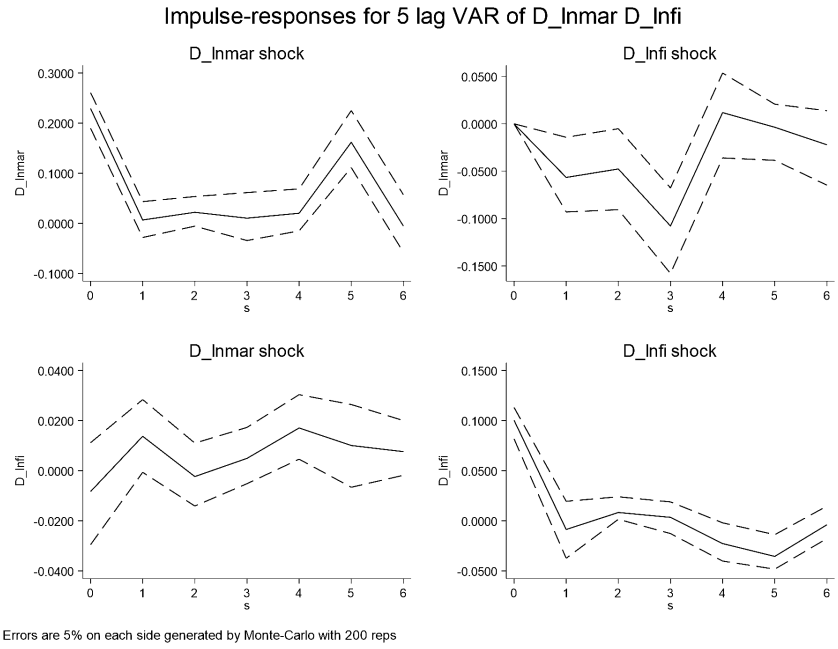


FIGURE 2
Robustness test.

TABLE 9 Panel Granger causality test.

Variables	D_lnmar	D_lnfi
D_lnmar		34.1390 (0.0000)
D_lnfi	9.561 (0.0890)	

The p-values are reported in parentheses.

rate of informatization to marine eco-efficiency is stable at 5%, while the contribution rate of marine eco-efficiency to informatization is stable at 25%, indicating a two-way relationship between the two. Therefore, the improvement of informatization will promote the improvement of marine eco-efficiency, while the improvement of marine eco-efficiency is also conducive to the development of informatization.

5 Conclusions, policy implications, limitations

5.1 Conclusions

This study examines the dynamic relationship between informatization and marine eco-efficiency. Based on the panel data of 11 Chinese coastal provinces from 2008 to 2021, the level of informatization was measured and evaluated using the improved entropy method, the level of marine eco-efficiency was measured and evaluated using the Malmquist index, and finally, the dynamic relationship between informatization and marine eco-efficiency was empirically analyzed using the PVAR model, and the following main conclusions were drawn. The overall level of informatization in China's coastal provinces shows a significant upward trend of fluctuations. Based on the weight, the impact of the four primary indicators on informatization is sequentially as follows: research environment level, industrial operation level, infrastructure level, and social application level. The results indicate that only Guangdong, Jiangsu, Zhejiang, and Shandong provinces are above the average level, reflecting that the overall level of informatization in China's coastal provinces is not high. The trend of changes in marine eco-efficiency in 11 coastal provinces of China is roughly the same as the trend of changes in informatization level. There are significant differences in marine eco-efficiency among different provinces, with Guangdong, Shanghai, and Jiangsu having the highest level of development, while Liaoning, Hainan, and Guangxi have lower levels of marine ecological development. This suggests that the level of marine ecological development in China's coastal provinces is uneven, with each province placing varying degrees of importance on the construction of ecological civilization. There is a long-term equilibrium relationship between informatization and marine eco-efficiency, and informatization is the Granger reason for marine eco-efficiency at a significant level of 5%. The GMM results indicate that informatization significantly drives marine eco-efficiency at a level of 1%. Additionally, marine eco-efficiency has a positive impact on informatization construction. Through pulse response analysis, it was found that informatization exhibits a certain inhibitory effect on marine eco-efficiency in the short term, but ultimately presents a promoting effect. The results of variance decomposition further reveal a bidirectional positive relationship between informatization and marine eco-efficiency.

5.2 Policy implications

To effectively promote the development of informatization, facilitate the construction of marine ecological civilization, reduce regional disparities, and achieve balanced development among provinces, we propose the following policy recommendations.

Firstly, the government should provide support for the construction of information infrastructure, enhance the application level of information infrastructure, promote the use of network thinking among individuals, establish a platform for public communication, and mobilize public participation. At the same

TABLE 10 Estimated results of PVAR.

Variables	h_D_lnmar			h_D_lnfi		
	b_GMM	se_GMM	t_GMM	b_GMM	se_GMM	t_GMM
L.h_D_Inmar	-0.3001	0.1081	-2.7759	0.0806	0.0672	1.1997
L.h_D_Infi	-0.6945	0.3233	-2.1483	0.0230	0.1798	0.1281
L2.h_D_Inmar	-0.0794	0.0910	-0.8732	0.0234	0.0636	0.3683
L2.h_D_Infi	-0.5739	0.3577	-1.6039	0.1436	0.0899	1.5969
L3.h_D_Inmar	-0.0428	0.0879	-0.4870	0.0486	0.0498	0.9758
L3.h_D_Infi	-0.8355	0.1760	-4.7468	0.1408	0.0783	1.7991
L4.h_D_Inmar	0.0771	0.0739	1.0435	0.1135	0.0429	2.6445
L4.h_D_Infi	0.1178	0.1597	0.7376	-0.0328	0.1569	-0.209
L5.h.D.Inmar	0.4489	0.0595	7.5384	0.0223	0.0242	0.9229
L5.h_D_Infi	0.2960	0.1043	2.8373	-0.2366	0.1889	-1.2521

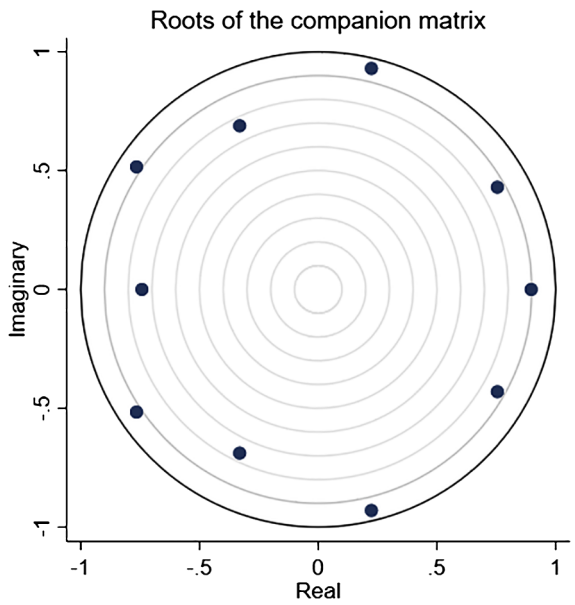


FIGURE 3
Impulse response function of informatization and ocean eco-efficiency.

time, it is important to consider strengthening the participation and contribution of enterprises to marine ecological civilization.

Secondly, it is necessary to adjust measures to local conditions and promote balanced development among regions. Through a comprehensive analysis of the regional economic level and development advantages, different marine ecological protection strategies will be formulated based on the characteristics of each province. Scientific supporting policies will be formulated, resources in each province will be reasonably allocated, technological innovation investment will be increased, and existing information silos will be eliminated through the establishment of big data ecological centers. This approach will enable the full process management of relevant business data in various fields of ecological civilization, from collection, processing, aggregation, release to exchange and sharing.

Finally, we strongly believe that it is crucial to increase research investments and accelerate the development of emerging marine industries, as well as the exploration and utilization of marine renewable resources. To this end, we will intensify our research and development efforts in domestic scientific and technological equipment, achieve key breakthroughs in core technologies, fill gaps in the domestic scientific and technological field, obtain a series of original technologies and invention patents. By utilizing universities as platforms, we will strengthen our exchanges with countries around the world, attract high-level talents from countries around the world, and strive to create distinctive ocean majors.

TABLE 11 Variance decomposition results for PVAR.

Variables	s	D_lnmar	D_lnfi
D_lnmar	10	0.7475	0.2525
D_lnfi	10	0.0547	0.9453
D_lnmar	20	0.7483	0.2517
D_lnfi	20	0.0566	0.9434
D_lnmar	30	0.7484	0.2516
D_lnfi	30	0.0567	0.9433

5.3 Limitations

Our study did not address the spatial and temporal evolution and spatial layout of informatization and marine eco-efficiency. In the next work, we can further investigate the influence between informatization and marine eco-efficiency through the spatial Durbin model while more comprehensive analysis and evaluation.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

BD: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing, Software. JC: Conceptualization, Data curation, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing, Software, Validation. GC: Data curation, Software, Writing – review & editing. CM: Funding acquisition, Resources, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This study was supported by The Natural Science Foundation of Shandong Province (No. ZR2020MA024).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Ahmed, Z., Nathaniel, S. P., and Shahbaz, M. (2021). The criticality of information and communication technology and human capital in environmental sustainability: evidence from latin american and caribbean countries. *J. Cleaner Production* 286, 125529. doi: 10.1016/j.jclepro.2020.125529

Aimin, W. (2016). Research on the coordination and interaction mechanism between marine technology and marine economy. *China Soft Sci.* 8, 40–49. doi: 10.3969/j.issn.1002-9753.2016.08.004

Aldakhil, A. M., Zaheer, A., Younas, S., Nassani, A. A., Abro, M. M. Q., and Zaman, K. (2019). Efficiently managing green information and communication technologies, high-technology exports, and research and development expenditures: A case study. *J. Cleaner Production* 240, 118164. doi: 10.1016/j.jclepro.2019.118164

Bai, L., Han, R., Liu, J., Choi, J., and Zhang, W. (2020). Random access and detection performance of internet of things for smart ocean. *IEEE Internet Things J.* 7, 9858–9869. doi: 10.1109/JIoT.6488907

Belucio, M., Rodrigues, C., Antunes, C. H., Freire, F., and Dias, L. C. (2021). Eco-efficiency in early design decisions: A multimethodology approach. *J. Cleaner Production* 283, 124630. doi: 10.1016/j.jclepro.2020.124630

Biao, H., and Yeteng, F. (2016). Measurement of ecological efficiency in China and empirical analysis of spatial differences based on sbm model and spatial autocorrelation. *J. arid land Resour. Environ.* 30, 6–12. doi: 10.13448/j.cnki.jalre.2016.173

Carauta, M., Grovermann, C., Heidenreich, A., and Berger, T. (2022). How eco-efficient are crop farms in the southern amazon region? insights from combining agent-based simulations with robust order-m eco-efficiency estimation. *Sci. Total Environ.* 819, 153072. doi: 10.1016/j.scitotenv.2022.153072

Chen, P., Xie, R., Lu, M., and Huang, Z. (2021). The impact of the spatio-temporal neighborhood effect on urban eco-efficiency in China. *J. cleaner production* 285, 124860. doi: 10.1016/j.jclepro.2020.124860

China Ocean Yearbook Editorial Committee (2021). *China ocean Yearbook*. No.57 Yuetan Nanjie, Sanlihe, Beijing 100826, P. R. China: China Statistics Press.

Dataset National Bureau of Statistics of China (2021). *National Bureau of Statistics of CHINA*. No.57 Yuetan Nanjie, Sanlihe, Beijing 100826, P. R. China: China Statistics Press.

Defeng, Z., Shuai, H., Caizhi, S., and Leting, L. (2018). Spatial-temporal evolution analysis and trend prediction of ecological efficiency in chinese mainland. *Geographical Res.* 37, 1034–1046. doi: 10.11821/dlyj201805014

Gilman, E., Castejón, V. D. R., Loganimoce, E., and Chaloupka, M. (2020). Capability of a pilot fisheries electronic monitoring system to meet scientific and compliance monitoring objectives. *Mar. Policy* 113, 103792. doi: 10.1016/j.marpol.2019.103792

Guo, X. (1998). Application of improved entropy method in evaluation of economic result. *Syst. Engineering-Theory Pract.* 18, 98–102. doi: 10.1088/0256-307X/16/9/020

Han, H., and Zhang, L. (2015). Analysis of threshold effect of agricultural informatization on agricultural total factor productivity growth. *Chin. Rural Economy* 8, 23. doi: CNKI:SUN:ZNJJ.0.2015-08-005

He, X., Ping, Q., and Hu, W. (2022). Does digital technology promote the sustainable development of the marine equipment manufacturing industry in China? *Mar. Policy* 136, 104868. doi: 10.1016/j.marpol.2021.104868

Ji, J., and Li, Y. (2021). The development of China's fishery informatization and its impact on fishery economic efficiency. *Mar. Policy* 133, 104711. doi: 10.1016/j.marpol.2021.104711

Lange, M., Cabana, D., Ebeling, A., Ebinghaus, R., Joerss, H., Rölfer, L., et al. (2023). Climatesmart socially innovative tools and approaches for marine pollution science in support of sustainable development. *Cambridge Prisms: Coast. Futures* 1, e23. doi: 10.1017/cft.2023.11

Lin, Z., Yushuo, Z., Di, W., Yongming, W., and Dianting, W. (2016). Measurement and spatiotemporal characteristics of inter provincial marine economic efficiency in China considering unexpected outputs. *Geographic Sci.* 36, 671–680. doi: 10.13249/j.cnki.sgs.2016.05.004

Liu, X., Guo, P., and Guo, S. (2019). Assessing the eco-efficiency of a circular economy system in China's coal mining areas: Emergy and data envelopment analysis. *J. Cleaner Production* 206, 1101–1109. doi: 10.1016/j.jclepro.2018.09.218

Liu, J., Zhang, J., and Fu, Z. (2017). Tourism eco-efficiency of chinese coastal cities–analysis based on the dea-tobit model. *Ocean Coast. Manage.* 148, 164–170. doi: 10.1016/j.ocecoaman.2017.08.003

Love, I., and Zicchino, L. (2006). Financial development and dynamic investment behavior: Evidence from panel var. *Q. Rev. Economics Finance* 46, 190–210. doi: 10.1016/j.qref.2005.11.007

Ma, J. (2020). Research on marine ecological civilization policies in shandong province based on content analysis. *Open J. Ecol.* 10, 264–288. doi: 10.4236/oje.2020.105017

Ma, C., Dai, Y., and Li, Z. (2022). Financing format selection for electronic business platforms with a capital-constrained e-tailer. *Transportation Res. Part E: Logistics Transportation Rev.* 162, 102720. doi: 10.1016/j.tre.2022.102720

Ma, C., Sun, Q., Xu, M., Dai, Y., and Zhang, M. (2023). Strategic selling agreement and information management under leakage in an e-commerce supply chain. *Electronic Commerce Res. Appl.* 61, 101288. doi: 10.1016/j.elerap.2023.101288

Ma, C., Yang, H., Zhang, W., and Huang, S. (2021). Low-carbon consumption with government subsidy under asymmetric carbon emission information. *J. Cleaner Production* 318, 128423. doi: 10.1016/j.jclepro.2021.128423

Mei, G., and Yarong, Z. (2019). Analysis of spatial pattern evolution and influencing factors of marine ecological efficiency in coastal provinces and regions of China. *Geographic Sci.* 39, 616–625. doi: 10.13249/j.cnki.sgs.2019.04.011

Ministry of Natural Resources (2022). *2021 CHINA Marine Economic Statistics Bulletin*. The state council the people's republic of China: Tech. rep.

National Bureau of Statistics of China (2021a). *China environmental statistical yearbook*. No.57 Yuetan Nanjie, Sanlihe, Beijing 100826, P. R. China: China Statistics Press.

National Bureau of Statistics of China (2021b). *China Statistical Yearbook*. No.57 Yuetan Nanjie, Sanlihe, Beijing 100826, P. R. China: China Statistics Press.

National Bureau of Statistics of China (2021c). *China Statistical Yearbook for Ocean*. No.57 Yuetan Nanjie, Sanlihe, Beijing 100826, P. R. China: China Statistics Press.

National Bureau of Statistics of China (2021d). *China Statistical Yearbook for Regional Economy*. No.57 Yuetan Nanjie, Sanlihe, Beijing 100826, P. R. China: China Statistics Press.

National Bureau of Statistics of China (2021e). *China Statistical Yearbook for Society*. No.57 Yuetan Nanjie, Sanlihe, Beijing 100826, P. R. China: China Statistics Press.

National Bureau of Statistics of China (2021f). *China Statistical Yearbook for Technology*. No.57 Yuetan Nanjie, Sanlihe, Beijing 100826, P. R. China: China Statistics Press.

National Bureau of Statistics of China (2021g). *Statistical Yearbook of CHINA's Third Industry*. No.57 Yuetan Nanjie, Sanlihe, Beijing 100826, P. R. China: China Statistics Press.

Niu, P., Zhu, J., and Sun, Y. (2021). Dynamic modeling and chaos control of informatization development in manufacturing enterprises. *Entropy* 23, 681. doi: 10.3390/e23060681

Qiao, F., Liu, J., and Ma, Y. (2021). Industrial big-data-driven and cps-based adaptive production scheduling for smart manufacturing. *Int. J. Production Res.* 59, 7139–7159. doi: 10.1080/00207543.2020.1836417

Qin, M., and Sun, M. (2021). Effects of marine ranching policies on the ecological efficiency of marine ranching—based on 25 marine ranching in shandong province. *Mar. Policy* 134, 104788. doi: 10.1016/j.marpol.2021.104788

Qin, M., Sun, M., and Li, J. (2021). Impact of environmental regulation policy on ecological efficiency in four major urban agglomerations in eastern China. *Ecol. Indic.* 130, 108002. doi: 10.1016/j.ecolind.2021.108002

Qingfeng, W., and Zhuchang, T. (2014). Two new methods for estimating capital stock k under the absence of investment information. *Quantitative Tech. economics* 31, 150–160. doi: CNKI:SUN:SLJY.0.2014-09-010

Qingyun, Y., Xixi, H., Xiren, J., Wenpeng, S., Liang, Q., and Xiaosong, M. (2020). Design of jiaozhou bay marine ecological protection information platform. *Mar. Dev. Manage.* 37, 33–37. doi: 10.20016/j.cnki.hykfygl.2020.08.006

Schwing, F. B. (2023). Modern technologies and integrated observing systems are "instrumental" to fisheries oceanography: A brief history of ocean data collection. *Fisheries Oceanography* 32, 28–69. doi: 10.1111/fog.12619

Sun, C., Wang, S., Zou, W., and Wang, Z. (2017). Estimating the efficiency of complex marine systems in China's coastal regions using a network data envelope analysis model. *Ocean Coast. Manage.* 139, 77–91. doi: 10.1016/j.ocecoaman.2017.02.005

Taleb, T., Afolabi, I., and Bagaa, M. (2019). Orchestrating 5g network slices to support industrial internet and to shape next-generation smart factories. *IEEE Network* 33, 146–154. doi: 10.1109/MNET.65

Wang, Z., Feng, C., and Zhang, B. (2014). An empirical analysis of China's energy efficiency from both static and dynamic perspectives. *Energy* 74, 322–330. doi: 10.1016/j.energy.2014.06.082

Wang, G., Li, S., and Ma, Q. (2018). Spatial-temporal evolution of chinese eco-efficiency from the perspective of human well-being. *Sci. Geogr. Sin.* 38, 1597–1605. doi: 10.13249/j.cnki.sgs.2018.10.003

Wu, D., and Zhu, J. (2020). Technical efficiency evolution model of the integration of information technology and manufacturing technology. *Math. Problems Eng.* 2020, 1–24. doi: 10.1155/2020/4905195

Xiao, H., Wang, D., Qi, Y., Shao, S., Zhou, Y., and Shan, Y. (2021). The governance-production nexus of eco-efficiency in chinese resource-based cities: A two-stage network dea approach. *Energy Economics* 101, 105408. doi: 10.1016/j.eneco.2021.105408

Xiaodi, Z. (2015). Industry and factor driven changes in ecological efficiency: based on input-output and system optimization models. *J. Natural Resour.* 30, 748–760. doi: 10.11849/zrzyxb.2015.05.004

Xiaozhong, L., and Qingjun, L. (2016). Research on the coupling and coordinated development of informatization and industrial transformation and upgrading in China. *Resource Dev. Market* 32, 971–977. doi: 10.3969/j.issn.1005-8141.2016.08.015

Xu, J., Han, L., and Yin, W. (2022). Research on the ecologicalization efficiency of mariculture industry in China and its influencing factors. *Mar. Policy* 137, 104935. doi: 10.1016/j.marpol.2021.104935

Yanqun, L., and Peng, Y. (2017). Spatial econometric analysis of industrial ecological efficiency and influencing factors in chinese provinces. *Resource Sci.* 39, 1326–1337. doi: 10.18402/resci.2017.07.10

Ye, M., Cai, J., Wang, K., and Wang, X. (2023). Green finance, economic growth, and carbon emissions: a pvar analysis. *Environ. Sci. pollut. Res.* 30, 119419–119433. doi: 10.1007/s11356-023-30719-x

Young, A. (2003). Gold into base metals: Productivity growth in the people's republic of China during the reform period. *J. political economy* 111, 1220–1261. doi: 10.1086/378532

Yuanyuan, S. (2016). Empirical analysis of the impact of informatization on China's tourism market. *Tourism Sci.* 30, 1–12+27. doi: 10.16323/j.cnki.lykx.2016.03.001

Yufei, R., and Chuanglin, F. (2017). Ecological efficiency evaluation and spatial pattern analysis at the county level in the beijing tianjin hebei urban agglomeration. *Prog. Geographic Sci.* 36, 87–98. doi: 10.18306/dlkxjz.2017.01.009

Zeyu, W., and Ganggang, J. (2019). Research on the coordinated response relationship between marine economy and informatization in coastal provinces and regions of China. *Resource Dev. Market* 35, 347–352. doi: 10.3969/j.issn.1005-8141.2019.03.009

Zeyu, W., Xuefeng, L., Caizhi, S., Zenglin, H., and Xiaofei, D. (2017). The evolution and influencing factors of the center of gravity of China's marine economy. *Economic Geogr.* 37, 12–19. doi: 10.15957/j.cnki.jjdl.2017.05.002

Zeyu, W., Zhen, Z., Zenglin, H., Caizhi, S., and Yingrui, L. (2016). Response measures of the marine economy to regional economic development. *Resour. Sci.* 38, 1832–1845. doi: 10.18402/resci.2016.10.02

Zhang, J., Wu, G., and Zhang, J. (2004). Interprovincial physical capital stock estimation in China: 1952–2000. *Econ. Res.* 10, 35–44. doi: CNKI:SUN:JJYJ.0.2004-10-004

Zhu, J., Liu, W., Li, Y., and Sun, Y. (2020). Exploring robustness management for dynamic technology fusion. *Nonlinear Dynamics* 102, 2969–3011. doi: 10.1007/s11071-020-05978-9

Zou, K. (2012). China's ocean policymaking: practice and lessons. *Coast. Manage.* 40, 145–160. doi: 10.1080/08920753.2012.652514

frontiers | Frontiers in Marine Science

TYPE Review
PUBLISHED 15 May 2024
DOI 10.3389/fmars.2024.1409772

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Nitin Agarwala,
Centre for Joint Warfare Studies, India
M. Jahanzeb Butt,
Shandong University, China

*CORRESPONDENCE
Ruiqiang Liu
liuruiqiang@cupl.edu.cn

RECEIVED 31 March 2024
ACCEPTED 01 May 2024
PUBLISHED 15 May 2024

CITATION
Liu R (2024) Revision of China's marine environmental protection law: history, background and improvement.
Front. Mar. Sci. 11:1409772.
doi: 10.3389/fmars.2024.1409772

COPYRIGHT
© 2024 Liu. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Revision of China's marine environmental protection law: history, background and improvement

Ruiqiang Liu*

School of Law, China University of Political Science and Law, Beijing, China

The law on marine environmental protection is a branch of the law on environmental protection and is the basis for the conduct of marine environmental protection. Since its promulgation in 1982, China's Marine Environmental Protection Law has undergone two revisions and three amendments, forming a legal system based on the Constitution, with the Environmental Protection Law as the overarching principle, the Marine Environmental Protection Law as the core, and various laws on the protection of marine elements as the gripping force. The revision of the Marine Environmental Protection Law in 2023 was based on the 2018 supervision and inspection of the enforcement inspection team of the Standing Committee of the National People's Congress, the implementation of the construction of a strong maritime country, and the adaptation to the reform of the ocean governance system. Compared with the previous Marine Environmental Protection Law, the improvements of the newly revised law are mainly reflected in the following: optimizing the institutional mechanism, reflecting the Land and Sea Coordination, strengthening supervision and management, strengthening marine litter pollution prevention and control, enhancing the protection of marine biodiversity, strengthening the regulation of estuaries, and strict liability.

KEYWORDS

marine environment protection, the Marine Environment Protection Law, law revision, legal review, background, improvement

1 Introduction

The seas play an important role in the world's economic activities as providers of food, transport and recreation for the global human community (Leous and Parry, 2005). The issue of marine ecosystem protection has been one of the topics of great concern to the international community. Coastal and marine ecosystems around the world have seriously deteriorated and are heavily polluted (Puthucherril, 2015). The escalating global environmental threats have led to increased environmental awareness around the world (McCreath, 2021). The seas are mobile, and marine pollution is transboundary, so states

should conduct their maritime activities in such a way as to safeguard the interests of all humanity and environmental security (Redgwell, 2015). China is a large maritime country, claiming a total area of about 3,000,000 square kilometers of sea under its jurisdiction, with more than 18,000 kilometers of mainland coastline and 14,000 kilometers of island coastline, and possessing most of the ecosystem types of the world's seas. With the rough and high-speed growth of the economy, China is facing various environmental problems, and the contradiction between the demand for sea use and the supply of limited marine resources is becoming more and more prominent (Jiang et al., 2020; Yue et al., 2023). In the course of China's development and use of the oceans, it has not fully understood the importance of protecting the marine environment, and its management efforts have been ineffective, resulting in the pollution and destruction of China's marine environment (Ma and Chen, 1986). Marine pollution comes mainly from dumping, ships and seabed activities (Fabra, 2021). More than 80% of the major pollutants in China's nearshore and offshore waters come from land-based sources (The Central People's Government, 2006). Although the relevant departments of the state have taken many measures to prevent and control pollution of the marine environment, the situation of the marine ecosystem in China is still unsatisfactory (Jiang and Li, 2021).

Compared to other Asian countries, China introduced modern legal concepts of environmental protection relatively late, although there are clear signs of a budding environmental consciousness in Chinese culture (Ross and Silk, 1987). In the last four decades, China has witnessed phenomenal economic growth, making it a world economic power. But environmental and social costs have not been sufficiently mitigated. China never paid much attention to pollution in the early days. It was not until 1972 that they attended the United Nations Conference on the Human Environment (Agarwala, 2022). It was not until 1982 that China enacted *the Marine Environmental Protection Law* (*MEPL*). The *MEPL* is a branch of environmental protection law that regulates the legal norms governing the social relations that occur in human activities of utilizing and protecting the marine environment. It serves as the basis for the conduct of marine environmental protection. The *MEPL* was formulated on the basis of summarizing China's experience in the management of the marine environment, taking into account the successful experience of other countries and the relevant provisions of international maritime law (Ma and Chen, 1986). The *MEPL* has undergone two revisions and three amendments, but there have been no major changes in the basic concept, overall structure, institutional logic and adjustment mechanism of the law. It has only been revised to varying degrees to adapt to the international and domestic development of the marine environment at different times and to harmonize relevant legislation.

The relationship between global ocean governance and ocean policy is that each country's ocean policy is an element of ocean governance. Global ocean governance includes shipping safety and security, environmental protection, spatial planning, integrated ocean management, etc. In order to further promote the cause of marine environmental protection and enhance its capacity in global ocean governance, China should strengthen its domestic legislation on marine environmental protection and adopt sustainable development initiatives, in addition to acceding to international conventions related to marine environmental protection (Butt and Zulfiqar, 2023). The enforcement inspection of marine environmental protection carried out by the Standing Committee of the National People's Congress (NPCSC) in 2018 pointed out that China's localized near-shore waters are seriously polluted, the situation of the marine ecosystem is grim, and the process of amending the *MEPL* should be initiated as soon as possible, since the issues accumulated and challenges faced by the *MEPL* over the years of its implementation can no longer be solved by minor amendments (Mei, 2023). The importance of legislators, the confusion of law enforcers, and the helplessness of law-abiding people (Deng, 2023, p. 1), coupled with the impetus of global ocean governance and international pressure, have combined to put the revision of the *MEPL* on the agenda. In 2023, the 6th session of the 14th NPCSC voted to adopt the revised *MEPL* (*MEPL2023*), which was implemented on 1 January 2024. The main objective of this amendment is to implement the achievements of China's ecological civilization system reform and to establish a complete legal system for marine environmental protection, with the functions and effects of strengthening the Land and Sea Coordination (LSC), perfecting the governance system, implementing the legal responsibility and optimizing the connection of the system as the main objectives.

This paper first reviews the laws related to marine environmental protection in China and the previous revisions of the *MEPL* and then analyses the background to the revision of *MEPL2023*. Finally, it focuses on summarizing the improvements and highlights of *MEPL2023*, and briefly raises the unresolved issues in *MEPL2023*.

2 Legal review

China's legislative work on marine environmental protection started relatively late, and the *MEPL* was not enacted until 1982. As China's opening to the outside world continues, it has sacrificed the environment for rapid economic development, and marine environmental problems have become increasingly prominent. Legislation on marine environmental protection has been prioritized and made significant progress (Zhu, 2016, p. 15).

2.1 Laws enacted by China relating to marine environmental protection

Paragraph 1 of Article 26 of the *Constitution* states, "The state shall protect and improve living environments and the ecological environment, and prevent and control pollution and other public hazards." This provision is the constitutional basis for the generation of China's legal system for marine environmental protection and provides a constitutional basis for developing and improving the *MEPL*. In accordance with the *Constitution*, China enacted the *Environmental Protection Law* (*EPL*) in 1989, which is the basis for environmental protection laws, as well as important legislation for environmental protection in China (Li and Xv, 2006,

p. 78). It provides an important directional guideline and systematic safeguard for marine environmental protection.

Compared with the *Constitution* and the *EPL*, the *MEPL* has a more notable position in China's legal system for marine environmental protection. In 1974, China promulgated the *Interim Provisions on the Prevention of Pollution in Coastal Waters*, which was the first normative legal document on marine environmental protection in China and opened the prelude to the era of the rule of law for marine environmental protection in China (Li, 2019). On 23 August 1982, the 24th session of the 5th NPCSC passed the *MEPL*, which entered into force on 1 March 1983, focusing on the legal regime and penalties related to the pollution and damage to the marine environment caused by the five primary sources of pollution (coastal engineering, offshore petroleum exploration and development, land-based pollutants, ships, and dumping of waste). The promulgation of the *MEPL* demonstrates the unprecedented importance that the state attaches to the protection of the marine environment and establishes basic guidelines and policies for the protection and improvement of the marine environment, the maintenance of the ecological balance, the protection of marine resources, the prevention and control of pollution, the promotion of sustainable economic and social development, and the safeguarding of human health (Qv and Qv, 2014, p. 20). It is an epoch-making milestone for China's marine environmental protection, bringing China's marine environmental protection to the rule of law.

In the field of maritime legislation, a legal system has been formed based on the *MEPL*, supplemented by administrative regulations such as the *Regulation on the Prevention and Control of Vessel-induced Pollution to the Marine Environment* (Xing et al., 2022). With the development of the cause of marine environmental protection and the gradual improvement of the rule of law on marine environmental protection, China's marine environmental protection has formed a legal system based on the *Constitution*, with the *EPL* as the overarching principle, the *MEPL* as the core, and the various laws on the protection of marine elements (Ma and Dong, 2007). (see Table 1)

In the area of marine environmental protection, in addition to enacting laws, China has issued many policies and documents. The *Rio Declaration on Environment and Development* and *Agenda 21* put forward the concept of sustainable development. China fully endorses and accepts this innovative concept and has put forward relevant goals and requirements in *China Agenda 21* in 1994, *China Ocean Agenda 21* in 1996, and the *White Paper on the Development of China's Marine Programs* in 1998 (Zhang, 2020).

TABLE 1 Laws Related to Marine Environmental Protection in China.

Law Type	Law Name
Basic Law	Constitution (Amendment 2018)
Environmental Protection	Law on the Prevention and Control of Environment Pollution Caused by Solid Wastes (2020 Revision) Law on Environmental Impact Assessment (Amendment 2018) Water Pollution Prevention and Control Law (Amendment 2017) Environmental Protection Law (2014 Revision)
Sea-related	Marine Environmental Protection Law (2023 Revision) Maritime Traffic Safety Law (Amendment 2017) Law on the Exploration and Development of Resources in Deep Seabed Areas (2016) Law on the Administration of Sea Areas (2001)
Water-related	Law on Ports (Amendment 2018) Water Law (Amendment 2016) Law on Flood Control (Amendment 2016) Fisheries Law (Amendment 2013) Island Protection Law (2009) Renewable Energy Law (Amendment 2009)
Others	Criminal Law (Amendment 2023) Wild Animal Conservation Law (2022 Revision) Civil Code (2020) Land Administration Law (Amendment 2019) Circular Economy Promotion Law (Amendment 2018) Agriculture Law (Amendment 2012) Mineral Resources Law (Amendment 2009)

2.2 The *MEPL*: two revisions and three amendments

The 1999 and 2023 revisions to the *MEPL* were major, while two minor and one moderate amendment were made in 2013, 2016, and 2017 (see Table 2). The main reasons for the amendments can be discerned from each amendment's context, primary purpose, and revised content.

2.2.1 1999 Revision

The promulgation of the *MEPL* in 1982 marked the beginning of China's marine environmental work on the track of the rule of law, and its introduction had played a significant role in promoting the construction of the coastal economy and advancing the cause of marine environmental protection. However, with the deepening of China's opening to the outside world, the rapid development of the marine economy and the evolution of the practice of marine environmental protection, the unadaptability of the *MEPL* and the issues exposed during its implementation had become more and more apparent. The reasons for the *MEPL* was manifested in the following: (a) The original *MEPL* was formulated at the early stage of reform and opening up, and due to the limitations in the understanding at that time, there were quite a number of defects in the provisions of the law, such as focusing on the regulation of preventing the damage to the marine environment caused by pollution of a single pollution source from the structure and content, and failing to make clear and specific provisions on the protection of the marine environment in general and the protection of marine ecosystems in particular. (b) With the further establishment and improvement of China's legal system and environmental management, a number of relevant laws had made many new provisions for the protection of the environment, and in the administrative rules and regulations formulated by the State Council (SC) and its relevant departments, a number of new systems and measures relating to the protection of the environment had been added, which were also urgently needed for the protection of the marine environment, and which should

TABLE 2 Different versions of the *MEPL*.

Version	Total Number of Chapters and Articles	Number of Revision	Revised Article
In 1982 (Formulation)	8 Chapters 48 Articles		
In 1999 (Revision)	10 Chapters 97 Articles	all articles	Articles 8, 17, 30, 31, 33, 34, 41, 42, 46, and 47 deleted. Other articles revised.
In 2013 (Amendment)	10 Chapters 98 Articles	3 articles	Articles 43, 54, and 80 revised.
In 2016 (Amendment)	10 Chapters 97 Articles	19 articles	Articles 3, 6, 7, 11, 12, 24, 32, 43, 44, 47, 48, 70, 73, 80, 83, 91, and 93 revised. Articles 12 and 78 deleted.
In 2017 (Amendment)	10 Chapters 97 Articles	2 articles	Articles 30 and 77 revised.
In 2023 (Revision)	9 Chapters 124 Articles	116 articles	Articles 27, 35, 41, 53, 65, 91, 95, and 96 retained. Other articles revised.

be recognized as such in the form of a law. (c) Since the implementation of the *MEPL*, China had successively ratified and acceded to several international conventions and protocols, especially after China ratified and acceded to the *United Nations Convention on the Law of the Sea* in 1996, and China's rights and obligations in international marine affairs had changed. (d) From the perspective of the overall state of China's marine environment, due to the large amount of urban sewage and industrial and agricultural wastewater discharged into the sea, the frequency of marine environmental disasters had continued to increase, together with other activities that seriously damage the marine environment, resulting in increasing pollution and damage to China's marine environment, the destruction of the primary conditions of marine resources, and the expansion of the polluted areas outwards, with the scope of the pollution expanding (Zhai, 2000).

In order to protect and improve the marine environment, maintain the ecological balance, conserve marine resources, and promote sustainable economic and social development, it was essential to amend the *MEPL*. The 1999 version of *MEPL* was a major revision, with all the articles were revised, and the total number of articles increased from 34 to 98. Supervision and management of the marine environment and protection of marine ecology, were added, and the original chapter on preventing pollution and damage to the marine environment from marine petroleum exploration and exploitation was expanded to preventing pollution and damage to the marine environment from marine engineering construction projects and almost all the articles of the entire law were amended.

2.2.2 2013 Amendment

In 2013, the SC decided to cancel and delegate a number of administrative approval projects and other matters. The reason for this minor revision of the *MEPL* was to implement the 2013 decision of the SC. Only Articles 43, 54, and 80 were amended, which mainly involved simplifying the procedures for reviewing and approving the environmental impact report and changing the competent authority's approval of the preparation of the oil spill contingency plan for the exploration and development of marine petroleum from approval to filing it with the maritime zones authority.

Article 43 stipulated that the environmental impact report may be approved by the administrative department for environmental protection only after being reviewed by the administrative department for marine affairs. Considering that the environmental impact report was carried out by the administrative department for environmental protection, changing the front-end examination of the administrative department for marine affairs to an internal consultation in the examination and approval process of the administrative department for environmental protection could also play the role of the administrative department for marine affairs, which was conducive to the convenience of the relative administrative management and improvement of the efficiency of the administrative examination and approval. The *MEPL* canceled the marine administrative department's front-end examination and approval procedure. At the same time, Article 80 on legal liability had been amended accordingly.

Article 54 stated, "For the exploration and development of offshore oil, and oil spill contingency plan must be prepared as legally required and submitted to the local sea area office of the state oceanic administrative department for recordation." In practice, the oil spill contingency plan mainly included three aspects: platform operation situation and environmental resource situation of the sea area, oil spill risk analysis, and oil spill contingency capacity. Considering that these contents had already been examined in another approval implemented by the environmental impact report and that emergency drills, exercises, and training should also be verified during the acceptance of the project, the same effect could be achieved by filing the plan and strengthening the responsibility of corporate environmental protection, the *MEPL* canceled the approval of the oil spill contingency plan and replaced it with the record management (The National People's Congress, 2013).

2.2.3 2016 Amendment

In 2012, the 18th CPC National Congress incorporated the construction of ecological civilization into the "five-in-one" overall layout of socialist modernization, emphasizing respect for nature, conformity to nature and protection of nature, and also pointing out the need to continue to simplify and decentralize government and improve administrative efficiency (Hu, 2012). The Chinese government had put forward new requirements for protecting the marine ecological environment, such as establishing a system of ecological protection red line, compensation for ecological protection, and main functional zones, which must be reflected in

the *MEPL* (The SOA, 2017a). The protection of the marine ecological environment was an important part of the construction of ecological civilization, and ruling the sea according to the law was the proper meaning of comprehensively implementing the rule of law. How to use the rule of law to change the mode of economic development, take care of the blue water and the blue sky, and build a beautiful ocean had become a concern of the public and an issue that China must solve. The reason for this amendment to the *MEPL* was to implement the requirements of the 18th CPC National Congress, to adapt to the new situation of building an ecological civilization, and to implement the new concept of ruling the sea in accordance with the law, to carry out the optimization of the administrative approval process, and to coordinate with the revised *EPL* in 2014.

The *Decision to Amend the MEPL* was adopted at the 24th session of the 12th NPCSC on 7 November 2016, amending 19 articles of the *MEPL*, focusing mainly on three aspects: (a) It implemented the new arrangements and requirements made by the CPC Central Committee and the SC on the promotion of ecological civilization and ecological civilization system reform. (b) It promoted the SC's reform on simplifying government, decentralization of power, a combination of management and optimization of services, cancellation of a portion of the administrative approval matters, and optimization of the administrative approval procedures. (c) It was in conjunction with the newly amended *EPL* in 2014, strengthening legal responsibilities and increasing the penalties for illegal acts (The SOA, 2017b, pp. 1-7).

2.2.4 2017 Amendment

The 2017 version of the *MEPL* amended Articles 30 and 77. The reason for this amendment was to further optimize administrative approval process, primarily in relation to sea outfalls, simplifying the approval procedure for the establishment of sea outfalls to a record procedure and modifying the notification procedure and penalty provisions accordingly. Paragraph 1 of Article 30 was amended to read, "Any outlets for discharging pollutants into the sea shall be sited in accordance with marine functional zoning plans, marine dynamic conditions and relevant provisions, and shall, after scientific demonstration, be reported to the environmental protection administrative department of the people's government at or above the level of a districted city for recordation." Paragraph 2 was amended to read, "The environmental protection administrative department shall, within 15 working days after completing recordation, notify the information on the setup of the outlets for discharging pollutants into the sea to the oceanic, maritime and fishery administrative departments and environmental protection departments of armed forces." At the same time, Article 77 added the following: "where the oceanic, maritime or fishery administrative department or environmental protection department of armed forces finds that the setup of an outlet for discharging pollutants into the sea violates the provision of Paragraph 1 or 3 of Article 30 of this Law, it shall notify the environmental protection administrative department to punish the violator in accordance with the provisions of the preceding paragraph."

3 Background to the revision of *MEPL2023*

3.1 The 2018 supervision and inspection of the enforcement inspection team of the NPCSC

The 13th NPCSC set up a law enforcement inspection group to implement the *MEPL* and conducted the supervision and inspection of the implementation of the *MEPL* in 2018. On 24 December 2018, at the 7th session of the 13th NPCSC, the law enforcement inspection group presented a Report on the MEPL implementation inspection (hereinafter referred to as *Report*) (The National People's Congress, 2018a). While affirming the achievements of China's marine environmental protection work over the years in accordance with the law, the *Report* pointed out that the pollution of China's nearshore local waters is relatively severe. The situation of the marine ecological environment is still grim, facing the following issues: prominent issues in the setting and management of outfalls into the sea, insufficient efforts to prevent and control land-based pollution, inadequate implementation of pollution prevention and control measures at sea, relative lagging in the protection and restoration of marine ecosystems, inadequate implementation of the system of supervision and management of the marine environment, scientific and technological support that needs to be strengthened, and imperfections in laws and regulations for the protection of marine ecosystems (The National People's Congress, 2018b). Several bays across the country are seriously polluted, the rate of natural shoreline retention on the mainland is low, and nearly half of the coastal zone is overloaded with resources and the environment. The issue of ecosystem destruction and degradation in some areas is relatively severe, especially the destruction of mangrove forests, coral reefs, coastal wetlands, and other critical habitats, which is particularly obvious, and ecological disasters are frequent and recurrent, mainly red tides and green tides. Environmental risks continue to increase, with incidents such as oil spills and leakage of hazardous chemicals (Sun, 2023).

The reasons for the imperfections in marine ecological environmental protection laws and regulations are manifold. Articles 3, 30, and 56 of the *MEPL* require the establishment of a system for controlling the total amount of pollution discharged into the sea from key areas, specific measures for offshore pollutant discharge outlets, and a catalog of ocean-dumped debris, which have not yet been issued. The *Administrative Regulations on the Prevention and Control of Pollution Damage to the Marine Environment by Land-sourced Pollutants* was formulated in 1990, making it difficult to adapt to the current management needs. Some provisions of local laws, regulations or normative documents of several provinces are inconsistent with the relevant provisions of higher laws, and there are issues such as illegal and irregular delegation of approval rights. There is a general call to amend the *MEPL* as soon as possible (The National People's Congress, 2018a). The *Report* addresses the issues in the laws and regulations on marine ecological environmental protection. It proposes that the strictest legal system protects the marine ecological environment.

The *MEPL* should be amended as soon as possible and should do an excellent job of linking up with the *Water Pollution Prevention and Control Law* and the *Law on the Prevention and Control of Environment Pollution Caused by Solid Wastes*; it should be refined and enriched to include legal systems for the joint prevention and control of critical areas; it should strengthen the prevention and control measures for land-based discharges, seawater aquaculture, and pollution control measures for ships; it should clarify the legal liability of the relevant departments; and it should increase the penalties for violations of laws and regulations (The National People's Congress, 2018a).

3.2 The need to build China into a strong maritime country

The oceans are the cradle of life, the treasure trove of resources, and the lifeblood of transport. Protecting the marine ecosystem must be the fundamental requirement and basic guarantee for constructing a strong maritime country and achieving harmonious coexistence between humans and the sea. Since the 18th CPC National Congress, China has accelerated the construction of the marine industry and increased its efforts to protect the marine environment and has made a series of major deployments to construction a strong maritime country. The report of the 18th CPC National Congress proposed that China should improve the capacity for marine development and the protection of marine ecosystems while developing the seas, and build China into a maritime power (Hu, 2012). The report of the 19th CPC National Congress explicitly proposed that China will promote the supporting role of marine science and technology in the development of marine resources and environmental protection, and build China into a strong maritime country (Xi, 2017). The report of the 20th CPC National Congress further emphasized that China will enhance its ability to safeguard maritime rights and interests, participate deeply in global maritime governance and build China into a strong maritime country (Xi, 2022). To accelerate the construction of a strong maritime country, it is necessary to deepen the theoretical study of marine legislation, improve the scientific nature of marine legislation, and improve the marine legal system from the top-level design level. It is necessary to speed up the revision of the *MEPL*, enhance the coordination and articulation between different marine legislation, strengthen the operability of the law, and bring the legal system closer to the requirements of the times and the objective needs of China's development of its marine cause, so as to provide a legal basis for safeguarding the country's maritime rights and interests (Zhang, 2023).

3.3 Adapting to the SC institutional reform in ocean governance

After the 2018 reform, the responsibilities of the State Oceanic Administration (SOA) were fulfilled by the newly formed Ministry of Ecology and Environment and Ministry of Natural Resources. The Ministry of Ecology and Environment, as the competent authority for marine environmental management and protection, is responsible for national marine ecological environmental protection and supervision. The Ministry of Natural Resources is responsible for marine economy and planning, protection of maritime rights and interests, and development and utilization of islands (Zhang and Chang, 2022). There is still a certain degree of cross-over of responsibilities between the two ministries in actual work, such as the investigation and research of marine resources and the exploration and development process, which will involve marine ecological environmental protection work. At the same time, there are duplication issues between the two ministries in terms of the building of marine professional teams, the technical capacity for marine ecological environment observation and monitoring, and the construction, use, and management of marine survey equipment (Zhang, 2020).

In addition, in accordance with the *Deepen Reform of Party and State Institutions*, China has established a unified maritime law enforcement agency and retained specialized law enforcement departments to build a professional environmental management team (Xing et al., 2022). The structure of the Coast Guard has also changed, from being under the leadership of the SOA to the People's Armed Police Force of China (Liu and Hu, 2024). This reform has led to significant changes in the regulatory and enforcement regime for marine dumping, particularly the separation of licensing and enforcement powers. At the same time, in order to better coordinate national and local marine law enforcement, comprehensive marine law enforcement teams have been set up in coastal areas. The Ministry of Ecology and Environment has established three new ecological and environmental regulatory agencies for watershed marine areas (Miao and Liu, 2023). As a result of the institutional reform, the functions of the SOA have been reconsolidated, and it is unclear how the *Provisions for the Supervision and Administration of the Marine Red Line*, which were originally drafted by the SOA in 2018, will be implemented (Zou and Wang, 2019). Therefore, revising the *MEPL* will help to clarify further the responsibilities of various law enforcement departments and the supervision of marine red lines.

4 Improvements of *MEPL2023*

4.1 Optimizing institutional mechanisms

The establishment of a modernized marine environmental management system must begin with a clear definition of the relationship between the main subjects of marine environmental management (Chen et al., 2021). *MEPL2023* not only provides legal safeguards for China's management system and mechanism for marine ecological environmental protection, which has undergone significant changes, but also adheres to an issue-oriented approach, focusing on the main contradictions, special issues, and outstanding features of marine environmental protection, and establishes and improves the relevant system to improve the quality of the marine environment (Miao and Liu, 2023). According to the *Deepen Reform of Party and State Institutions*, *MEPL2023* specifies the

division of responsibilities among the competent departments of the SC in charge of ecological and environmental, natural resources, transport, fishery, as well as the departments of development and reform, forestry and grasslands, housing and urban-rural development, water administration. It specifies the marine environmental protection duties of the coast guard agency in accordance with China's Coast Guard Law.[1] (see Table 3)

MEPL2023 stipulates that coastal governments are responsible for the quality of the marine environment in the areas under their jurisdiction, and emphasizes that the state has implemented a target responsibility system for the protection of the marine environment, as well as an assessment and evaluation system.[2] It specifies that coastal governments may establish regional cooperation mechanisms for marine environmental protection, and that cross-regional marine environmental protection work shall be determined by higher-level governments. The Ministry of Ecology and Environment shall be responsible for the coordination of major trans-departmental marine environmental protection work. Where coordination fails, the above work shall be determined by the SC.[3] The Ministry of Ecology and Environment, in conjunction with relevant units, shall formulate a national plan for the protection of marine ecological environment;[4] in conjunction with the relevant departments, delineate the national environmental governance priority sea areas and their control areas, and formulate an action plan for comprehensive governance;[5] in conjunction with the natural resources department of the SC, prepare a national ocean dumping area plan, request comments from the transport, fishery, other departments of the SC and coast guard agencies[6].

4.2 Reflecting LSC

The land and the sea are two ecosystems that influence and constrain each other. Marine environmental issues manifest in the sea and have their roots on land. Land-based activities are the main cause of marine pollution, including intensive human settlement of coastal areas (Fabra, 2021). There has long been a relatively serious disconnect and lack of coordination between China's land-based ecological environmental protection and its marine ecological protection, which has led to a certain extent to several contradictions in the overall ecological environmental protection and effects of ecological environmental protection, and the deterioration of the marine ecological environment (Li, 2021).

China Ocean Agenda 21 proposed integrating land development planning for coastal land areas and marine areas based on the strategy of integrating land and sea (Gu et al., 2023). The concept of LSC was introduced at the beginning of the century; LSC centers on the relationship between land and sea (Yuan and Chang, 2021; Yue et al., 2023). The essence of LSC lies in "transforming the land and the sea, as well as the various elements within the land and the sea, from disorder to order, from dysfunction to harmony, and in the articulation and benign interaction of all aspects" (Li et al., 2016). LSC governance is one of the prominent features of the regional structure of modern marine environmental governance in China (Chen et al., 2021). Article 60 of the *Yangtze River Protection Law* and Article 8 of the *Coast Guard Law* contain requirements for LSC.

MEPL2023 has added provisions on the principles of marine environment protection, including the principle of LSC.[7] Compared with the previous *MEPL*, the principle of LSC is a new element, which strengthens the position of *MEPL2023* as the basic law for marine environmental protection to integrate land and sea environmental protection. *MEPL2023* no longer distinguishes between the two but rather unifies the supervision and management of the marine environment under the competent ecological and environmental authorities, an adjustment that aligns with the spirit of the SC institutional reform and the requirement of LSC.[8] China is implementing an LSC system for the supervision and management of the marine environment and its articulation and coordination.[9] These are not covered in the previous *MEPL*, and this new provision indicates the direction of the system for the supervision and management of the marine environment (Li and Cheng, 2023). *MEPL2023* puts forward the requirements for the coordination and unity of the land and sea planning system,[10] stipulates the requirements for the protection of marine biodiversity in the development and utilization of marine and coastal zone resources,[11] of which the provisions on coastal zones were not deployed in the previous *MEPL*, which also reflects the importance attached by *MEPL2023* to the ecological protection of the transitional space between the land and the sea.

4.3 Strengthening supervision and management

With the rapid population growth in China's coastal areas, the marine environment is facing serious challenges and problems, and an effective marine management system must be established in order to coordinate the protection and development of marine resources and to achieve the harmonious development of mankind and the seas (Teng et al., 2021). Compared with the

1 Article 4 of *MEPL2023*.

2 Article 5 of *MEPL2023*.

3 Article 6 of *MEPL2023*.

4 Article 14 of *MEPL2023*.

5 Article 20 of *MEPL2023*.

6 Article 73 of *MEPL2023*.

7 Article 3 of *MEPL2023*.

8 Article 4 of *MEPL2023*.

9 Article 12 of *MEPL2023*.

10 Articles 13, 14, and 15 of *MEPL2023*.

11 Article 36 of *MEPL2023*.

TABLE 3 Responsibilities for marine environmental protection by department.

Department	Responsibility
Ministry of Ecology and Environment	It is responsible for the supervision and administration of the national marine environment, for the environmental protection in relation to nation-wide prevention and control of marine environmental pollution damage caused by land-based pollutants, coastal and marine construction projects, and wastes dumped into the sea, and for guidance on, coordination of, and supervision of national marine ecological protection and repair.
Ministry of Natural Resources	It is responsible for the supervision and administration of marine protection, development, and utilization and for the repair of national marine ecology, coastlines, and islands.
Ministry of Transport	It is responsible for the supervision and administration of the pollution to the marine environment caused by nonmilitary vessels inside the harbor waters under its jurisdiction and that caused by non-fishing vessels and non-military vessels outside the harbor waters under its jurisdiction and organizing, coordinating, and directing contingency response to major marine oil spills. It is specifically responsible for the supervision and administration of the marine environmental pollution caused by vessels in the above waters and for investigating and handling pollution accidents. In the event of a pollution accident caused by a foreign vessel navigating, berthing or operating in the sea under the jurisdiction of China, inspection and treatment shall be conducted on board the vessel in question.
Ministry of Water Resources	It is responsible for investigating and dealing with major water-related offenses, coordinating and arbitrating cross-provincial water disputes, and guiding water supervision and water administrative law enforcement. Guiding the management, protection and comprehensive utilization of water conservancy facilities, waters and their shorelines.
Ministry of Agriculture and Rural Affairs	It is responsible for the supervision and control over the marine environment pollution caused by non-military vessels inside the fishing port waters and that caused by fishing vessels outside the fishing port waters. It is also responsible for the protection of the ecological environment in the fishing zones, and shall investigate and handle the fishery pollution accidents other than those specified in the preceding paragraph.
National Development and Reform Commission	Promoting the implementation of sustainable development strategies, promoting the construction and reform of ecological civilization, and coordinating the protection and restoration of the ecological environment and the conservation and comprehensive use of energy and resources.
The Coast Guard agency	It shall conduct the supervisory inspection of marine construction projects, pollution damage caused to the marine environment by wastes dumped into the sea, and the protection and utilization of the seaward side of the coastline of nature reserves, and other activities within the scope of its duties, investigating and punishing violations, and participating in the contingency response to and investigation and handling of marine environmental pollution accidents in accordance with the prescribed authority.
People's Liberation Army	It is responsible for the supervision and control over the marine pollution caused by military vessels and for the investigation and handling of the pollution accidents caused by military vessels.

previous *MEPL*, *MEPL2023* presses down on departmental and local responsibilities, clarifies the labor, and strengthens the duties of relevant departments.[12] Relevant national and local units should enhance the monitoring and sharing of information on the management of the marine environment in accordance with applicable regulations.[13] Coastal governments are responsible for the quality of the marine environment in the areas under their jurisdiction. China should implement an assessment and evaluation system and a target responsibility system for marine environmental protection to enhance the level of supervision and management of the marine environment. The duties of local governments include the protection and rational use of sea areas, the supervision and management of human-related marine activities, and the assessment of the effectiveness of protection; according to the national marine ecological environmental protection planning, they organize the marine environmental protection work in the sea area under their jurisdiction; and governments will not approve additional environmental impact reports for construction projects in sea areas where the targets for marine environmental protection have not been met, and will interview the main person in charge of the sea areas and require them to carry out timely rectification.[14]

MEPL2023 values the guiding role of marine ecological environmental protection planning and strengthens the articulation and coordination of supervision and management systems. Governments should improve their capacity for the supervision and management of the marine environment through the adoption of high-technology measures.[15] *MEPL2023* strengthens the supervision during and after the incident and adds provisions such as the installation and use of online monitoring equipment for ocean dumping, as well as strengthens the reporting system for dumping operations so as to improve the effectiveness of supervision.[16] For the public, access to information on the marine environment is not yet sufficiently smooth and convenient (Zou and Wang, 2019). *MEPL2023* increases the system of the zone-based ecological and environmental management and control, comprehensive treatment of key sea areas, interview and correction, information sharing, credit evaluation, sequestration, or impoundment. At the same time, *MEPL2023* improves the systems of planning, standards,

12 Article 23 of *MEPL2023*.

13 Article 25 of *MEPL2023*.

14 Articles 5, 13, 14, and 18 of *MEPL2023*.

15 Article 12 of *MEPL2023*.

16 Articles 75 and 76 of *MEPL2023*.

monitoring, early warning, investigation, environmental impact assessment, and contingency response (The Central People's Government, 2023).

4.4 Strengthening marine litter pollution prevention and control

Marine ecosystems determine the maintenance and development of the entire Earth's life system. Human activities and climate change are the main causes of the deterioration of the global marine environment (Wang, 2021). "Pollution of the marine environment" means the discharge of substances into the sea by human beings, resulting in hazards to marine life and resources, which in turn pose a threat to human health.[17] Marine litter is one of the marine pollution issues that people feel most directly and reflect most strongly (Sheavly and Register, 2007). The prevention and control of marine litter pollution is an issue of widespread concern to the international community. China's marine environment is seriously polluted, and as far as marine plastics are concerned, China, as the world's largest producer and consumer of plastics, is one of the largest contributors to marine plastic pollution worldwide (Fürst and Feng, 2022). This does not match China's status as an active participant in global ocean governance.

Compared with the previous *MEPL*, *MEPL2023* provides that coastal governments are responsible for the prevention and control of marine litter pollution in the sea areas under their jurisdiction, establish a system for monitoring and cleaning up marine litter, coordinate the planning and construction of land-based facilities for receiving, transferring, and treating marine litter, specify the areas for management and control of marine litter by relevant departments, townships, towns, sub-districts, enterprises, and public organizations, among others, establish and organize the implementation of a system for monitoring, intercepting, collecting, removing, transporting, and treating marine litter.[18] These provisions reflect a systematic approach to governance, with multiple links and initiatives to curb the amount of marine debris entering the sea, and the interception, collection and removal of debris that has already entered the sea and its disposal on land, forming a closed loop for the integrated management of marine debris on land and at sea.

The regulation of marine waste dumping is significant for the coordination of high-quality development protection and marine ecological environmental of the oceans. *MEPL2023* addresses the outstanding issues in the regulation of marine waste dumping, combines domestic practical experience with international compliance achievements, improves the approval and management system, optimizes the access and layout of construction projects, strengthens the regulation of marine sand mining, optimizes the approval level of marine waste dumping permits, and improves the monitoring and reporting of dumping operations, and strengthens source management of waste.[19] *MEPL2023* explicitly prohibits discarding, placing, and treating solid wastes on a beach, and effective measures shall be taken to prevent the solid wastes from entering the sea.[20] An important requirement for the protection of ecological civilization is to raise people's awareness of marine protection (Jiang et al., 2020). *MEPL2023* requires effective measures to encourage and support public participation in activities related to the prevention and control of marine litter pollution.[21] *MEPL2023* makes provisions for strengthening the prevention and control of vessel pollution. It adds provisions on the control of vessel ballast water and sediment discharge, pollution prevention and control of vessel dismantling, green low-carbon smart shipping, and control areas for the discharge of pollutants from vessels. It also requires that monitoring and surveillance to be carried out according to the relevant regulations when carrying out activities involving the discharge of vessel pollutants, ballast water and sediment, and operations, and that a multi-departmental regulatory system for the reception, transfer, treatment, and disposal of ship vessels be established.[22] *MEPL2023* attaches importance to preventing and controlling marine sand mining. Mining of sea sand within the strictly protected shoreline is prohibited, and the development and utilization of sea sand resources in other areas in accordance with the law shall take strict measures to protect the marine environment. Carrying sea sand resources shall hold a legal source certificate, and those who violate the law shall be ordered to make corrections and be fined.[23]

4.5 Enhancing the protection of marine biodiversity

Marine biodiversity is an important foundation for human survival and sustainable development, with functions of resource supply, climate regulation, and cultural services (Li and Pang, 2024). Humans are having an increasing impact on the abundance and diversity of marine life, and inappropriate human uses of the seas are leading to the extinction or near-extinction of an increasing number of species (Lotze, 2021). Overloading of marine life will alter ecosystems, reduce biodiversity and lead to continued deterioration or even collapse of ecosystems (Crain et al., 2009). As people's understanding of the harmonious coexistence of mankind and the seas gradually increases, the protection of biodiversity is also receiving more and more attention from the theoretical and practical sectors (Selig et al., 2014).

Marine biodiversity plays a vital role in maintaining healthy marine ecosystems. Although the *National Biodiversity Strategy and*

17 Article 1(4) of the *United Nations Convention on the Law of the Sea*.

18 Article 57 of *MEPL2023*.

19 Chapter VI of *MEPL2023*.

20 Article 56 of *MEPL2023*.

21 Article 57 of *MEPL2023*.

22 Chapter VII of *MEPL2023*.

23 Articles 64 and 97 of *MEPL2023*.

Action Plan 2011–2030 contains relevant policy measures on marine biodiversity and provides a general framework for marine biodiversity conservation, China still lacks comprehensive marine biodiversity law (Wang and Zou, 2020). China is one of the wealthiest countries in terms of biodiversity globally and one of the countries where biodiversity is most seriously threatened (Zhang et al., 2022). However, the previous *MEPL* did not have provisions on marine biodiversity protection. Therefore, *MEPL2023* stipulates that "the state strengthens the protection of marine biodiversity, improves the survey, monitoring, assessment, and protection system for marine biodiversity, maintains and repairs important marine ecological corridors, and prevents damage to marine biodiversity. When marine and coastal zone resources are developed and utilized, important marine ecosystems, biological species, and biological genetic resources shall be effectively protected to maintain marine biodiversity. Any introduction of marine animal or plant species shall be subject to scientific assessment so as to avoid damages to marine ecosystems".[24] In addition, *MEPL2023* also provides for the restoration of marine biodiversity and the repair and improvement of marine ecology, and makes it clear that marine ecological repair shall focus on improving habitats and restoring biodiversity and basic ecosystem functions, be based on natural restoration supplemented with artificial repair, and give priority to repairing representative marine ecosystems.[25]

4.6 Strengthening the regulation of estuaries

Marine ecological environment protection should not only focus on the sea but also on the land facing the sea, and estuaries as the link between the sea and the land is bound to become a key factor in the management of marine ecology. The LSC governance pattern must focus on solving the issue of land-based pollution caused by estuaries (Wang and Pei, 2023). The *Report* pointed out that the estuaries set up irregularities, lax supervision, and other issues are more prominent, requiring the development of estuaries filing and management methods, the revision of the *MEPL*, the standardization of estuaries setup, the strengthening of supervision, a comprehensive traceability investigation of estuaries to be carried out, and the found of a file to strengthen the direct discharge of sea pollution sources, clean up and other work (The National People's Congress, 2018a). As far as China's Bohai Sea estuaries are concerned, they are characterized by their large number and wide distribution, the seasonal and intermittent nature of sewage discharge, and the generally weak construction of coastal drainage infrastructure (Xv and Yan, 2023).

In response to the current problems of estuaries and requirements for the *Report*, *MEPL2023* requires compiling data on monitoring, survey, and surveillance of estuaries entering the sea.[26] The relevant departments should determine indicators for strictly controlling the ecological flow of rivers entering the sea and actively take protective measures for the ecological restoration of estuaries.[27] The relevant departments shall coordinate the prevention and control of the pollution of the rivers, so as to ensure that the water quality of river estuaries complies with requirements related to environmental quality of estuaries, strengthen the management and control of total nitrogen and total phosphorus discharge into the sea, and formulate and organize the implementation of a control plan.[28] The entity responsible for an outfall shall strengthen the monitoring of the outfall and conduct surveillance and automated monitoring in accordance with applicable provisions. Coastal local governments shall arrange for relevant departments to investigate, improve, and daily supervise and administer various outfalls within their respective administrative regions, and establish and improve a governance system for nearshore water bodies, marine outfalls, sewers, and pollution sources. The Ministry of Ecology and Environment are responsible for formulating specific measures for the establishment and management of marine outfalls, developing technical specifications for marine outfalls, and organizing the building of a unified information platform for marine outfalls.[29] Legal liabilities will be added for illegal acts such as establishing a marine outfall without recordation and failing to conduct surveillance and automated monitoring in accordance with applicable provisions.[30] In addition, where pollutants are discharged into the sea through an open ditch (gutter), the open ditch (gutter) are subject to water environmental quality management according to relevant local and national provisions and standards.[31] It is prohibited to build industrial outfalls and urban sewage treatment plant's outfalls in natural reserves, important fishery waters, bathing beaches, ecological protection red line areas, and other specially protected areas.[32]

4.7 Strict liability

The previous *MEPL* imposed lighter penalties for marine environmental pollution offences and failed to combat marine violations effectively (Zhang and Chang, 2022). Marine environmental protection should adhere to the principles of sustainable development, prevention as the mainstay, integration of

24 Article 36 of *MEPL2023*.

25 Article 42 of *MEPL2023*.

26 Article 24 of *MEPL2023*.

27 Article 40 of *MEPL2023*.

28 Article 50 of *MEPL2023*.

29 Article 47 of *MEPL2023*.

30 Article 99 of *MEPL2023*.

31 Article 49 of *MEPL2023*.

32 Article 48 of *MEPL2023*.

prevention and treatment, and polluter pays (Dzidzornu, 1998). In formulating laws on environmental protection, it is necessary to clarify the liability and compensation for pollution damage and to increase penalties (Joyner, 1996). *MEPL2023*, in response to the current situation of marine environmental pollution and ecological damage, has increased the number of penalties, increased the severity of penalties, and enriched the ways of counting penalties and the means of imposing them in terms of legal liability, thus preventing or reducing marine environmental pollution and ecological damage and enhancing the deterrent effect of the implementation of the law.

In response to the frequent occurrence of illegal dumping activities at sea and the light penalties for such offenses, *MEPL2023* increases the amount of penalties[33], increases the manner of imposing fines, stipulates fines per area according to the characteristics of damaging marine ecosystems or nature reserves,[34] and increases fines per occasion for individual who discards, places, and treats municipal solid waste on a beach without authorization[35]. *MEPL2023* increases penalties for offenses related to aquaculture and waste dumping activities at sea,[36] adds penalties for offenses of failing to conduct surveillance and automated monitoring in accordance with applicable provisions, conducting production and construction activities violating the ecological and environmental access list, failing to keep a list of harmful materials on board the vessel, to continuously update it when building, operating, and repairing the vessel, or make it available to an entity engaged in vessel dismantling before the vessel is dismantled.[37] A new system of joint and several liability has been added. If the entity that receives permission for the dumping of wastes violates the provisions, it should bear joint and several liability with the agent that causes environmental pollution and ecological damage.[38] *MEPL2023* establishes a marine environmental target responsibility system and assessment and evaluation system.[39] *MEPL2023* introduces the penalty of "restriction".[40] As a preventive administrative penalty, "restriction" is incorporated into the law, which is more in line with the needs of the governance of the risk society and the information society, and it can help to effectively prevent the pollution of the marine environment based on the protection of the rights of the relative to be restricted. It is important to effectively prevent marine environmental pollution and ecological damage (Miao and Liu, 2023).

From the above, it can be seen that *MEPL2023* has overcome many issues of the previous *MEPL* and has made great improvements, but it is not perfect, and there are still some unresolved issues. For example, ocean governance and marine environmental protection require multichannel and multidisciplinary international cooperation (Grip, 2017), and *MEPL2023* does not have sufficient clarity on international cooperation on marine environment protection. In addition, there is a lack of smooth connection with other laws on marine environmental protection. Although *MEPL2023* has provisions for marine ecosystem compensation, its provisions are more general and principled (Wang, 2023). Ecological changes caused by land reclamation and water bodies, although an essential element of marine pollution, are not specified in *MEPL2023*. Marine protected areas (MPAs) are important measures for protecting the marine environment (Boonzaier and Pauly, 2016). The establishment of MPAs is currently a widespread practice in the international community (Guzmán et al., 2023). MPAs have the function of protecting, restoring and maintaining ecosystem resilience, fish stocks, habitat structure and biodiversity diversity (Gjerde, 2007). In contrast, *MEPL2023* has minimal provisions for MPAs.

5 Conclusion

China is a large maritime country with vast seas, long coastlines, numerous islands, abundant resources and diverse ecosystems. It possesses most of the ecosystem types of the world's seas. Marine environmental protection is an integral part of the construction of an ecological civilization and a beautiful China. China's marine environmental protection has formed a legal system with the *MEPL* as the core, along with various marine protection laws and regulations. Although China's marine environmental protection laws are constantly increasing and improving, the level of marine environmental governance has not been significantly improved, and some aspects are even deteriorating. It seems to be a huge and perfect legal system, but there are still many issues. Since its promulgation in 1982, the *MEPL* has undergone two revisions and three amendments. Amending the *MEPL* is of great significance for protecting and improving the marine environment, enabling the people to enjoy better the blue sea, blue sky, and clean beaches, safeguarding ecological security and public health, safeguarding the country's rights and interests in the seas, building a strong maritime country, promoting sustainable economic and social development, and realizing the harmonious coexistence between human and nature.

The 2018 supervision and inspection of the enforcement inspection team of the NPCSC, the implementation of building a strong maritime country, and the adaptation to the reform of the ocean governance system have jointly promoted *MEPL2023*. *MEPL2023* focuses on the outstanding issues of marine ecological environmental protection, summarizes the practical experience of marine ecological environmental protection, and has many institutional innovations and pragmatic and practical initiatives. Compared with the previous *MEPL*, the improvements of *MEPL2023* are mainly reflected in the following: optimizing the institutional mechanism, reflecting LSC, strengthening supervision and management, strengthening marine litter pollution prevention and control, enhancing the protection of marine biodiversity, strengthening the regulation of estuaries, and strict liability. However, no law is permanent and perfect, and *MEPL2023*

33 Articles 93 and 103 of *MEPL2023*.

34 Article 96 of *MEPL2023*.

35 Article 93 of *MEPL2023*.

36 Articles 98 and 106 of *MEPL2023*.

37 Articles 99, 102, and 110 of *MEPL2023*.

38 Article 78 of *MEPL2023*.

39 Article 18 of *MEPL2023*.

40 Articles 106 and 107 of *MEPL2023*.

still has some unresolved issues that need to be further improved at a later stage.

Author contributions

RL: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was funded by China's National Social Sciences Foundation (No.17ZDA146).

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Agarwala, N. (2022). China: Combating environmental degradation. *Int. J. Environ. Stud.* 79, 5. doi: 10.1080/00207233.2021.1974756

Boonzaier, L., and Pauly, D. (2016). Marine protection targets: An updated assessment of global progress. *Oryx* 50, 1. doi: 10.1017/S0030605315000848

Butt, M. J., and Zulfiqar, K. (2023). "The role of China in global ocean governance: A marine environmental perspective," in *Maritime Law Perspectives Old and New*, vol. 2 . Eds. P. K. Mukherjee, J. Xu and M. Q. Mejia Jr. (Nova Science Publishers, New York).

Chen, Q., Yu, H., and Wang, Y. (2021). Research on modern marine environmental governance in China: Subject identification, structural characteristics, and operational mechanisms. *Int. J. Environ. Res. Public Health* 18, 9. doi: 10.3390/ijerph18094485

Crain, C. M., Halpern, B. S., Beck, M. W., and Kappel, C. V. (2009). Understanding and managing human threats to the coastal marine environment. *Ann. N. Y. Acad. Sci.* 1162, 1. doi: 10.1111/j.1749-6632.2009.04496.x

Deng, H. F. (2023). *Exploration of the institutional framework of marine environmental protection legislation* (Beijing: Tsinghua University Press).

Dzidzornu, D. M. (1998). Four principles in marine environment protection: A comparative analysis. *Ocean Dev. Int. Law* 29, 2. doi: 10.1080/00908329809546119

Fabra, A. (2021). "The protection of the marine environment pollution and fisheries," in *The Oxford Handbook of International Environmental Law*, *2nd edn*. Eds. L. Rajamani and J. Peel (Oxford: Oxford University Press). 529–C31.S27. doi: 10.1093/law/9780198849155.003.0031

Fürst, K., and Feng, Y. (2022). China's regulatory respond to plastic pollution: Trends and trajectories. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.982546

Gjerde, K. M. (2007). High seas marine protected areas and deep-sea fishing. *FAO Fish. Rep.* 838, 141–180.

Grip, K. (2017). International marine environmental governance: A review. *Ambio* 46, 4. doi: 10.1007/s13280-016-0847-9

Gu, X. D., Zhao, X. J., and Wang, Y. Q. (2023). The collaborative governance mechanism of watershed and sea areas environment under the principle of Land-Sea coordination—Innovations and prospects of the Marine Environmental Protection Law. *Environ. Prot.* 51, 21.

Guzmán, D. H., Mier, R. L., Vergara, A., and Milanes, C. B. (2023). Marine protected areas in Colombia: A historical review of legal marine protection since the late 1960s to 2023. *Mar. Policy* 155, 105726. doi: 10.1016/j.marpol.2023.105726

Hu, J. T. (2012) *Firmly march on the path of socialism with Chinese characteristics and strive to complete the building of a moderately prosperous society in all respects—Report to the 18th National Congress of the Communist Party of China*. Available online at: https://www.gov.cn/ldhd/2012-11/17/content_2268826.htm (Accessed February 1, 2024).

Jiang, Q., Feng, C., Ding, J., Bartley, E., Lin, Y., Fei, J., et al. (2020). The decade long achievements of China's marine ecological civilization construction, (2006–2016). *J. Environ. Manage.* 272, 111077. doi: 10.1016/j.jenvman.2020.111077

Jiang, S. S., and Li, J. M. (2021). Do political promotion incentive and fiscal incentive of local governments matter for the marine environmental pollution? Evidence from China's coastal areas. *Mar. Policy* 128, 104505. doi: 10.1016/j.marpol.2021.104505

Joyner, C. C. (1996). The 1991 Madrid environmental protection protocol. Contributions to marine pollution law. *Mar. Policy* 20, 3. doi: 10.1016/0308-597X(96)00012-7

Leous, J. P., and Parry, N. B. (2005). Who is responsible for marine debris? The international politics of cleaning our oceans. *J. Int. Aff.*, 257–269.

Li, L. F. (2019). Forty years of rule of law in China's marine environment: Development history, practical dilemmas and legal improvements. *J. Zhejiang Ocean Univ. (Humanities Soc. Sci. Edi.)* 36, 20–28.

Li, Z. P. (2021). Reconstruction of China's legal system of eco-environmental protection from the perspective of land and sea coordination. *Acad. J. Zhongzhou* 6, 46–53.

Li, Z. P., and Cheng, X. Y. (2023). Disscussion on the thorough expression and implementation of "land-sea coordination" in the new Marine Environmental Protection Law. *Environ. Prot.* 51, 21.

Li, J. Y., Li, J. X., and Zhang, C. Y. (2016). Ideas of promoting overall planning for land and marine to the national strategy. *Reg. Econ. Rev.* 3, 29–38.

Li, L. M., and Pang, B. J. (2024). The influencing factors and development strategies of marine biodiversity conservation—Taking the Beibu Gulf of Guangxi as an example. *Environ. Prot.* 52, 2.

Li, Y. Z., and Xv, X. M. (2006). *On the ocean century and marine development strategy of China* (Qingdao: Ocean University of China Press).

Liu, R., and Hu, Z. (2024). Controversies and amendment proposals on the China Coast Guard Law. *Mar. Policy* 163, 106115. doi: 10.1016/j.marpol.2024.106115

Lotze, H. K. (2021). Marine biodiversity conservation. *Curr. Biol.* 31, 19. doi: 10.1016/j.cub.2021.06.084

Ma, X., and Chen, Z. (1986). On the marine environmental protection law. *Chin. Law Gov.* 19, 1. doi: 10.2753/CLG0009-4609190164

Ma, Y. Y., and Dong, Y. J. (2007). On the defects and countermeasures in legal system of marine environment protection in China. *Mar. Sci.* 12, 16–18.

McCreath, M. (2021). Community interests and the protection of the marine environment within national jurisdiction. *Int. Comp. Law Q.* 70, 3. doi: 10.1017/S0020589321000208

Mei, H. (2023). The new revision of Marine Environmental Protection Law: Uphold fundamental principles and break new ground. *Environ. Prot.* 51, 21.

Miao, Z. H., and Liu, H. Y. (2023). Review of the newly revised Marine Environmental Protection Law of the People's Republic of China. *Ocean Dev. Manage.* 40, 12.

Puthucherril, T. G. (2015). Protecting the marine environment: Understanding the role of international environmental law and policy. *J. Indian Law Inst.* 57, 1.

Qv, G. Q., and Qv, B. (2014). *Law of the Sea* (Beijing: Renmin University of China Press).

Redgwell, C. (2015). "Transboundary pollution: Principles, policy and practice," in *Transboundary Pollution*. Eds. E. S. Jayakumar, T. Koh, R. Beckman and H. D. Phan (Cheltenham: Edward Elgar Publishing), 11–35. doi: 10.4337/9781784715793.00009

Ross, L., and Silk, M. A. (1987) *Environmental law and policy in the People's Republic of China*. Available online at: https://www.osti.gov/biblio/6105240 (Accessed November 15, 2023).

Selig, E. R., Turner, W. R., Troëng, S., Wallace, B. P., Halpern, B. S., Kaschner, K., et al. (2014). Global priorities for marine biodiversity conservation. *PloS One* 9, 1. doi: 10.1371/journal.pone.0082898

Sheavly, S. B., and Register, K. M. (2007). Marine debris & plastics: Environmental concerns, sources, impacts and solutions. *J. Polym. Environ.* 15, 301–305. doi: 10.1007/s10924-007-0074-3

Sun, Y. H. (2023). Interpretation on the major changes and contents of the revised Marine Environmental Protection Law of 2023. *Environ. Prot.* 51, 21.

Teng, X., Zhao, Q., Zhang, P., Liu, L., Dong, Y., Hu, H., et al. (2021). Implementing marine functional zoning in China. *Mar. Policy* 132, 103484. doi: 10.1016/j.marpol.2019.02.055

The Central People's Government (2006) *Serious pollution of China's near-shore waters 80% from land-based sources of discharge*. Available online at: https://www.gov.cn/jrzg/2006-10/18/content_417030.htm (Accessed November 26, 2023).

The Central People's Government (2023) *Guarding the blue sea, blue sky and clean beaches with the power of the rule of law—Interpreting the new highlights of the newly revised marine environmental protection law*. Available online at: https://www.gov.cn/yaowen/liebiao/202310/content_6911491.htm (Accessed February 12, 2024).

The National People's Congress (2013) *Decision of the Standing Committee of the National People's Congress on amending seven laws, including the Marine Environmental Protection Law*. Available online at: http://www.npc.gov.cn/zgrdw/npc/xinwen/2013-12/30/content_1821988.htm (Accessed January 6, 2024).

The National People's Congress (2018a) *Report of the law enforcement inspection group of the Standing Committee of the National People's Congress on the inspection of the implementation of the Marine Environmental Protection Law of the People's Republic of China*. Available online at: http://www.npc.gov.cn/zgrdw/npc/zfjc/zfjcelys/2018-12/25/content_2069494.htm (Accessed January 8, 2024).

The National People's Congress (2018b) *Marine Environmental Protection Law enforcement inspection report reveals seven major issues*. Available online at: http://www.npc.gov.cn/zgrdw/npc/cwhhy/13jcwh/2018-12/26/content_2068297.htm (Accessed January 9, 2024).

The SOA (2017a) *Comprehensively establish and implement the marine ecological red line system, and firmly guard the fundamental bottom line of marine ecological security*. Available online at: https://www.gov.cn/xinwen/2016-06/16/content_5082772.htm (Accessed January 10, 2024).

The SOA (2017b). *Interpretation of the amendments to the Marine Environmental Protection Law of the People's Republic of China* (Beijing: China Ocean Press).

Wang, J. (2021). "Chinese law and policy on marine environmental protection," in *Implementation of the United Nations Convention on the Law of the Sea: State practice of China and Japan* (Singapore: Springer), 151–177. doi: 10.1007/978-981-33-6954-2_9

Wang, T. (2023). Problems identification and improvement path of China's marine ecological compensation legal system. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1094912

Wang, Y. W., and Pei, Z. B. (2023). A legal study on the regulation of land-based pollution caused by discharge outlets into the sea on the basis of Marine Environmental Protection Law. *Ocean Dev. Manage.* 40, 8.

Wang, J., and Zou, K. (2020). China's efforts in marine biodiversity conservation: Recent developments in policy and institutional reform. *Int. J. Mar. Coast. Law* 35, 2. doi: 10.1163/15718085-BJA10008

Xi, J. P. (2017) *Secure a decisive victory in building a moderately prosperous society in all respects and strive for the great success of socialism with Chinese characteristics for a new—Delivered at the 19th National Congress of the Communist Party of China*. Available online at: https://www.gov.cn/zhuanti/2017-10/27/content_5234876.htm (Accessed February 3, 2024).

Xi, J. P. (2022) *Hold high the great banner of socialism with Chinese characteristics and strive in unity to build a modern socialist country in all respects—Report to the 20th National Congress of the Communist Party of China*. Available online at: https://www.gov.cn/xinwen/2022-10/25/content_5721685.htm (Accessed February 4, 2024).

Xing, H., Cao, X., and Su, Z. (2022). The rule of law for marine environmental governance in maritime transport: China's experience. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.1083420

Xv, M., and Yan, S. B. (2023). Supervision status and suggestions of effluent outfalls into sea and sewage discharge mixing zone. *Environ. Prot.* 51, 19.

Yuan, W., and Chang, Y. C. (2021). Land and sea coordination: Revisiting integrated coastal management in the context of community interests. *Sustainability* 13, 15. doi: 10.3390/su13158183

Yue, W., Hou, B., Ye, G., and Wang, Z. (2023). China's land-sea coordination practice in territorial spatial planning. *Ocean Coast. Manag.* 237, 106545. doi: 10.1016/j.ocecoaman.2023.106545

Zhai, Y. (2000). Main elements of the revision of the Marine Environment Protection Law. *People Congr. China* 4, 10–14.

Zhang, H. W. (2020). Review and prospect of the development of "Marine Environmental Protection Law of the People's Republic of China". *Environ. Sustain. Dev.* 45, 4.

Zhang, J. Q. (2023). Opportunities and challenges facing China's construction of a strong maritime country. *People Trib.* 20, 26–29.

Zhang, K., and Chang, Y. C. (2022). Daily penalty system under revision of the Marine Environment Protection Law in China: Review and prospect. *Sustainability* 14, 22. doi: 10.3390/su142214994

Zhang, S., Zhou, Y., Yu, R., Xu, X., Xu, M., Li, G., et al. (2022). China's biodiversity conservation in the process of implementing the sustainable development goals (SDGs). *J. Clean. Prod.* 338, 130595. doi: 10.1016/j.jclepro.2022.130595

Zhu, J. G. (2016). *China's legal regime for marine environmental protection* (Beijing: China University of Political Science and Law Press).

Zou, K., and Wang, J. (2019). Enforcing marine environmental law in China: Some new measures. *Chin. J. Int. Law* 18, 1. doi: 10.1093/chinesejil/jmz006

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 16 May 2024
DOI 10.3389/fmars.2024.1398720

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
University of International Business and Economics, China

REVIEWED BY
Oran Young,
University of California, Santa Barbara, United States
M Jahanzeb Butt,
School of Law, Shandong University, China
Dag Øivind Madsen,
University of South-Eastern Norway (USN), Norway

*CORRESPONDENCE
Quansheng Wang
wangquansheng@sdu.edu.cn

RECEIVED 10 March 2024
ACCEPTED 06 May 2024
PUBLISHED 16 May 2024

CITATION
Huang L, Zhou R and Wang Q (2024) Toward better governance of the marine environment: an examination of the revision of China's marine environmental protection law in 2023.
Front. Mar. Sci. 11:1398720.
doi: 10.3389/fmars.2024.1398720

COPYRIGHT
© 2024 Huang, Zhou and Wang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Toward better governance of the marine environment: an examination of the revision of China's marine environmental protection law in 2023

Lansong Huang, Rui Zhou and Quansheng Wang*

Law School, Shandong University, Weihai, China

The marine economy has become an increasingly important contributor to the global economy due to advancements in science and technology and humans' growing ability to manipulate nature. As a country with a vast marine territory, China has the important responsibility of utilizing marine resources rationally and promoting sustainable development of the marine economy. Since the introduction of the Marine Environmental Protection Law of the People's Republic of China (MEPL) in 1982, China has made significant progress in strengthening the legal framework for marine environmental protection. MEPL has undergone several revisions to improve its legal content under the guidance of national policies. On October 24, 2023, the Standing Committee of the National People's Congress revised and adopted MEPL again. This paper analyzes the changes in the contents of the new law and the legal background at home and abroad while integrating the domestic and international legal backgrounds. This paper provides an in-depth analysis of the changes made in the new law, summarizes the revision ideas, and examines the new law in the context of domestic and international laws. The aim is to provide a clear understanding of the spirit and purpose of the legislation.

KEYWORDS

law of the people's republic of china on marine environmental protection, ocean power, marine environmental governance, ocean strategy, united nations convention on the law of the sea

1 Introduction

The current Law of the People's Republic of China on Marine Environmental Protection (hereinafter referred to as the Marine Environmental Protection Law) was adopted in 1982 and has been amended four times. Therefore, this paper focuses on analyzing the revision history, background, motivation, focus, and ideas of the Marine Environmental Protection Law. The aim is to provide a more in-depth understanding of the

system construction of the law, which is crucial for comprehending the state's key areas of regulation of marine environmental pollution. This analysis will also serve as a better guide for judicial practice and the effective implementation of the law, ultimately leading to better governance of the marine environment. The law will be more in-depth to analyze the system construction of the Marine Environmental Protection Law.

Give full play to the guiding role of marine ecological environment laws. The protection and governance of the marine ecological environment require a mature and complete legal system for protection (Gullett, 2023; Keyuan, 1999). The Marine Environment Protection Law is a legal guide for the country to carry out marine economic development, marine environmental protection, and marine resource utilization, which is in line with national policies and guidelines. This article offers a detailed explanation of the updated Marine Environmental Protection Law of 2023. It aims to provide insight into the main direction of national marine governance, clarify the responsible parties and their respective duties, assist relevant organizations and individuals in understanding their obligations, avoid potential legal risks, and serve as a guide for all parties involved.

There is a close relationship between domestic and international law regarding the realization of a community with a shared future for the ocean (Verlaan, 2007). The formulation of domestic law should be consistent with international law. Analyzing the background of international law in the revision of marine environmental law can help clarify the international development trend of relevant marine protection laws. It can also align domestic law with international law, safeguard China's marine rights and interests, reduce conflicts of international marine interests, achieve sustainable development of the marine environment, and promote the improvement of the domestic marine environmental protection legal system. Undertaking international responsibility for protecting the marine environment can help achieve a community with a shared future for the ocean (Matthews, 1992).

We are promoting the realization of the strategy of ocean power. China is in a period of transition from a large marine country to a strong marine country, and the revision of the Marine Environmental Protection Law is one of the results of implementing the strategic task of a strong marine country (Ma et al., 2024). This paper analyzes the motivation behind the revision of the Marine Environmental Protection Law in China. It aims to achieve the legislative purpose of protecting China's marine ecological environment and promoting the realization of the strategic task of a strong marine nation (Chen et al., 2023a).

2 Materials, methods, and analytical framework

The fundamental basis for investigating the governance of China's marine environment is the Marine Environment Protection Law of the People's Republic of China (referred to as the "Marine Environment Protection Law"). China's Marine Environmental Protection Law was first enacted in 1982 and has been amended five times, resulting in a more perfect regulation of China's marine environmental protection law. The laws are available on the NPC website. In addition to the aforementioned legislation, this paper also conducted a comprehensive search of the relevant literature on the topic of "Marine Environmental Governance" from databases such as CNKI and Web of Science. This served as the basis for the literature review.

The primary methodologies employed in this thesis are those of legal dogmatic and social science law. The methodology of legal dogmatic encompasses the methodologies of legal hermeneutics and legal dogmatic. Its principal activities include the description of the extant effective law, the study of the legal concept system of the extant effective law, and the formulation of solutions to complex problems (normative practice). The method of social science law advocates the use of the method of social science to analyze legal problems. The method of social science law emphasizes the empirical study of law, that is, the grasp of social facts. However, people's judgments regarding legal questions and their view of legal phenomena often have an experiential foundation. Literature analysis cannot be separated from existing research results; it must be sorted to refine the theme of research and facilitate innovative development.

The theoretical analysis framework of this paper is based on a comparison of legal texts and related institutional analysis. This analysis will focus not only on the changes to China's Marine Environmental Protection Law over time and its impact on the governance of the marine environment but also on the relationship between China's Marine Environmental Protection Law and the rules of the relevant marine national conventions. This will reflect an assessment of China's compliance with the United Nations Convention on the Law of the Sea and other international conventions. Finally, the amendments to the Marine Environment Protection Law of the People's Republic of China will be examined in detail to assess their impact on the marine environment governance system. The Law of the Sea and other international conventions will be considered, and finally, the impact of the amendments to the Marine Environment Protection Law of the People's Republic of China on the marine environment governance system will be examined systematically. This will enable an objective reflection of China's marine environmental protection law, thereby promoting the role of China's marine environmental governance.

3 The process of change in China's marine environmental protection law

In the 70 years since the establishment of the People's Republic of China, the Marine Environmental Protection Law has gone through three stages: foundation, development, and improvement.

3.1 Foundation stage of China's marine environmental protection law

During the early days of the People's Republic of China, the Communist Party of China (CPC) was primarily focused on ensuring the survival of the nation. Its awareness of the governance and protection of the marine environment was relatively weak, and there was a lack of laws on marine environmental protection from the

perspective of preventing marine pollution. However, there are existing laws related to the development of the marine industry. The current maritime strategy of the country focuses on maintaining sovereignty and security, with three main aspects. First, the country is building a strong naval force. Second, it is guarding national sovereignty and territorial integrity. Third, it is advocating for maritime rights in nearby areas. Under the guidance of national strategy, China has successively formulated laws and regulations related to the ocean (He, 1986). See Table 1.

During the 1970s, two oil crises led to a significant increase in oil exploration. However, this also resulted in disastrous consequences for the ocean, including the formation of oil spills and the contamination of black sea stones. These are clear examples of the ecological damage caused to marine life. Preventing and controlling marine pollution is imperative. In this context, in 1974, China issued the Provisional Regulations of the People's Republic of China on the Prevention of Pollution in Coastal Waters, which first attached importance to the prevention and control of coastal marine pollution (MaChen, 1986). In addition, the promulgation of the Environmental Protection Law (Trial) has also made principled provisions for the protection of the marine environment. These have laid a solid legal foundation for the later formulation of China's Marine Environmental Protection Law, marking the initial stage of the construction of the rule of law for marine environmental protection in China.

TABLE 1 Marine laws and regulations formulated by China between 1949 and 1982.

Set time	Legal and regulatory names	Existing validity	legislative purpose
1952	Interim Measures for the Administration of the Import and Export of Foreign Ships of the People's Republic of China	No	Promote the development of a foreign-related economy.
1954	Provisional Regulations of the People's Republic of China on the Administration of Seaports	No	Safeguarding the sovereignty of seaports
1956	Order on Prohibited Fishing Areas for Machine Wheel Towing Nets in the Bohai Sea, Yellow Sea, and East China Sea	Yes	Protecting aquatic resources and safeguarding people's interests
1958	Notice of the State Council on Establishing Marine Hydrometeorological Stations in Coastal Areas	Yes	Promoting economic and national defense construction
1958	Declaration of the Government of the People's Republic of China on the Territorial Sea	Yes	Safeguarding national sovereignty over territorial waters
1959	Rules for Investigation and Handling of Average Accidents	No	Resolving maritime accident liability disputes
1964	Management Rules for Non-Military Ships of Foreign Nationality Passing through the Qiongzhou Strait	Yes	Safeguarding national sovereignty
1979	Environmental Protection Law of the People's Republic of China (Trial)	No	Protecting the environment (including the marine environment)

The preliminary development of an international legal system for marine protection is necessary. Before 1982, China made significant progress in the development of international marine fishery resources and trade. However, the international conventions related to the ocean that China joined mainly focused on maritime sovereignty and security issues, with few direct provisions for marine environmental protection (see Table 2).

In 1982, the adoption of the United Nations Convention on the Law of the Sea meant that there were finally clear international provisions for the protection of the marine environment and the prevention and control of marine pollution. The twelfth part of the Convention outlines the legal framework for marine environmental protection laws in various countries. It is divided into three parts, specifically addressing the protection and preservation of the marine environment.

Firstly, it sets out the general obligations of all countries to prevent marine pollution. The Convention on the Law of the Sea not only stipulates that all countries must protect the marine environment but also clarifies that all countries have the sovereign right to develop natural resources, achieving a balance between rights and obligations. Secondly, it emphasizes strengthening global and regional cooperation. When a country discovers pollution damage and related hazards, it should immediately notify the relevant country or organization. Encourage countries to extend a helping hand to developing countries, provide technical assistance, and enable them to enjoy preferential treatment from international organizations. Thirdly, establish implementation standards and safeguard measures to clarify the compensation responsibilities of each country arising from the implementation of these measures. Countries should take timely remedial measures for marine pollution damage and actively fulfill their remedial obligations (Kerr, 2022; Kim & Norodom, 2022).

The United Nations Convention on the Law of the Sea is committed to balancing the rights and obligations of all countries in the field of marine environmental protection. On the premise of respecting the sovereignty of all countries, it is required that all countries take all necessary measures to protect the marine environment and prevent marine pollution. With the introduction of the United Nations Convention on the Law of the Sea and the continuous development of China's marine resource development, the country is also paying more and more attention to the legislative work of marine environmental protection. The release of the United Nations Convention on the Law of the Sea provides a favorable opportunity for the formulation of China's Marine Environmental Protection Law and lays the foundation for international law.

3.2 The development stage of China's marine environmental protection law

The opening and signing of the United Nations Convention on the Law of the Sea in 1982 also promoted the preliminary

TABLE 2 The relevant international maritime conventions that China joined between 1949 and 1982.

Joining time	Name of the Convention	Existing validity	Legislative purpose
1954	Agreement between the Government of the People's Republic of China and the Government of the Socialist Republic of Vietnam on Fisheries Cooperation in the Beibu Gulf	No	Promoting the development of marine fisheries
1955	Agreement on Fisheries in the Yellow Sea and East China Sea	No	
1958	Treaty of Commerce and Navigation between the People's Republic of China and the Union of Soviet Socialist Republics	Yes	Promote cooperation and development, friendly trade, and mutual benefit between both parties.
1959	Treaty of Commerce and Navigation between the People's Republic of China and the German Democratic Republic	Yes	
1961	Treaty of Commerce and Navigation between the People's Republic of China and the People's Republic of Albania	Yes	
1962	Treaty of Commerce and Navigation between the People's Republic of China and the Democratic Republic of Vietnam	Yes	
1962	Treaty of Commerce and Navigation between the People's Republic of China and the People's Democratic Republic of Korea	Yes	
1973	International Convention on Load Lines of Ships	Yes	Protecting life and property at sea

development of the legal system for marine environmental protection in China. Against the backdrop of reform and opening up, the rapid development of maritime commerce has also accelerated the legislative process for marine environmental protect ion. On August 23, 1982, China passed its first Marine Environmental Protection Law, which consists of eight chapters and forty-eight articles. This law established a legal framework for marine environmental protection in China and was promoted by various factors.

The legislative purpose of this law can be summarized as protecting the marine environment and preventing marine pollution. Based on this legislative purpose, the general provisions of this law mainly stipulate the obligations of various units and individuals in marine environmental protection. Starting from the perspectives of coastal engineering, offshore oil exploration and development, land-based pollutants, ships, and dumping of waste, detailed regulations are made on the problem of marine environmental pollution damage, regulating the pollution behavior of each subject. Chapter 7 stipulates legal liability issues, mainly focusing on liability for damages. Chapter 8 Supplementary Provisions lists some legal concepts related to professional terminology. The promulgation of the Marine Environmental Protection Law is the first law in China related to marine environmental protection, which is of significant significance. Since then, China's marine environmental protection has entered an era with a legal basis (Keyuan, 1999).

Afterward, the country also formulated or added other laws and regulations on marine environmental protection, but mainly supplemented the five major pollution sources in Marine Environment Protection. For instance, the Regulations on the Management of Environmental Protection for Marine Oil Exploration and Development, the Regulations on the Prevention of Ship Pollution in the Sea Area, and the revised Regulations on the Management of Marine Dumping were all in effect on December 29, 1983, and March 6, 1985, respectively. The Convention for the Prevention of Marine Pollution by Dumping of Waste and Other Substances was ratified on September 6, 1985. Additionally, the amendment to Annex I of the 1973 International Convention for the Prevention of Pollution from Ships and its 78th Protocol was announced on May 18, 1988. The Regulations on the Prevention of Ship Dismantling Pollution in the Environment were also announced on May 18, 1988, and automatically accepted on January 7,1986. These laws expand the content of the Marine Environmental Protection Law and promote the improvement and development of the legal system for marine environmental protection.

3.3 The improvement stage of China's marine environmental protection law

Due to insufficient legislative experience and an incomplete understanding of marine environmental protection at the time, the provisions on the legal responsibility in the Marine Environmental Protection Law were not perfect. With the rapid development of the economy after the reform and opening up, the speed of marine resource development and utilization has been increasing, and more and more problems have emerged. The Marine Environmental Protection Law is difficult to adapt to social development and urgently needs to be revised and improved. Since 1982, the Marine Environmental Protection Law has undergone five revisions, as shown in Figure 1.

3.3.1 First modification

On December 25, 1999, the 13th meeting of the 9th Standing Committee of the National People's Congress passed the amendment to the Marine Environment Protection Law, which was stipulated to come into effect on April 1, 2000. This revision is a large-scale one, and the Environment and Resources Committee of the 8th National People's Congress began working on it in 1995. After conducting thorough research and consulting with multiple experts and scholars, a revised draft of the Marine Environmental Protection Law was formulated. On June 22, 1999, the Vice Chairman of the Environment and Resources Committee of the National People's

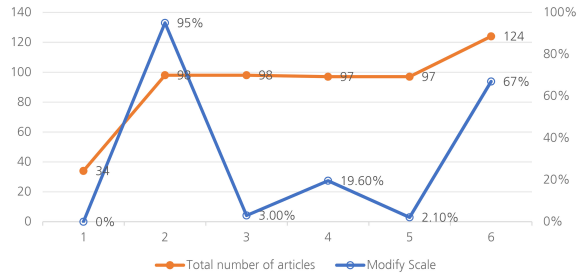


FIGURE 1
Five revisions of China's Marine Environmental Protection Law after 1982.

Congress delivered a legislative statement during the 10th meeting of the Standing Committee of the National People's Congress. After four rounds of deliberation, it was passed at the 13th meeting. From the perspective of the content of the legal system, the newly revised Marine Environment Protection Law has expanded from the original eight chapters and forty-eight articles to ten chapters and ninety-eight articles, adding two new chapters: "Marine Environment Supervision and Management" and "Marine Ecological Protection." It has expanded one of the original five major pollution sources," Marine Oil Exploration and Development," to " Marine Engineering Construction Projects," and the scope of the modifications almost covers all provisions.

3.3.2 Second modification

On December 28, 2013, the 6th meeting of the Standing Committee of the 12th National People's Congress decided on amending seven laws, including the Marine Environment Protection Law of the People's Republic of China. The revised provisions are Article 43, Article 50, and Article 80. This is only a small-scale modification. From the content perspective, this revision emphasizes the necessity of the Environmental Impact Assessment (EIA) report and the filing procedures for preparing an oil spill emergency plan. The purpose of this revision is to respond to the national policy of streamlining administration and delegating power and to implement the decision to cancel and delegate administrative approval projects.

3.3.3 Third modification

On November 7, 2016, the 24th meeting of the Standing Committee of the 12th National People's Congress decided on amending the Marine Environment Protection Law of the People's Republic of China, which consists of 19 items and is mainly divided into three aspects. The first is to increase the severity of penalties for illegal actions, such as adjusting the upper limit of fines and holding enterprise personnel accountable. The second is to establish a system that aligns with national policies, such as setting red lines for marine ecological protection and implementing a compensation system. There are three proposed methods for improving marine ecological protection. The second is to establish a system that aligns with national policies, such as setting red lines for marine ecological protection and implementing a compensation system. The third is to streamline the administrative approval process. For instance, it is required that pertinent departments prepare and receive authorization for reports on the impact of marine environment, and facilities for environmental protection must undergo inspection. This revision is the result of implementing the national promotion of ecological civilization construction and ecological compensation system construction.

3.3.4 Fourth modification

On November 4, 2017, the 30th meeting of the 12th Standing Committee of the National People's Congress approved the draft amendment to the Marine Environment Protection Law, which only improved two provisions. The main modifications include the setting of discharge outlets into the sea and compensation issues.

3.3.5 Fifth revision

On October 24, 2023, the 6th meeting of the Standing Committee of the 14th National People's Congress voted to pass the newly revised Marine Environmental Protection Law, which will come into effect on January 1, 2024. The newly revised Marine Environmental Protection Law consists of nine chapters, and the changes in its provisions mainly focus on the following three aspects: One is to adhere to the coordinated regional linkage between land and sea. The second is to clarify the responsibilities of various regions and departments and achieve clear rights and responsibilities. For example, an assessment and evaluation system has been added, as well as a responsibility system for marine environmental protection goals. The third is to protect marine biodiversity. Regulate from the aspects of development, utilization, ecological restoration, etc.

4 The international legal background of the revision of China's marine environmental protection law in 2023

The revision of the Marine Environment Protection Law in 2023 is not only influenced by the domestic legal environment and the development of the marine economy but also by the changes in the construction of the marine legal system internationally, which have significant guiding significance in domestic legislation. In recent years, international legal efforts have focused on global marine environmental protection, including biodiversity preservation, pollution prevention and control, and addressing global climate change. Legal activities related to marine environmental protection have been carried out globally in recent years.

4.1 United nations agreement on the protection of high seas biodiversity

On March 4, 2023, representatives of various countries drafted an agreement on the protection of biodiversity under the provisions of the United Nations Convention on the Law of the Sea. The draft

agreement focuses on addressing the current crises on Earth, such as climate change, biodiversity loss, and environmental pollution. The agreement focuses on the conservation of marine biodiversity and aims to maintain the integrity of marine ecosystems and achieve sustainable development goals. From a content perspective, the agreement establishes large-scale marine protected areas and imposes restrictions on fishing volume, shipping routes, and exploration activities, including deep-sea mining (Morgera et al., 2023).

4.2 Beijing convention on the judicial sale of ships

On September 5, 2023, the United Nations International Convention on the Judicial Sale of Ships was signed in Beijing. This convention is the first United Nations convention in the maritime industry named after a Chinese city, reflecting the high recognition of China's leading role in the formation of the convention by various countries. The convention aims to address the issue of cross-border recognition in the judicial sale of ships, ensuring that the ownership of the buyer in the judicial sale of ships is recognized in other contracting countries, and enhancing the stability of related rights. The signing of the convention is conducive to jointly promoting the development of international maritime legislation in a more open direction and making greater contributions to the construction of the global maritime rule of law (Chuah et al., 2023).

4.3 International convention on the control of harmful anti-fouling bottom systems on ships (AFS convention)

China joined the AFS Convention on March 3, 2011. From June 10 to June 17, 2021, the International Maritime Organization's Marine Environment Protection Committee held its 76th meeting and passed amendments to the AFS Convention, which came into effect on January 1, 2023. The law defines anti-fouling bottom systems as "coatings, paints, surface treatments, surfaces, or devices that control or prevent the attachment of harmful organisms." The convention requires all ships to prohibit the use of anti-fouling bottom systems containing cyberne. This is to prevent the leakage of non-compliant AFS substances and protect the marine environment (Cariou and Randrianarisoa, 2023).

4.4 Conference of the special parties to the three major conventions

On May 1, 2023, more than 2000 representatives from around the world participated in the Special Meetings of the Parties to the Stockholm Convention, Basel Convention, and the Rotterdam Convention in Geneva, Switzerland. The theme of this meeting is "Accelerating Action: The Goal of Harmless Management of Chemicals and Waste." Include some new chemicals in the three conventions. It is particularly emphasized that the chemicals listed in Annex III of the Rotterdam Convention are mainly pesticides with long-term high risks to aquatic organisms, achieving protection for aquatic organisms (Gullett, 2023).

4.5 Convention on biological diversity

The 15th Conference of the Parties to the Convention on Biological Diversity (COP15) held its second phase in Montreal, Canada, from December 7th to 20th, 2022. The conference, led by China, adopted the long-awaited 'Kunming Montreal Global Biodiversity Framework.' Biodiversity loss is a significant global environmental issue. The adoption of this framework provides direction and clarity for global biodiversity conservation, including marine biodiversity conservation (Hao et al., 2023; Parks & Tsioumani, 2023).

4.6 Draft resolution on ending plastic pollution

On March 2, 2022, the Fifth United Nations Environment Assembly passed the draft resolution on ending plastic pollution. It is worth noting that this is only a legally binding draft, and all parties are still committed to continuing to promote it in 2024, making it a formally promulgated law. This legally binding resolution aims to promote global governance of plastic pollution. As the world's plastic production increases year by year, the harm of plastic pollution to the world is further expanding. One of the most effective measures to end plastic pollution is to introduce legally binding resolutions. This resolution also has an effect on plastic pollution in the ocean (Islam et al., 2023).

5 The intrinsic motivation behind the revision of China's marine environmental protection law in 2023

In recent years, China has prioritized the development of its marine economy, proposing strategies such as building a strong maritime power, coordinating land and sea, and managing the ocean to explore new economic growth points in the country.

5.1 The strategy of becoming a maritime power

In 2012, the 18th National Congress of the Communist Party of China set the strategic goal of building a maritime power, emphasizing the construction of a maritime power multiple times. General Secretary Xi Jinping also pointed out the important position of the marine economy in the national economy, stating

that "an economic powerhouse must be a maritime and shipping powerhouse." (Kiyota, 2023). The revision of the 2017 Marine Environment Protection Law is one of the measures to implement this strategic goal. The 2022 report of the 20th National Congress of the Communist Party of China reiterated the importance of accelerating the construction of a maritime power. This suggests that China has not yet fully developed into a maritime power and needs to make new achievements in promoting its construction with new initiatives (Wang, 2024). In the last decade, marine technology has continuously innovated, and the marine economy has entered a phase of high-quality development. The construction of the marine rule of law also needs further improvement. Therefore, the revision of the Marine Environmental Protection Law was included in the legislative work plan for 2022.

5.2 Land-sea coordination strategy

The concept of land-sea coordination first appeared in the 12th Five-Year Plan, proposed in 2010. The 19th National Congress of the Communist Party of China's report in 2017 reiterated the proposal to implement the strategy of regional coordinated development, adhere to land-sea coordination, and accelerate the construction of maritime power. At this point, the land-sea coordinated strategy has officially risen to a national-level strategy, highlighting the important position of the ocean in the socialist economic cause with Chinese characteristics. The land-sea coordinated strategy mainly targets the contradiction of imbalanced development between land and sea, breaks the traditional concept of valuing land over sea, and achieves complementary land-sea resources and ecological connectivity between land and sea. The land-sea strategy is hard to achieve through markets alone. It should be part of national macroeconomic regulation, urban and rural planning, industrial development planning, ecological protection planning, and more. Use legal, economic, cultural, and other policies to implement this strategy. The revision of the Marine Environmental Protection Law is one of the legal means to implement this strategy (Wang et al., 2023).

5.3 Strategy for managing the ocean

"Jinglve" means "managing the world with a slight touch of the world." "Managing the ocean" generally refers to the comprehensive management of ocean interests and security by a country through political, economic, technological, military, and other means to achieve the goal of utilizing ocean resources, developing ocean interests, and defending ocean sovereignty (Long et al., 2023). Since the 21st century, there has been continuous exploration and development in the fields of marine economics and marine technology innovation. The proposed strategy for managing the ocean is conducive to promoting the integration of China's marine resources and energy development system with the world. The revision of the Marine Environmental Protection Law further promotes the implementation of the strategy of managing the ocean.

6 Basic ideas for the revision of the marine environment protection law in 2023

The 2023 revision of China's Marine Environmental Protection Law aims to transform international conventions that China has joined into domestic law and actively assume international legal obligations. It also seeks to strengthen coordination between domestic marine environmental laws and regulations and improve the top-level design of marine environmental protection systems. Additionally, it aims to elevate the policies of the party and the state to the legal level and effectively implement the party and the state's marine economic development policies.

6.1 Translation of international convention requirements

The relationship between international law and domestic law is a fundamental theoretical issue in the field of law, and there are two theories in academia: monism and dualism. Monism refers to the priority of domestic law or the priority of international law, while dualism holds that international law and domestic law have a parallel or opposing relationship, meaning that if international law wants to apply within a country, it needs to be transformed into domestic law. Most people in academia support the binary theory. Therefore, to better link domestic marine environmental protection law and international maritime law, the new law turns international conventions into domestic law. This allows them to regulate legal relationships and acts (Boviatsis & Vlachos, 2022).

The new law strengthens the prevention and control of marine garbage pollution and extensively supplements and modifies Chapter 7, which focuses on pollution prevention and control from ships and related operational activities. The new law incorporates relevant provisions from the 2004 International Convention on the Control and Management of Ships' Ballast Water and Sediments (referred to as the Ballast Water Convention). The new law contains provisions for regulating ship ballast water pipes. It aims to ensure consistency between ballast water treatment standards and international convention treatment standards, as well as comply with international ballast water replacement requirements and implement ballast water management measures (Wright, 2021).

The new law transformed certain provisions of the 2009 Hong Kong Convention on International Safety and Environmentally Sound Dismantling of Ships (referred to as the Convention). Article 87 of the new law corresponds to the Convention on Ship Dismantling, which requires that measures taken by units engaged in ship dismantling be safe and environmentally friendly to prevent marine pollution (Tolian et al., 2020).

6.2 Connecting domestic legal systems

China has more than ten maritime laws, more than 20 maritime administrative regulations, as well as more than 30 regulatory

documents of the State Council and local maritime laws and regulations. These laws and regulations involve different maritime fields, such as fisheries, mineral resources, ports, surveying and mapping, ship pollution, ocean dumping, and so on. To avoid conflicts between different laws, the formulation and modification of each law should refer to and absorb specific provisions of other relevant laws. The new law pays special attention to linking individual clauses with relevant maritime clauses to reduce differing legal outcomes caused by the same legal act. This aims to protect the marine environment (Montazeritabar & Ye, 2024).

The first paragraph of Article 84 of the new law stipulates the responsibilities and obligations of the consignor of goods and clarifies the subject of performance obligations. This is in line with similar provisions in China's Maritime Traffic Safety Law and Maritime Law. In addition, the new law stipulates the legal consequences of shippers violating relevant obligations and specifies that shippers can be fined up to 2,000 yuan. Article 85: Clearly define the responsible parties for the overall planning and construction of facilities for the reception and transportation of pollutants from ships. This is the second time that the responsibilities of coastal local governments have been clarified through legislation, following the Water Pollution Prevention and Control Law and the Yangtze River Protection Law.

The revision of the law not only emphasizes existing provisions but also includes corresponding supplements. For instance, Article 64 of the Air Pollution Prevention and Control Law proposes designating ship air pollutant emission control zones in coastal waters. The new law aims to add control zones for ship pollutants, remove the word 'atmosphere,' and increase control zone requirements.

6.3 Implementing national policy guidance

The strategic principles of the party and the state are the important experience of the CPC in governing the country. The legislature should take the national strategic principles as guidance, adhere to the problem orientation, and reflect the development requirements of the party and the state promptly. In addition, the new law incorporates China's concepts and achievements in protecting biodiversity into specific legal provisions. Under the guidance of these national policies, the old laws have gradually developed and improved, keeping pace with the times and becoming a good law to effectively solve national development problems, protect the interests of the people, and protect the marine environment.

7 The main content of the revision of China's marine environmental protection law in 2023

The revised Marine Environmental Protection Law adheres to land-sea coordination and regional linkage, comprehensively strengthens the prevention and control of marine environmental pollution, improves marine ecological protection, strengthens marine environmental supervision and management, promotes the extraterritorial application of marine environmental protection laws, and has many institutional innovations and practical measures.

7.1 Establishing a marine environment supervision and management system

7.1.1 Consolidate government responsibilities

The new law outlines the specific regulations for the responsibilities of both central and local governments. The fourth article clarifies the scope of responsibilities for the relevant competent departments of the state. Compared to the old version, the content has been further expanded and improved. Specifically, it includes departments such as the State Council's ecological environment, natural resources, transportation, fisheries, development and reform, water administration, housing and urban-rural construction, forestry and grassland, maritime police agencies, and military ecological environment departments, which have the characteristics of broad fields and scope. In addition, Articles 5 to 8 stipulate the responsibilities of local people's governments at or above the county level along the coast and require all regions to implement a marine environmental protection target responsibility system and an assessment and evaluation system, truly taking responsibility for the marine environment within their management areas (Guo, 2020).

7.1.2 Improve government regulatory capacity

The new law emphasizes the government's obligation to disclose information, use the power of the public to supervise the government's administrative actions and promote internal self-improvement through external supervision. Furthermore, it involves utilizing the environmental impact assessment system to oversee national spatial planning and related plans for potential risks of polluting the marine environment. It also entails enhancing the approval process of the State Council to monitor the national marine ecological environment protection plan. Additionally, the use of ecological environment zoning control planning and an ecological environment access list system is necessary to supervise and manage the ecological environment and resource utilization of the sea area. The use of mechanisms for assessing marine environmental quality has improved the planning, monitoring, early warning, investigation, environmental impact assessment, emergency response, and other systems related to local marine environmental standards. This has enhanced the regulatory capacity of relevant departments of the State Council and local government departments to some extent (Cariou and Randrianarisoa, 2023b).

7.2 Implementing the strategy of land-sea coordination and regional coordination

7.2.1 Promote the integration of coastal engineering and marine engineering

The new law combines the 'Prevention and Control of Pollution Damage to the Marine Environment by Coastal Engineering Construction Projects' chapter and the 'Prevention and Control

of Pollution Damage to the Marine Environment by Marine Engineering Construction Projects' chapter from the old law. This unifies the marine environmental protection requirements of coastal engineering and marine engineering construction projects. The distinction between coastal pollution and marine engineering pollution is no longer made (Bai et al., 2024).

This change means unifying the bottom line of pollution prevention and control in engineering projects along the coast, replacing post-punishment with early prevention, and using legal means to intervene in the control of marine pollution earlier. "Coast ocean" is no longer a relative concept in marine environmental protection law. The new law adopts a unified legal standard to regulate pollution in construction projects, which is helpful for the application and implementation of the new law, helps to avoid conflicts between legal rules of different construction projects, reduces repetitive work of local government departments, and implements the land-sea coordination strategy (Li, 2023).

7.2.2 Clarify the regional cooperation mechanism

Article 6 of the General Provisions of the New Law stipulates that "local governments at or above the county level along the coast may establish a regional cooperation mechanism for marine environmental protection and organize and coordinate their management of environmental protection work in the sea areas." The new law also stipulated that relevant governments should negotiate and resolve cross-regional marine environmental protection work. This is different from the old law. However, the new law did not explicitly propose the establishment of a regional cooperation mechanism. This change is an important manifestation of legislators highlighting the implementation of regional linkage strategies. In addition, Article 12 also clearly states that the state implements a marine environment supervision and management system that integrates land and sea resources and regional linkage. The reason why regional cooperation mechanisms are integrated into the legal system is that they are conducive to better solving the problem of different standards for cross-regional marine environmental protection, breaking the boundaries between administrative regions, integrating coastal regional resources, promoting integrated development of coastal regions, and accelerating the goal of building a maritime power (Xing et al., 2022).

7.2.3 Implement the requirements for river-sea linkage

The issue of marine environmental protection is closely related to the prevention and control of pollution in terrestrial rivers. According to the requirements of river-sea linkage and following relevant laws and administrative regulations on water pollution prevention and control, strengthen the management of rivers entering the sea. Develop and implement plans for ecological restoration and other protection measures in estuaries to prevent marine pollution from the source. The integration of rivers and seas requires strengthening the management of rivers entering the sea and strengthening the comprehensive monitoring of water, sand, salt, tidal flats, etc., to prevent seawater backflow and invasion. Article 50 of the new law stipulates that provincial governments in river basins that enter the sea must formulate and implement plans to control total nitrogen and phosphorus emissions. Land-sea coordination is more about the coordination of land-river ecology and marine environment, and river-sea linkage is an important measure to achieve the land-sea coordination strategy (Qu et al., 2023).

7.3 Strengthening the protection of marine biodiversity

7.3.1 Reasonably utilize marine resources

The ocean is the source of life, and ocean resources provide many services for human life, such as oxygen sources in the air, climate regulation, food and medicine, and so on. China is one of the countries with the richest marine biodiversity in the world. Protecting marine biodiversity cannot rely solely on people's moral behavior but also effective legal regulation. The new law mandates that the development and utilization of marine and coastal resources must prioritize the protection of marine ecosystems, biological genetic resources, and other related factors. The law emphasizes that protection and development are not mutually exclusive. The utilization of marine resources should be kept within reasonable limits, and excessive development is prohibited. Article 35 of the new law, central and provincial governments are required to establish mechanisms for compensating for ecological damage caused by resource development (Dong et al., 2024).

7.3.2 Establish a sound marine biodiversity protection system

The marine biodiversity conservation system is not composed of a single protection measure but is composed of four aspects: investigation, monitoring, evaluation, and protection. Firstly, experts, scholars, and other professionals within the administrative region shall conduct a biodiversity survey of the jurisdictional waters to gain a preliminary understanding of the basic situation of biodiversity in the waters. Subsequently, monitor the biodiversity situation, regularly understand the changes in the number of biological species in the sea area, and evaluate the overall richness of biodiversity in the sea area. By integrating the above steps, develop a biodiversity conservation plan for this region. In addition, the new law also stipulates the maintenance and restoration of marine ecological corridors to prevent damage to biodiversity (Xing et al., 2022).

7.3.3 Restoration of marine biodiversity

The preservation of marine biodiversity cannot depend solely on protective measures. Active measures must also be taken to restore the biodiversity of marine organisms that have already been damaged. The state encourages the adoption of measures such as releasing artificial fish reefs, seagrass beds, and corals, according to local conditions to artificially restore marine biodiversity and improve marine ecology. At the same time, it is emphasized that the restoration of the marine ecology should focus on restoring

biodiversity and the basic functions of ecosystems, with natural restoration as the main focus. In addition, the new law stipulates that a cautious attitude should be taken and scientific argumentation should be conducted when introducing foreign animal and plant species. The law comprehensively outlines restoration methods and priorities for marine biodiversity, including natural and artificial restoration, as well as introducing foreign organisms and improving local ecology (Dube, 2024).

7.4 Strengthen the supervision of discharge outlets into the sea

7.4.1 Strengthen the quality control of the marine environment

The supervision of marine quality at discharge outlets into the sea is a crucial step in the overall protection of the marine environment. Article 19 of the new law stipulates that the state shall promote comprehensive management of marine areas, strictly manage marine pollution discharge permits, and improve the quality of the marine environment in key areas by raising the standards of marine pollution discharge permits. The new law stipulates in detail that all engineering units that need to discharge wastewater and sewage as well as other units and producers that treat sewage, should obtain a pollution discharge permit under the law. That is, obtaining a pollution discharge permit is necessary for discharging sewage into the sea. In addition, all enterprises and institutions should strictly follow the types, concentrations, emissions, and destinations of pollutants recorded on the pollution discharge permit. They should prohibit the implementation of improper measures, such as tampering or forging monitoring data, to evade supervision (Valentim et al., 2024).

7.4.2 Establish a full-chain governance system

The new law optimizes the setting of discharge outlets into the sea, requiring responsible parties to strengthen monitoring and carry out automatic monitoring under legal provisions. This reduces government monitoring costs. For instance, factory farming units should self-monitor aquaculture wastewater. The new law stipulates that the selection of the location of the discharge outlet into the sea should comply with the requirements of the national spatial control, scientifically demonstrate, and report to the relevant environmental regulatory department for record. At the same time, the ecological environment regulatory department should timely synchronize the setting of discharge outlets into the sea with departments such as fisheries and natural resources, as well as maritime police agencies and maritime management agencies. The people's governments at or above the county level along the coast shall conduct political and daily supervision and management of various types of discharge outlets into the sea within their administrative regions and establish and improve a complete chain governance system for nearshore water bodies, discharge outlets into the sea, discharge pipelines, and pollution sources (Karantoni et al., 2023).

7.4.3 Develop management measures for discharge outlets into the sea

The above introduction mainly focuses on the procedural and principled regulations for the management of discharge outlets into the sea. In addition, the new law also stipulates specific measures for the establishment and management of discharge outlets into the sea. The competent ecological and environmental department of the State Council formulates these measures. Article 47 of the new law stipulates that it is prohibited to set up industrial wastewater or urban sewage discharge outlets in areas that require special protection, such as natural reserves, bathhouses, and ecological protection red lines. Areas with favorable conditions should implement offshore discharge. The new law requires the construction of an information platform for discharge outlets into the sea, achieving information sharing and openness, and facilitating public supervision. At this point, the new law combines the principle rules and specific rules for the management of discharge outlets into the sea, strengthening the supervision of discharge outlets into the sea (Du et al., 2022).

7.5 Strengthen the prevention and control of marine garbage pollution

7.5.1 Prevent solid waste from entering the ocean

The land-sea junction is usually the source of marine debris pollution, so the new law has made clear provisions for the treatment of solid waste. Unlike the old law, Article 56 of the new law adds a prohibition on the disposal, stacking, and treatment of solid waste on beaches, requiring effective measures to be taken to prevent solid waste from entering the ocean. The transfer of hazardous waste through China's domestic waters and territorial waters is strictly prohibited, and potential marine debris pollution hazards are eliminated. The new law changes the original "beach" to "coastal land area," expands the prohibited scope of solid waste disposal, uses more accurate legal concepts to improve relevant legal rules, and reduces the occurrence of disputes in the legal application (Qiu et al., 2024).

In addition, special circumstances not specified in the new law may arise in judicial practice. To better apply the law and achieve the authority of the law, except for those otherwise provided by laws and administrative regulations. This has been added after Article 56. This change addresses the potential practical issues.

7.5.2 Formulate government pollution prevention and control measures

Governments at all levels play an important role in preventing and controlling marine environmental pollution. Article 57 of the new law requires local governments at or above the county level in coastal areas to prevent and control garbage pollution. It establishes a monitoring and cleaning system for marine garbage, coordinates the treatment of land garbage, constructs facilities for receiving, transporting, and processing marine garbage, and clarifies the marine garbage control areas of various departments, streets, and units. Furthermore, the law mandates the creation of a system to

monitor, salvage, transport, and dispose of marine debris to comprehensively address the problem of marine debris pollution and encourage public participation in governance. Under the premise of clarifying the division of responsibilities, relevant departments of the State Council strengthen the supervision of the prevention and control of marine garbage pollution (Solihuddin et al., 2024).

7.5.3 Strengthen the prevention and control of pollution from ship waste and other sources

Ships are important tools for human activities at sea, and ship debris is an important component of marine debris. Preventing and controlling marine garbage pollution cannot ignore ship pollution. Therefore, the prevention and control of marine garbage pollution cannot ignore the pollution caused by ships. Article 80 of the new law states that ships' structures and anti-pollution equipment must comply with national standards and undergo inspection and qualification. Additionally, ships must possess certificates for the prevention and control of marine environmental pollution and monitor relevant pollution measures. When delivering goods that pose a risk of pollution, it is important to inform the recipient of the necessary protective measures to reduce the likelihood of pollution incidents occurring (Chen et al., 2023).

Article 85 of the new law adds the responsibilities that the government should fulfill for ship pollutants. The government should coordinate the planning and construction of disposal facilities for ship pollutants and establish a multi-departmental joint supervision system. Standardize the recycling and disposal of domestic sewage and fishery waste, and construct pollution prevention and control equipment. Promote the construction of marine pollution prevention and control through the government's public power (Guo et al., 2024).

8 Conclusion and policy recommendations

China's marine environment protection law was adopted in 1982 and revised in 1999. It was amended three times in 2013, 2016, and 2017. The law has played an important role in marine environmental protection since its implementation. The overall marine ecological environment has improved, the ecosystem service function of some marine areas has improved significantly, and awareness of marine ecological environment protection has increased significantly. However, problems such as pollution and ecological degradation of the marine environment are still prominent in China, the improvement of water quality in the coastal waters is not yet firm, and the trend of marine ecological degradation has not been fundamentally curbed. Marine ecological disasters occur frequently, causing an increase in species and regional spread. Environmental risks, such as oil spills and dangerous chemical spills, continue to increase. At the same time, there are some problems in the work of marine ecological environment protection, such as the lack of marine pollution prevention and control, the relatively backward work of marine ecological protection and restoration, and the imperfect supervision and management system of the marine environment. Revising the 2023 Marine Environmental Protection Law is an inevitable step to promote good governance of the marine environment.

It is necessary to study further how to transform the written law into law in action and how to improve the implementation mechanism of the 2023 revised Marine Environmental Protection Law. The following are several aspects of improving China's Marine Environmental Protection Law implementation mechanism recommendations:

First, the coordination of ocean management within the department needs to be strengthened. Although the 2023 version of Article 4 of the Marine Environment Protection Act has improved the responsibilities of marine administrations, the multi-agency management model remains unchanged. For instance, ten departments under the State Council, including the Department of Ecology and Environment and the Department of Natural Resources, are involved. Although the revised marine environment protection law has clarified the responsibilities of the various competent departments, it is suggested that the State Council establish a Marine Ecological Environment Coordination Committee. This committee would be responsible for coordinating the functions and responsibilities of the various departments to effectively and urgently deal with marine ecological incidents.

Second, the responsibilities of local governments for marine environmental management need to be further clarified. According to Articles 5 and 6 of the newly amended Marine Environment Protection Law, local governments at or above the county level in the People's Republic of China are responsible for maintaining the quality of the marine environment in the areas under their management. The state has implemented a responsibility system and an assessment and evaluation system for achieving marine environmental protection objectives. This includes the assessment and evaluation of the achievement of these objectives. Secondly, local governments in the People's Republic of China at or above the county level may establish a regional cooperation mechanism for marine environmental protection. They are responsible for organizing and coordinating environmental protection efforts in the areas under their management. Cross-regional marine environmental protection issues in the People's Republic of China will be resolved through consultation by the relevant local coastal government or coordination with the superior government. The competent Department of Ecology and Environment under the State Council will coordinate major inter-departmental marine environmental protection work. If coordination fails, the State Council will make a decision. This provision also suffers from poor operability. The first responsibility is to outline the marine environmental governance duties of local governments in China at or above the county level. The second responsibility is to establish a regional coordination mechanism for marine environmental protection at the national level. For instance, provincial-level governments in China have established regional coordination mechanisms for marine environmental protection in their designated areas, and the State Council has established regional coordination mechanisms for marine environmental protection in its designated areas.

Third, joint law enforcement agencies should be established to supervise and administer the marine environment. The newly

revised Marine Environment Protection Law only provides for sharing law enforcement information on marine environment supervision and management in Article 25. The subjects related to the supervision and management provided in Article 29 can carry out joint law enforcement. The Standing Committee of the National People's Congress inspection report on the enforcement of the marine environment protection law highlights the urgent need for China to establish a joint enforcement mechanism for the marine environment. However, the law on the joint enforcement mechanism for the marine environment is unclear. The Shenzhen Maritime Police Station, in conjunction with the Shenzhen Qianhai Procuratorate, the Municipal Marine Integrated Law Enforcement Detachment, the Municipal Public Security Bureau, the Municipal Maritime Affairs Bureau, and various street offices, launched the 'Qinggang Qingwan' joint law enforcement operation (Nguyen, 2023). This operation aims to build a marine security barrier through sea-land joint defense and control, providing an excellent exploratory experience in some places. To improve coordination and linkage functions, it is suggested that a joint law enforcement agency be established for the supervision and administration of the marine environment in provinces and cities of the People's Republic of China, involving the law enforcement bodies of the State Council, Provincial Government, and district-based municipal government.

Fourth, the clarification of supervision and management responsibilities among the main bodies of marine environmental governance is crucial. A perfect supervision mechanism is necessary to ensure effective implementation of the law. The term 'supervision' appears 59 times in the legal provisions of the newly revised Marine Environment Protection Law. It refers to the supervision duties of the Marine Environmental Management departments at the same level and the oversight and management responsibilities of the Government of the People's Republic of China and their departments. The Marine Environment Protection Act, as a national law, is not yet suitable for making detailed and operable provisions at all levels. Therefore, the provinces with legislative power and the Municipal People's Congress or Government of the People's Republic of China with district-based powers should issue regulations or rules for implementation. It is important to clarify the supervision and management responsibilities of various governance bodies to improve the operability of the law.

Fifth, the detailed legal liability of the establishment. Chapter 8 of the recently amended Marine Environmental Protection Law includes a special section on legal liability. This section outlines the legal responsibility of the various parties involved in marine environmental protection, including administrative, civil, and criminal liability. The provisions in this section provide more detail than those in the previous law on marine environmental protection. However, there is still room for improvement, particularly in the imposition of fines. The penalties range from 20,000 to 200,000 yuan for administrative and civil liability, and from 200,000 to 1 million yuan for criminal liability. The discretion of the law enforcement body concerned is too great, and it is possible to distinguish between different situations, refine the administrative penalty's fine, and increase law enforcement's fairness. The primary law enforcement information system should not appear to have multiple heads or be repetitive. It is recommended that the legal responsibility of provincial and district-based municipal legislatures for marine environmental protection laws be further specified, targeted, and timely.

Sixth, push forward the standardization of law enforcement by the People's Congress. The inspection of law enforcement by the People's Congress is a means to effectively promote the implementation of the legal system and a way to supervise the law enforcement subject to enforce the law according to the law. Since the enactment of China's Marine Environmental Protection Law in 1982, the Standing Committee of the National People's Congress has conducted two inspections, in 1998 and 2018. However, these inspections are insufficient to ensure effective implementation of the law. The organs of the People's Congress cannot effectively supervise their supervisory power. It is recommended that the Standing Committee of the National People's Congress conduct marine environmental enforcement inspections every five years and that the provincial People's Congress conduct marine environmental enforcement inspections every two years.

This study has some limitations, including the absence of a comparison with overseas legal systems for marine environmental protection and the lack of empirical evidence regarding the effects of amending the provisions of the Marine Environmental Protection Law. The latter will be the focus of our next topic.

Author contributions

LH: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Writing – original draft. RZ: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Supervision, Writing – original draft. QW: Conceptualization, Funding acquisition, Project administration, Resources, Software, Supervision, Visualization, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by the Youth Fund for Humanities and Social Sciences Research of the Ministry of Education(23YJC820013).

Acknowledgments

The paper was written thanks to focused discussions on this topic among team members at the Weihai Legislative Research Center of Shandong University.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Bai, J., Yan, Y., Cao, Y., Cui, Y., Chang, I., and Wu, J. (2024). Marine ecological security shelter in China: Concept, policy framework, mechanism and implementation obstacles. *J. Environ. Manage.* 351, 119662. doi: 10.1016/j.jenvman.2023.119662

Boviatsis, M., and Vlachos, G. (2022). Sustainable operation of unmanned ships under current international maritime law. *Sustainability* 14 (12), 7369. doi: 10.3390/su14127369

Cariou, P., and Randrianarisoa, L. M. (2023a). Stakeholders' participation at the IMO marine environmental protection committee. *Mar. Policy* 149, 105506. doi: 10.1016/j.marpol.2023.105506

Cariou, P., and Randrianarisoa, L. M. (2023b). Stakeholders? participation at the IMO Marine Environmental Protection Committee. *Mar. Policy* 149, 105506. doi: 10.1016/j.marpol.2023.105506

Chen, P., Chen, H., Chen, K., Ke, H., and Cai, M. (2023a). Quantitative assessment of the response of seawater environmental quality to marine protection policies under regional economic development –A case study of Xiamen Bay, China. *Mar. Environ. Res.* 186, 105934. doi: 10.1016/j.marenvres.2023.105934

Chen, P., Chen, H., Chen, K., Ke, H., and Cai, M. (2023b). Quantitative assessment of the response of seawater environmental quality to marine protection policies under regional economic development –A case study of Xiamen Bay, China. *Mar. Environ. Res.* 186, 105934. doi: 10.1016/j.marenvres.2023.105934

Chuah, L. F., Mokhtar, K., Ruslan, S. M. M., Bakar, A. A., Abdullah, M. A., Osman, N. H., et al. (2023). Implementation of the energy efficiency existing ship index and carbon intensity indicator on domestic ships for marine environmental protection. *Environ. Res.* 222, 115348. doi: 10.1016/j.envres.2023.115348

Dong, F., Shi, M., and Li, W. (2024). Research on ecological protection mechanisms in watersheds based on evolutionary games-inter-provincial and intra-provincial perspectives. *Water Resour. Manage.* 38, 2377–2397. doi: 10.1007/s11269-024-03773-4

Du, W., Zhou, K., Wang, K., and Lin, X. (2022). Research on marine environmental protection and sustainable development of marine industrial structure in the new era. *Fresenius Environ. Bull.* 31, 3142–3149.

Dube, K. (2024). A comprehensive review of climatic threats and adaptation of marine biodiversity. *J. Mar. Sci. Eng.* 12 (2), 344. doi: 10.3390/jmse12020344

Gullett, W. (2023). The contribution of the law of the sea convention to marine environmental protection: 40 years of shimmering seas or high hopes dashed against juridical rocks? *Mar. Policy* 149, 105498. doi: 10.1016/j.marpol.2023.105498

Guo, J. (2020). The developments of marine environmental protection obligation in article 192 of UNCLOS and the operational impact on China's marine policy - A South China Sea fisheries perspective. *Mar. Policy* 120, 104140. doi: 10.1016/j.marpol.2020.104140

Guo, J., Jiang, Z., Chu, X., and Wang, W. (2024). Parallel intelligent monitoring system of port water quality based on the ACP method. *J. Mar. Sci. Eng.* 12 (2), 218. doi: 10.3390/jmse12020218

Hao, Y., Wu, M., Zhang, X., Wang, L., and He, J. (2023). Research on the implementation of the convention on biological diversity among the Shanghai Cooperation Organisation countries. *Regional Sustainability* 4, 322–331. doi: 10.1016/j.regsus.2023.08.005

He, G. (1986). Legal responsibility issues in the marine environmental-protection law. *Chin. Law Government* 19, 111–114. doi: 10.2753/CLG0009-46091901111

Islam, M. S., Lee, Z., Shaleh, A., and Soo, H. S. (2023). The United Nations Environment Assembly resolution to end plastic pollution: Challenges to effective policy interventions. *Environ. Dev. Sustainability.* 26, 10927–10944. doi: 10.1007/s10668-023-03639-6

Karantoni, M. E., Panagopoulos, T., Tampakis, S., Karanikola, P., and Tampaki, Z. (2023). Stakeholder views on environmental protection policies in the National Marine Park of Alonissos Northern Sporades, Greece. *Sustain. Horizons* 7, 100065. doi: 10.1016/j.horiz.2023.100065

Kerr, B. P. (2022). Binding the international maritime organization to the united nations convention on the law of the sea. *Int. Organizations Law Rev.* 19, 391–422. doi: 10.1163/15723747-19020006

Keyuan, Z. (1999). Implementing marine environmental protection law in China: progress, problems and prospects. *Mar. Policy* 23, 207–225. doi: 10.1016/S0308-597X(98)00043-8

Kim, H. J., and Norodom, A. T. (2022). An appraisal of article 300 of the united nations convention on the law of the sea. *Ocean Dev. Int. Law* 53, 214–231. doi: 10.1080/00908320.2022.2107965

Kiyota, T. (2023). The nexus of naval modernization in India and China: strategic rivalry and the evolution of maritime power (Oxford international relations in south asia). *Int. Relations Asia-Pacific* 23, 545–548. doi: 10.1093/irap/lcad005

Li, M. (2023). Fishery legislative reform towards Japan's Fukushima nuclear wastewater discharge into the sea–A Chinese perspective. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1135125

Long, Y., Zhou, W., Hong, M., Zhao, Di, Wen, D., Zhang, Y., et al. (2023). "A new exploration of the "Three Lines One Permit" policy: Marine zoning strategy based on land-sea coordination," in *Environmental impact assessment review*. (Amsterdam: Elsevier). 103. doi: 10.1016/j.eiar.2023.107260

Ma, X. C., and Chen, Z. G. (1986). On the marine environmental-protection law. *Chin. Law Government* 19, 64–78. doi: 10.1016/j.ocecoaman.2023.106885

Ma, J., Wu, Z., Guo, M., and Hu, Q. (2024). Dynamic relationship between marine fisheries economic development, environmental protection and fisheries technological Progress—A case of coastal provinces in China. *Ocean Coast. Manage.* 247, 106885. doi: 10.1016/j.ocecoaman.2023.106885

Matthews, G. J. (1992). International law and policy on marine environmental protection and management: Trends and prospects. *Mar. pollut. Bull.* 25, 70–73. doi: 10.1016/0025-326X(92)90189-D

Montazeritabar, M., and Ye, H. (2024). The role of China in protecting the Arctic against pollutions from vessels: a legal perspective. *Environ. Sci. pollut. Res.* doi: 10.1007/s11356-023-31765-1

Morgera, E., Mcquaid, K., La Bianca, G., Niner, H., Shannon, L., Strand, M., et al. (2023). Addressing the ocean-climate nexus in the BBNJ agreement: strategic environmental assessments, human rights and equity in ocean science. *Int. J. Mar. Coast. Law* 38, 447–479. doi: 10.1163/15718085-bja10139

Nguyen, H. K. T. (2023). Law and (Dis)order in the south China sea: analyzing maritime law - enforcement activities in 2010-22. *Asia Policy* 18, 127–164. doi: 10.1353/asp.2023.0027

Parks, L., and Tsioumani, E. (2023). Transforming biodiversity governance? Indigenous peoples' contributions to the Convention on Biological Diversity. *Biol. Conserv.* 280. doi: 10.1016/j.biocon.2023.109933

Qiu, J., Jin, J., Zuo, X., Fan, X., Wei, J., Xu, D., et al. (2024). Chronology of drill cores and the inferred coastal environmental evolution on Haitan Island, South China. *J. Quaternary Sci.* 39 (4), 626–637 doi: 10.1002/jqs.3606

Qu, Y., Wang, S., Tian, Y., Jiang, G., Tao, Z., and Liang, M. (2023). Territorial spatial planning for regional high-quality development—An analytical framework for the identification, mediation, and transmission of potential land utilization conflicts in the Yellow River Delta. *Land Use Policy* 125, 104462. doi: 10.1016/j.landusepol.2022.106462

Solihuddin, T., Triana, K., Rachmayani, R., Husrin, S., Pramudya, F. A., Salim, H. L., et al. (2024). The impact of coastal erosion on land cover changes in Muaragembong, Bekasi, Indonesia: a spatial approach to support coastal conservation. *J. Coast. Conserv.* 28, 43. doi: 10.1007/s11852-024-01045-2

Tolian, R., Makhsoosi, A. H., and Bushehri, P. K. (2020). Investigation of heavy metals in the ballast water of ship tanks after and before the implementation of the ballast water convention: Bushehr Port, Persian Gulf. *Mar. pollut. Bull.* 157, 11378. doi: 10.1016/j.marpolbul.2020.111378

Valentim, H. I. L., Feio, M. J., and Almeida, S. F. P. (2024). Fluvial protected areas as a strategy to preserve riverine ecosystems–a review. *Biodiversity Conserv.* 33, 439–462. doi: 10.1007/s10531-023-02774-w

Verlaan, P. A. (2007). Experimental activities that intentionally perturb the marine environment: Implications for the marine environmental protection and marine scientific research provisions of the 1982 United Nations Convention on the Law of the Sea. *Mar. Policy* 31, 210–216. doi: 10.1016/j.marpol.2006.07.004

Wang, W. (2024). Reconciling China's maritime discourses of nationalism and international engagement with left Confucian logic. *Humanities Soc. Sci. Commun.* 11, 275. doi: 10.1057/s41599-024-02774-3

Wright, D. A. (2021). Compliance assessment for the ballast water convention: time for a re-think? *A UK Case study. J. Mar. Eng. Technol.* 20, 254–261. doi: 10.1080/20464177.2018.1513686

Xing, H., Cao, X., and Su, Z. (2022). The rule of law for marine environmental governance in maritime transport: China's experience. *Front. Mar. Sci.* 9, 1083420. doi: 10.3389/fmars.2022.1083420

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 23 May 2024
DOI 10.3389/fmars.2024.1388636

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Xiaolong Chen,
Liaoning Normal University, China
M. Jahanzeb Butt,
Shandong University, China

*CORRESPONDENCE
Yanwei Wang
wyw2952648592@163.com

RECEIVED 20 February 2024
ACCEPTED 15 April 2024
PUBLISHED 23 May 2024

CITATION
He Y and Wang Y (2024) Research on subject behavior choice of marine carbon sink projects under risk conditions.
Front. Mar. Sci. 11:1388636.
doi: 10.3389/fmars.2024.1388636

COPYRIGHT
© 2024 He and Wang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Research on subject behavior choice of marine carbon sink projects under risk conditions

Yixiong He and Yanwei Wang*

School of Economics and Management, Zhejiang Ocean University, Zhoushan, China

Marine carbon sink projects are important carriers for the development and utilization of marine carbon sink resources. The risk factors existing in the development process of marine carbon sink projects will significantly affect the behavior of the project subject, and then affect whether or not the project development can be conducted smoothly. Based on the evolutionary game method, this paper analyzes the behavior choice of each project subject under the risk condition, and explores the influencing factors that promote the change of its action probability. The results show the following: (1) Government subsidies can promote the development of marine carbon sink projects, but when the subsidies are too large, the government's willingness decreases, which may lead to significant changes in the decisions of relevant practitioners. (2) The government pays more attention to image improvement, is not sensitive to risks, and always chooses active subsidies. In the case that the risk poses a great threat to the project, the behavior strategies of the relevant practitioners and investors will influence each other, and both sides will determine the behavior strategies that can obtain more returns according to the other side's behavior decision. (3) The behavior of relevant practitioners and investors has an impact on the strategy of the demander. When the risk increases, the former has a greater impact on the demander's choice not to buy marine carbon sink. Relevant policy suggestions are put forward: (1) the government should flexibly adjust the subsidy mechanism; (2) the government should enhance the influence and popularity of marine carbon sink projects; and (3) the government should reduce the risks faced by the practitioners.

KEYWORDS

risk, marine carbon sink project, evolutionary game, behavior choice, coping strategy

1 Introduction

Rapid economic development has caused excessive emissions of greenhouse gases such as carbon dioxide. As the increasingly severe global warming situation becomes worse, countries have put forward their own targets of carbon neutral carbon peak (Li X. Q. et al., 2022), aiming to relieve environmental pressure by reducing carbon dioxide emissions and increasing carbon sink by relying on biological behavior. The essence of carbon sink by

biological behavior is to use carbon sink to offset carbon emissions, which includes two categories: terrestrial carbon sinks and marine carbon sinks (Nellemann et al., 2009). Compared with terrestrial carbon sinks, marine carbon sink has a higher carbon fixation rate (Mcleod et al., 2011), a longer carbon storage time (Li J. et al., 2022), and a greater decarbonization potential (Sabine et al., 2004). Research shows that marine carbon dioxide storage accounts for approximately 55% of the global marine carbon capture (Zhang et al., 2022). It can be said that the ocean plays a vital role in absorbing and storing carbon dioxide (Zhuang et al., 2023). However, the development of marine carbon sinks is difficult, and neither the marine carbon sink enhancement technology nor the marine carbon capture and storage technology has been widely used (He et al., 2022a). However, the economic, ecological, and spatial effects of marine carbon sinks have attracted much attention in the carbon market (Bañolas et al., 2020). Marine carbon sink projects are one of the main forms of marine carbon sink development. Most of the developed marine carbon sink projects are fishery carbon sink projects and mangrove carbon sink projects (Zhang et al., 2020; He et al., 2023b), and by using the market mechanism to transform the ecological benefits of marine carbon sink into economic benefits, we can give full play to the positive role of marine ecosystems in coping with climate change (Yang et al., 2021; Wei et al., 2023).

Analyzing the behavior of relevant subjects is an important foundation for promoting the development of marine carbon sink projects. The existing research mainly discusses the behavior of subjects from the perspective of market transactions (Li M. X. et al., 2022). On the other hand, there are risks in the development process of marine carbon sink projects, such as natural risks, policy risks, human behavior risks, technical risks, and market risks. Existing research has shown that risks can have a huge impact on the development of marine carbon sink projects (He et al., 2022b; He et al., 2023b). Therefore, it is necessary to explore the behavioral choices of marine carbon sink project entities under risk conditions.

Different subjects adopt different strategies to avoid risks, and the essence of risk avoidance decisions is the result of the game between the relevant subjects (Giulia et al., 2023; Karol, 2023; Zhou et al., 2023; Zhang K. X. et al., 2023). Through the continuous game, the risk response level of the subject has been continuously improved (Masud et al., 2018; Chen et al., 2021; Li X. N. et al., 2022). In recent years, game theory has been increasingly applied in the study of marine carbon sinks. For example, He et al. used the evolutionary game method to construct a tripartite mathematical model of fishery practitioners, scientific research institutions, and the government, discussing the respective decisions of the three subjects (He and Zhang, 2023). Yu et al. compared the cost and benefit of independent and collaborative management models through game theory and concluded that regional collaborative management is more conducive to promoting marine carbon sink market transactions (Yu et al., 2023). Zhang et al. used the complex network evolutionary game, based on the assumptions of the WS small-world model on social network relationships, focused on the groups of fishermen, and explored the dynamic evolution law of cooperative behavior diffusion in the development of marine carbon sink fisheries (Zhang et al., 2023a). He et al. determined the decision of each entity to maximize the efficiency of blue carbon trading in the game between the demander, supply side, the government, and third-party institutions, and pointed out that high or low prices cannot achieve the goal of long-term blue carbon trading (He et al., 2023a). After constructing an evolutionary game model between the government and the supply side and demanders of blue carbon, Cao et al. combined specific cases of blue carbon credit and found that changes in government subsidies at different stages of the blue carbon trading market can promote the success rate of blue carbon trading (Cao et al., 2022). Zhang et al. first used evolutionary game theory to compare and demonstrate the actual effect and value of government regulation, media supervision, and the net benefits of marine carbon sinks on the disclosure of true information by high carbon emitting enterprises. Then, based on differential game theory, they explored the price formation of marine carbon sinks to improve the quality of carbon emission information disclosure by high carbon emitting enterprises and realize the value of marine carbon sink (Zhang et al., 2023b). However, in general, there are few studies on the risk response of marine carbon sink projects, especially the relevant behavior studies on the learning mode and risk response of marine carbon sink projects.

Considering that the behavior of the subject is a constantly changing process of evolutionary learning process, this paper selects the evolutionary game method due to the fact that evolutionary game theory is more suitable than traditional game theory in solving multiple equilibrium problems in the decision-making process, especially in the research on decision-making of behavioral subjects based on assumptions of bounded rationality and learning mechanisms (Fan et al., 2021; Zhao et al., 2022), discussing the game relationship of different subjects (enterprises and other marine carbon sink demanders, enterprises and fishermen, the government and other regulatory authorities, financial institutions, enterprises, and other investors). Based on this, countermeasures and suggestions to enhance the effectiveness of risk response for marine carbon sink projects have been proposed. The possible marginal contributions of this paper are as follows: (1) The government's reward and punishment mechanism is introduced to explore the behavior strategies of each of the subjects and the interactions between each of the subjects under the influence of risk. (2) Based on the classic tripartite game model of marine carbon sink projects demanders, relevant practitioners, and the government, investors are introduced to conduct a four-party evolutionary game. Through simulation and analysis of the specific impacts of various relevant factors on the willingness of the four parties under risk conditions, the behavior choices of each party are clarified, and the application methods and approaches of the four-party evolutionary game method in the field of marine environment and policy research are expanded. (3) Considering the risks and the behavior characteristics of marine carbon sink subjects, analysis has been made to deduce how better to improve the risk response effect of marine carbon sink project subjects, so as to provide support for the smooth development of marine carbon sink projects.

The structure of the remaining part of this paper is as follows: Section 2 sets the parameters according to the basic assumptions and constructs the game matrix of the returns of the marine carbon sink demanders, relevant practitioners, governments, and investors

in different circumstances. Section 3 analyzes the stability of the main body strategy, explores the stability of the system, and explores the risk response effect of the marine carbon sink project. Section 4 summarizes the contents of this research paper and gives countermeasures and suggestions to improve the risk response effect of the main body of the marine carbon sink projects.

2 Basic assumptions and model construction of the problem

2.1 Basic assumptions and basis

Although the common goal of each subject of marine carbon sink projects is to maximize their own interests, the specific interests of each of the subjects are different. The corporate image improvement due to the purchase of marine carbon sinks by the demander can play a great role in the development of the main business of the enterprise. At the same time, enterprises can buy marine carbon sinks to offset the carbon emissions from their own activities. Relevant practitioners adjust their development strategies according to the marine carbon sink price and the supply–demand relationship of the carbon sink market, and consider whether the government subsidies, marine carbon sink trading volume, the derivative value of marine carbon sink products, and the investment amount of investors can be higher than the development cost and the changing risk cost. The government needs to boost its image to gain popular support and uses policy tools to ensure smooth marine carbon sink trading to mitigate environmental problems and obtain environmental benefits. Investors will make stable investment decisions only when they ensure that the income from image enhancement, the amount of marine carbon sink transactions, and the economic return from the derivative value of marine products are higher than their investment and risk response expenditure. That is, the specific performance of the interests concerning investors, relevant practitioners, and demanders is different: investors consider the return on investment, the relevant practitioners consider increasing income and satisfying investors, the government gains public support by enhancing its image, and the demander considers how to meet the carbon emission reduction target without being punished by the government. Therefore, there is cooperation and competition among marine carbon sink demanders, relevant practitioners, the government, and investors, and they are constantly playing games on the benefits of marine carbon sink projects to achieve their most satisfactory results.

Accordingly, this paper summarizes the specific relationships between key subjects such as the demander, relevant practitioners, the government, and investors of marine carbon sink projects as shown in Figure 1.

It is assumed that the subjects implementing or participating in the marine carbon sink project, namely, the marine carbon sink demanders, the relevant practitioners, the government, and the investors, are all limited and rational decision-makers. The probability that the demander chooses to buy the marine carbon sink is x, and the probability of choosing not to buy the marine carbon sink is $1 - x$, including $x \in (0, 1)$; the probability that the relevant practitioners will choose to develop the marine carbon sink is y, and the probability of choosing not to develop the marine carbon sink is $1 - y$, including $y \in (0, 1)$; the probability of the government choosing the incentive is g and the probability of choosing no excitation is $1 - g$, including $g \in (0, 1)$; the probability of investors choosing to invest is z, and the probability of choosing not to invest is $1 - z$, including $z \in (0, 1)$.

All the parameters are set as shown in Table 1, and some of the special parameters are explained in this paper. The government mainly plays a regulatory role in marine carbon sink trading by encouraging both supply and demand. Therefore, this paper sets the government incentive as L; among them, certain subsidies S_{ub} will be given to relevant practitioners who choose to develop marine carbon sinks, and the marine carbon sink demander will be punished for exceeding the limit of carbon dioxide emissions P_{un}. The improvement of the ecological environment, social culture, and

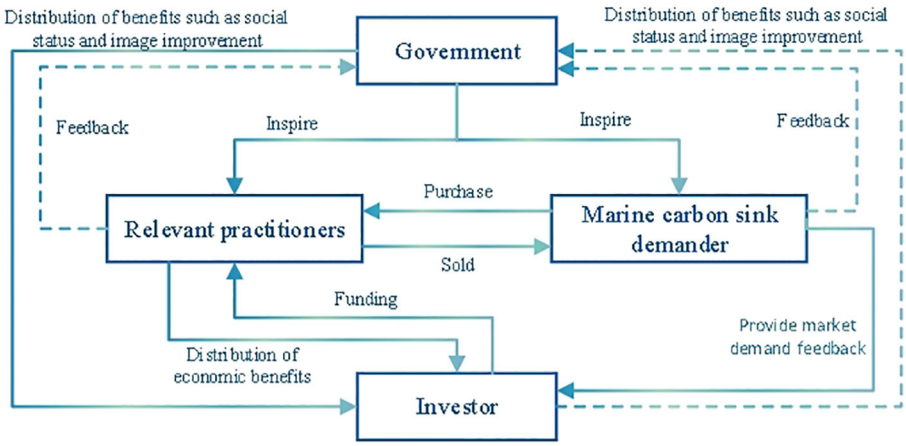


FIGURE 1
Relationship between the demander, related practitioners, the government, and investors of marine carbon sink projects.

TABLE 1 Basic parameters' setting.

Symbol	Symbolic meaning	Symbol	Symbolic meaning
L	Government incentives (including subsidy S_{ub} and overlimit penalty P_{un})	V	Derivative value of marine carbon sink products
Q	Image improvement of the demander	R	Marine carbon sink development risk (including risks borne by relevant practitioners R_1 and investors $R_2{}^I$)
δF	Image improvement of the government	C	Development cost of marine carbon sink
N	Environmental benefit	T_r	Trading volume of marine carbon sink
T_o	Investment amount of investors	τ	Distribution coefficient of economic benefits
$(1\text{-}\delta)$F	Image improvement of investors	ω	Risk coefficient of marine carbon sink development (including risks borne by relevant practitioners ω_1 and investors ω_2)
$(1-\tau)(Tr+V)$	Economic returns for investors	δ	Distribution coefficient of image enhancement

other aspects brought about by government incentives can enhance the image of the government, and investors also have similar considerations, hoping to build a better social image by participating in marine carbon sink projects. Therefore, this paper sets δ as the distribution coefficient of image improvement; the revenue of government image improvement is δF, and the return of investor image improvement is $(1-\delta)F$. For investors, it is also crucial to invest in marine carbon sink projects and get economic returns through the transaction volume of marine carbon sink T_r. In addition to image improvement and direct economic benefits, investors can also obtain some derivative value of marine carbon sink products V. For example, mangroves themselves can produce marine carbon sink and be used to develop tourism, fishery, and other industries (Watanabe et al., 2020; Chen, 2021). Here, the derivative value and the marine carbon sink trading volume are both related to investors and related practitioners, which need to be distributed in a certain proportion. Therefore, the distribution coefficient of economic income is set to τ, and investors can get the economic return of $(1-\tau)(Tr+V)$. In addition, the natural attribute of marine carbon sink increases the risk probability and risk impact degree of marine carbon sink projects, such as the loss caused by the risk caused by natural factors such as wind, storm, tide, and sea water temperature change. Thus, this paper divides the risk coefficient ω into ω_1 and ω_2, representing the risk coefficient of practitioners and investors, respectively; the risk of marine carbon sink development undertaken by both subjects is R_1 and R_2. For the demander, its purchase of marine carbon sinks can show the responsibility of the enterprise for environmental protection, virtually win the goodwill of consumers, and promote consumers to be more willing to buy the products of the enterprise, which is of great benefit for the improvement and development of corporate image Q.

1 Although the demander also has risks, it may focus more on whether marine carbon sink can be supplied on time and whether prices will change, which can be included in the risks faced by relevant practitioners and investors. Therefore, this article will not separately consider the demander's risks.

2.2 Model building

Based on the above parameters' setting, the game matrix of the returns of the demanders, relevant practitioners, the government, and investors in different situations is listed in Table 2.

According to the game matrix, we can get the expected return of the four subjects after the decision and then calculate the average expected return. The specific process is shown in Equations 1–20.

(1) Suppose that the expected return of the marine carbon sink demander choosing to purchase marine carbon sink is E_{DY}, the expected income of not purchasing the marine carbon sink is E_{DN}, and the average expected income is $\bar{E}_D$, then the expected income of the marine carbon sink demander for purchasing the marine carbon sink is:

$$\begin{aligned} E_{DY} = {} & (Q - T_r)ygz + (Q - T_r)yg(1 - z) + (Q - T_r)y(1 - g)z \\ & + (Q - T_r)y(1 - g)(1 - z) + (- P_{un})(1 - y)gz + (\\ & - P_{un})(1 - y)g(1 - z) \end{aligned} \tag{1}$$

The expected income of the marine carbon sink demander who does not purchase the marine carbon sink is:

$$\begin{aligned} E_{DN} = {} & (- P_{un})ygz + (- P_{un})yg(1 - z) + (- P_{un})(1 - y)gz + (\\ & - P_{un})(1 - y)g(1 - z) \end{aligned} \tag{2}$$

Average expected return of the marine carbon sink demander:

$$\bar{E}_D = xE_{DY} + (1 - x)E_{DN} \tag{3}$$

(2) Suppose that the expected return of relevant practitioners to choose to develop marine carbon sinks is E_{SY}, the expected return of not developing marine carbon sink is E_{SN}, and the average expected return is $\bar{E}_S$, then the expected return of relevant practitioners to develop marine carbon sink is:

$$\begin{aligned} E_{SY} = {} & (S_{ub} + T_o + \tau(Tr + V) - C - \omega_1 R_1)xgz + (S_{ub} + Tr + V - C - \omega_1 R_1)xg(1 - z) + (T_o + \\ & \tau(Tr + V) - C - \omega_1 R_1)x(1 - g)z + (Tr + V - C - \omega_1 R_1)x(1 - g)(1 - z) + (S_{ub} + T_o + \tau V - \\ & C - \omega_1 R_1)(1 - x)gz + (S_{ub} + V - C - \omega_1 R_1)(1 - x)g(1 - z) + (T_o + \tau V - C - \omega_1 R_1) \\ & (1 - x)(1 - g)z + (V - C - \omega_1 R_1)(1 - x)(1 - g)(1 - z) \end{aligned} \tag{4}$$

Expected benefits of relevant practitioners not developing marine carbon sink:

TABLE 2 Foursquare game matrix of the marine carbon sink project.

Marine carbon sink demander	Relevant practitioners	Government			
		Government incentives (*g*)		Government does not encourage (1-*g*)	
		Investors invest (*z*)	Investors do not invest (1-*z*)	Investors invest (*z*)	Investors do not invest (1-*z*)
Demanders purchase marine carbon sink(*x*)	Relevant practitioners develop marine carbon sink (*y*)	$a_1 = Q - T_r$	$a_2 = Q - T_r$	$a_3 = Q - T_r$	$a_4 = Q - T_r$
		$b_1 = S_{ub} + T_o + \tau(Tr + V) - C - \omega_1 R_1$	$b_2 = S_{ub} + Tr + V - C - \omega_1 R_1$	$b_3 = T_o + \tau(Tr + V) - C - \omega_1 R_1$	$b_4 = Tr + V - C - \omega_1 R_1$
		$c_1 = \delta F + N - S_{ub}$	$c_2 = F + N - S_{ub}$	$c_3 = N$	$c_4 = N$
		$d_1 = (1 - \delta)F + (1 - \tau)(Tr + V) - T_o - \omega_2 R_2$	$d_2 = 0$	$d_3 = F + (1 - \tau)(Tr + V) - T_o - \omega_2 R_2$	$d_4 = 0$
	Relevant practitioners do not develop marine carbon sink(1-*y*)	$a_5 = -P_{un}$	$a_6 = -P_{un}$	$a_7 = 0$	$a_8 = 0$
		$b_5 = 0$	$b_6 = 0$	$b_7 = 0$	$b_8 = 0$
		$c_5 = \delta F$	$c_6 = F$	$c_7 = 0$	$c_8 = 0$
		$d_5 = (1 - \delta)F$	$d_6 = 0$	$d_7 = F$	$d_8 = 0$
Demanders do not purchase marine carbon sink (1-*x*)	Relevant practitioners develop marine carbon sink (*y*)	$a_9 = -P_{un}$	$a_{10} = -P_{un}$	$a_{11} = 0$	$a_{12} = 0$
		$b_9 = S_{ub} + T_o + \tau V - C - \omega_1 R_1$	$b_{10} = S_{ub} + V - C - \omega_1 R_1$	$b_{11} = T_o + \tau V - C - \omega_1 R_1$	$b_{12} = V - C - \omega_1 R_1$
		$c_9 = P_{un} + \delta F + N - S_{ub}$	$c_{10} = P_{un} + F + N - S_{ub}$	$c_{11} = N$	$c_{12} = N$
		$d_9 = (1 - \tau)V + (1 - \delta)F - T_o - \omega_2 R_2$	$d_{10} = 0$	$d_{11} = (1 - \tau)V + F - T_o - \omega_2 R_2$	$d_{12} = 0$
	Relevant practitioners do not develop marine carbon sink(1-*y*)	$a_{13} = -P_{un}$	$a_{14} = -P_{un}$	$a_{15} = 0$	$a_{16} = 0$
		$b_{13} = 0$	$b_{14} = 0$	$b_{15} = 0$	$b_{16} = 0$
		$c_{13} = P_{un} + \delta F$	$c_{14} = P_{un} + F$	$c_{15} = 0$	$c_{16} = 0$
		$d_{13} = (1 - \delta)F$	$d_{14} = 0$	$d_{15} = F$	$d_{16} = 0$

$$E_{SN} = 0 \tag{5}$$

Average expected return of relevant practitioners:

$$\bar{E}_S = yE_{SY} + (1 - y)E_{SN} \tag{6}$$

(3) Suppose that the expected return of the government choosing incentives is E_{GY}, the expected return of non-incentives is E_{GN}, and the average expected return is $\bar{E}_G$, then the expected return of government incentives is:

$$\begin{aligned} E_{GY} = {} & (\delta F + N - S_{ub})xyz + (F + N - S_{ub})xy(1 - z) + \delta Fx(1 - y)z + Fx(1 - y)(1 - z) + \\ & (P_{un} + \delta F + N - S_{ub})(1 - x)yz + (P_{un} + F + N - S_{ub})(1 - x)y(1 - z) + \\ & (P_{un} + \delta F)(1 - x)(1 - y)z + (P_{un} + F)(1 - x)(1 - y)(1 - z) \end{aligned} \tag{7}$$

Expected return of government non-incentive:

$$E_{GN} = Nxyz + Nxy(1 - z) + N(1 - x)yz + N(1 - x)y(1 - z) \tag{8}$$

Average expected return of the government:

$$\bar{E}_G = gE_{GY} + (1 - g)E_{GN} \tag{9}$$

(4) Suppose that the expected return of investors' investment is E_{TY}, the expected return of investors' non-investment is E_{TN}, and the average expected return is $\bar{E}_T$, then the expected return of investors' investment is:

$$\begin{aligned} E_{TY} = {} & ((1 - \delta)F + (1 - \tau)(Tr + V) - T_o - \omega_2 R_2)xyg + (F + (1 - \tau)(Tr + V) - T_o - \omega_2 R_2) \\ & xy(1 - g) + (1 - \delta)Fx(1 - y)g + Fx(1 - y)(1 - g) + ((1 - \delta)F + (1 - \tau)V - T_o - \omega_2 R_2) \\ & (1 - x)yg + (F + (1 - \tau)V - T_o - \omega_2 R_2)(1 - x)y(1 - g) + \\ & (1 - \delta)F(1 - x)(1 - y)g + F(1 - x)(1 - y)(1 - g) \end{aligned} \tag{10}$$

Expected return of investors not investing:

$$E_{TN} = 0 \tag{11}$$

Average expected return of investors:

$$\bar{E}_T = zE_{TY} + (1-z)E_{TN} \quad (12)$$

According to the income function of the above four parties, the corresponding replication dynamic equation is obtained to express the dynamic form of the subject behavior evolution, as follows:

$$F(x) = dx/dt = x(E_{DY} - \bar{E}_D) = x(1-x)(\ P_{un}yg + Qy - T_r y) \quad (13)$$

$$F(y) = dy/dt = y(E_{SY} - \bar{E}_S) = y(1-y)(\ V - C - Vz + \ \tau Vz - \omega_1 R_1 + S_{ub}g + T_o z + T_r x - T_r xz + \tau T_r xz) \quad (14)$$

$$F(g) = dg/dt = g(E_{gY} - \bar{E}_g) = g(1-g)(F - S_{ub}y - (1-\delta)F + (1-x)P_{un}) \quad (15)$$

$$F(z) = dz/dt = z(E_{TY} - \bar{E}_T) = z(1-z)(F - \delta Fg - \omega_2 R_2 y + Vy - \tau Vy - T_o y + (1-\tau)T_r\ xy) \quad (16)$$

3 Stability analysis and simulation implementation

3.1 Stability analysis of agent strategy

3.1.1 Strategies for the marine carbon sink demander

The replication dynamic equation of the behavior strategy of marine carbon sink demander is derived as follows:

$$F'(x) = (1-2x)(\ P_{un}yg + Qy - T_r y) \quad (17)$$

According to the stability theorem of differential equations, when $F(x) = 0$ and $F'(x) < 0$, then the behavior strategy of the marine carbon sink demander is stable.

Proposition 1:

When $g < g_0$, the marine carbon sink demander does not buy marine carbon sink as a stable strategy; when $g > g_0$, the marine carbon sink demander buys marine carbon sink as a stable strategy; when $g = g_0$, the marine carbon sink demander cannot determine the stability strategy, where the threshold value is $g_0 = {}^{(T_r - Q)}/_{P_{un}}$. This proposition shows that the probability of the government choosing incentive is positively correlated with the choice of the marine carbon sink demander, that is, the increase of the probability of selecting incentive makes the marine carbon sink demander more inclined to choose to buy marine carbon sink. The reason is that the government will punish the marine carbon sink demander for not purchasing marine carbon sinks, resulting in excessive carbon emissions, and this punishment is greater than the expenditure of the demander on purchasing marine carbon sinks, forcing the demander to face the carbon emissions problem.

Prove:

Let $\phi_X(g) = \ P_{un}yg + Qy - T_r y$, when ${}^{\partial \phi_X(g)}/_{\partial g} > 0$, $\phi_X(g)$ is an increasing function of g. In this case, when $g < g_0$, $\phi_X(g) < 0, F(x)|_{x=0} = 0$, and $F'(x)|_{x=0} < 0$, then $x = 0$is in the steady state; when $g > g_0$, $\phi_X(g) > 0$, $F(x)|_{x=1} = 0$, and $F'(x)|_{x=1} < 0$, then $x = 1$ is in the steady state; when $g = g_0$, $\phi_X(g) = F(x) = F'(x) = 0$, then any value of x is a stable strategy; that is, the strategy choice of the marine carbon sink demander cannot be defined.

3.1.2 Strategies for relevant practitioners

The replication dynamic equation of the behavior strategy of relevant practitioners is derived as follows:

$$F'(y) = (1-2y)(\ V - C - Vz + \ \tau Vz - \omega_1 R_1 + S_{ub}g + T_o z + T_r x - T_r xz + \tau T_r xz) \quad (18)$$

According to the stability theorem of differential equations, when $F(y) = 0$ and $F'(y) < 0$, then the behavior strategy of the marine carbon sink supplier is stable.

Proposition 2:

When $g < g_1$, relevant practitioners do not develop marine carbon sink as a stability strategy; when $g > g_1$, relevant practitioners develop marine carbon sink as a stability strategy; when $g = g_1$, relevant practitioners cannot determine the stability strategy, where the threshold value is $g_1 = {}^{(C+Vz+\omega_1 R_1 + T_r xz - V - \tau Vz - T_r x - \tau T_r xz)}/_{S_{ub}}$. When $x < x_0$, relevant practitioners do not develop marine carbon sink as a stability strategy; when $x > x_0$, relevant practitioners develop marine carbon sink as a stability strategy; when $x = x_0$, relevant practitioners cannot determine the stability strategy, where the threshold value is $x_0 = {}^{(C+Vz+\omega_1 R_1 - S_{ub}g - V - \tau Vz)}/_{(T_r + \tau T_r z - T_r z)}$. This proposition shows that when the government actively promotes the development of marine carbon sinks, the government will give certain subsidies to relevant practitioners for the development of marine carbon sinks, which can be used as additional income to help relevant practitioners achieve greater economic benefits. Therefore, relevant practitioners will also choose to actively develop marine carbon sink projects. On the other hand, the marine carbon sink market is greatly driven by the demander, and when the marine carbon sink demander has a strong willingness to purchase, the rise in carbon sink prices and the increase in demand can drive relevant practitioners to develop marine carbon sink projects, and when the marine carbon sink demander trading intention is insufficient, related practitioners will decline.

Prove:

Let $\phi_Y(g) = V - C - Vz + \ \tau Vz - \omega_1 R_1 + S_{ub}g + T_o z + T_r x - T_r xz + \tau T_r xz$, when ${}^{\partial \phi_Y(g)}/_{\partial g} > 0$, $\phi_Y(g)$ is an increasing function of g. When $g < g_1$, $\phi_Y(g) < 0$, $F(y)|_{y=0} = 0$, and $F'(y)|_{y=0} < 0$, then $y = 0$ is in the steady state; when $g > g_1$, $\phi_Y(g) > 0$, $F(y)|_{y=1} = 0$, and $F'(y)|_{y=1} < 0$, then $y = 1$ is in the steady state; when. $g = g_1$, $\phi_Y(g) = F(y) = F'(y) = 0$, then any value of y is a stable strategy; that is, the strategy choice of relevant practitioners cannot be defined.

3.1.3 Strategies for the government

The replication dynamic equation of the behavior strategy of the government is derived as follows:

$$F'(g) = (1-2g)(F - S_{ub}y - (1-\delta)Fz + (1-x)P_{un}) \quad (19)$$

According to the stability theorem of differential equations, when $F(g) = 0$ and $F'(g) < 0$, then the behavior strategy of the government is stable.

Proposition 3:

When $z < z_0$, government incentive is a stability strategy; when $z > z_0$ the stable strategy is no incentive; when $z = z_0$, the government cannot determine the stability strategy, where the threshold value is $z_0 = {(F+(1-x)P_{un}-S_{ub}y)}/{(1-\delta)F}$. When $x < x_1$, government incentive is a stability strategy; when $x > x_1$, the stable strategy is no incentive; when $x = x_1$, the government cannot determine the stability strategy, where the threshold value is $x_1 = {(F-S_{ub}y-(1-\delta)Fz+P_{un})}/{P_{un}}$. This proposition shows that when investors are less willing to invest, the government will provide subsidies to compensate for investors' economic returns, thus pushing marine carbon sink trading smoothly. Considering the additional cost of buying marine carbon sinks, the demander will not actively buy the marine carbon sink to offset the carbon emission, which runs counter to the government's concept of protecting the environment. At this time, the government as the regulator will use policy tools to turn the demander around to buy marine carbon sink through penalties.

Prove:

Let $\phi_G(z) = F - S_{ub}y - (1-\delta)Fz + (1-x)P_{un}$, when ${\partial \phi_G(z)}/{\partial z} < 0$, $\phi_G(z)$ is a subtraction function of z; when $z < z_0$, $\phi_G(z) > 0$, $F(g)|_{g=1} = 0$, $F(g)|_{g=1} = 0$ and $F'(g)|_{g=1} < 0$, then $g = 1$ is in the steady state; when $z > z_0$, $\phi_G(z) < 0$, $F(g)|_{g=0} = 0$, and $F'(g)|_{g=0} < 0$, then $g = 0$ is in the steady state; when $z = z_0$, $\phi_G(z) = F(g) = F'(g) = 0$, any value g taken is a stable strategy; that is, the government's strategy choice is unknown. Similarly, when ${\partial \phi_G(x)}/{\partial x} < 0$, $\phi_G(x)$ is a subtraction function of x; when $x < x_1$, $\phi_G(x) > 0$, $F(g)|_{g=1} = 0$ and $F'(g)|_{g=1} < 0$, then $g = 1$ is in the steady state; when $x > x_1$, $\phi_G(x) < 0$, $F(g)|_{g=0} = 0$, and $F'(g)|_{g=0} < 0$, then $g = 0$ is in the steady state; when $x = x_1$, $\phi_G(x) = F(g) = F'(g) = 0$, any value g taken is a stable strategy; that is, the government's strategy choice is unknown.

3.1.4 Strategies for the government

The replication dynamic equation of the behavior strategy of investors is derived as follows:

$$F'(z) = (1-2z)(F - \delta Fg - \omega_2 R_2 y + Vy - \tau Vy - T_o y + (1 - \tau)T_r\ xy) \tag{20}$$

According to the stability theorem of differential equations, when $F(z) = 0$ and $F'(z) < 0$, then the behavior strategy of investors is stable.

Proposition 4:

When $x < x_2$, investors' stable strategy is not to invest; when $x > x_2$, investors' stable strategy is to invest; when $x = x_2$, investors cannot determine the stability strategy, where the threshold value is $x_2 = {(\delta Fg+\omega_2 R_2 y+\tau Vy+T_o y-F-Vy)}/{(1-\tau)T_r y}$. When $g < g_2$, investors' stable strategy is to invest; when $g > g_2$, investors' stable strategy is not to invest; when $g = g_2$, investors cannot determine the stability strategy, where the threshold value is $g_2 = (F + Vy + (1-\tau)T_r\ xy - \omega_2 R_2 y - \tau Vy - T_o(y))/\delta F$. This proposition shows that with the increasing willingness of the demander to buy marine carbon sink, the potential market scale of marine carbon sink trading is constantly expanding, and the probability of investors making investment also increases. In the process of trading marine carbon sinks, the government's decisions will affect the implementation of investor behavior because of the distribution of image improvement income between the government and investors. The lower the government's incentive willingness, the less the income from image improvement, and the greater the investment probability of investors.

Prove:

Let $\phi_Z(x) = F - \delta Fg - \omega_2 R_2 y + Vy - \tau Vy - T_o y + (1-\tau)T_r\ xy$, when ${\partial \phi_Z(x)}/{\partial x} > 0$, $\phi_Z(x)$ is an increasing function of x. When $x < x_2$, $\phi_Z(x) < 0$, $F(z)|_{z=0} = 0$ and $F'(z)|_{z=0} < 0$, then $z = 0$ is in the steady state; when $x > x_2$, $\phi_Z(x) > 0$, $F(z)|_{z=1} = 0$ and $F'(z)|_{z=1} < 0$, then z=1 is in the steady state; when $x = x_2$, $\phi_Z(x) = F(z) = F'(z) = 0$, any value z taken is a stable strategy; that is, the investors' strategy choice is unknown. Similarly, when ${\partial \phi_Z(g)}/{\partial g} < 0$, $\phi_Z(g)$ is a subtraction function of g; when $g < g_2$, $\phi_Z(g) < 0$, $F(z)|_{z=0} = 0$, and $F'(z)|_{z=0} < 0$, then $z = 1$ is in the steady state; when $g > g_2$, $\phi_Z(g) > 0$, $F(z)|_{z=1} = 0$, and $F'(z)|_{z=1} < 0$, then $z = 0$ is in the steady state; when $g = g_2$, $\phi_Z(g) = F(z) = F'(z) = 0$, any value z taken is a stable strategy; that is, the investors' strategy choice is unknown.

3.2 System stability analysis

According to the conclusion of Ritzberger and Weibull (1995), in studying the progressive stability of the multigroup evolutionary game, one only needs to discuss $E_3(1,1,0,0)$, $E_4(1,1,1,0)$, $E_5(1,1,1,1)$, $E_6(0,1,0,0)$, $E_7(0,1,1,0)$, $E_8(0,1,1,1)$, $E_{13}(1,1,0,1)$, and $E_{16}(0,1,0,1)$. Therefore, this part adopts Lyapunov's first rule and judges the stability of the above eight pure strategy points with the help of a Jacobian matrix (Friedman, 1998; Lyapunov, 2007; Yang, 2022). The specific rule is as follows: the eigenvalues of Jacobian matrix are less than 0, indicating that the equilibrium point is gradually stable. The Jacobian matrix of the four party evolutionary game system is shown in Equation (21).

$$J = \begin{pmatrix} \partial F(x)/\partial x & \partial F(x)/\partial y & \partial F(x)/\partial g & \partial F(x)/\partial z \\ \partial F(y)/\partial x & \partial F(y)/\partial y & \partial F(y)/\partial g & \partial F(y)/\partial z \\ \partial F(g)/\partial x & \partial F(g)/\partial y & \partial F(g)/\partial g & \partial F(g)/\partial z \\ \partial F(z)/\partial x & \partial F(z)/\partial y & \partial F(z)/\partial g & \partial F(z)/\partial z \end{pmatrix} \tag{21}$$

where $\partial F(x)/\partial x = (1-2x)(P_{un}yg + Qy - T_r y)$, $\partial F(x)/\partial y = x(1-x)(P_{un}g + Q - T_r)$, $\partial F(x)/\partial g = x(1-x)P_{un}y$, and $\partial F(x)/\partial z = 0$.

$\partial F(y)/\partial x = y(1-y)(T_r - T_r z + \tau T_r z)$, $\partial F(y)/\partial y = (1-2y)(V - C - Vz + \tau Vz - \omega_1 R_1 + S_{ub}g + T_o z + T_r x - T_r xz + \tau T_r xz$, $\partial F(y)/\partial g = y(1-y)S_{ub}$, and $\partial F(y)/\partial z = y(1-y)(\tau V - V - T_r x + \tau T_r x)$.

$\partial F(g)/\partial x = 0$, $\partial F(g)/\partial g = -g(1-g)S_{ub}$, $\partial F(g)/\partial g = (1-2g)(F - S_{ub}y - (1-\delta)Fz + (1-x)P_{un})$, and $\partial F(g)/\partial z = -g(1-g)(1-\delta)F$.

$\partial F(z)/\partial x = z(1-z)(1-\tau)T_r y$, $\partial F(z)/\partial y = z(1-z)(V - \omega_2 R_2 - \tau V - T_o + (1-\tau)T_r x)$, $\partial F(z)/\partial g = -z(1-z)\delta F$, and $\partial F(z)/\partial z = (1-2z)(F - \delta Fg - \omega_2 R_2 y + Vy - \tau Vy - T_o y + (1-\tau)T_r\ xy)$.

The equilibrium conditions of the system can be obtained from Table 3, as shown in Table 4. From the stability of the equilibrium

TABLE 3 Eigenvalues of Jacobian Matrix (marine carbon sink demanders, related practitioners, the government, and investors).

Equilibrium point	Characteristic value			
	λ_1	λ_2	λ_3	λ_4
$E_1(0,0,0,0)$	0	$V-C-\omega_1 R_1$	$F+P_{un}$	F
$E_2(1,0,0,0)$	0	$C+\omega_1 R_1-V-T_r$	F	F
$E_3(1,1,0,0)$	T_r-Q	$C+\omega_1 R_1-V-T_r$	$F-S_{ub}$	$F-\omega_2 R_2+(1-\tau)V-T_o+(1-\tau)T_r+(1-\tau)T_r$
$E_4(1,1,1,0)$	T_r-Q-P_{un}	$C+\omega_1 R_1-V-T_r-S_{ub}$	$-F+S_{ub}$	$(1-\delta)F-\omega_2 R_2+(1-\tau)V-T_o+(1-\tau)T_r$
$E_5(1,1,1,1)$	T_r-Q-P_{un}	$C+\omega_1 R_1-S_{ub}-\tau V-\tau T_r-T_o$	$-\delta F+S_{ub}$	$\omega_2 R_2+T_o-(1-\delta)F-(1-\tau)V-(1-\tau)T_r$
$E_6(0,1,0,0)$	$Q-T_r$	$C+\omega_1 R_1-V$	$F-S_{ub}+P_{un}$	$F-\omega_2 R_2+(1-\tau)V-T_o$
$E_7(0,1,1,0)$	$P_{un}+Q-T_r$	$C+\omega_1 R_1-V-S_{ub}$	$S_{ub}-F-P_{un}$	$(1-\delta)F-\omega_2 R_2+(1-\tau)V-T_o$
$E_8(0,1,1,1)$	$P_{un}+Q-T_r$	$C+\omega_1 R_1-\tau V-S_{ub}-T_o$	$S_{ub}-\delta F-P_{un}$	$\omega_2 R_2+T_o-(1-\delta)F-(1-\tau)V$
$E_9(0,0,1,0)$	0	$V+S_{ub}-\omega_1 R_1-C$	$-F-P_{un}$	$(1-\delta)F$
$E_{10}(0,0,1,1)$	0	$\tau V+S_{ub}+T_o-C-\omega_1 R_1$	$-\delta F-P_{un}$	$-(1-\delta)F$
$E_{11}(0,0,0,1)$	0	$\tau V+T_o-C-\omega_1 R_1$	$\delta F+P_{un}$	$-F$
$E_{12}(1,0,0,1)$	0	$\tau V+\tau T_r+T_o-C-\omega_1 R_1$	δF	$-F$
$E_{13}(1,1,0,1)$	T_r-Q	$C+\omega_1 R_1-T_o-\tau V-\tau T_r$	$\delta F-S_{ub}$	$\omega_2 R_2+T_o-F-(1-\tau)V-(1-\tau)T_r$
$E_{14}(1,0,1,1)$	0	$\tau V+\tau T_r+S_{ub}+T_o-C-\omega_1 R_1$	$-\delta F$	$-(1-\delta)F$
$E_{15}(1,0,1,0)$	0	$V-C-\omega_1 R_1+T_r+S_{ub}$	$-F$	$(1-\delta)F$
$E_{16}(0,1,0,1)$	$Q-T_r$	$C+\omega_1 R_1-\tau V$	$\delta F+P_{un}-S_{ub}$	$\omega_2 R_2+T_o-F-(1-\tau)V$

TABLE 4 Equilibrium point stability analysis.

Equilibrium point	Characteristic value				Constraint condition	Stability
	λ_1	λ_2	λ_3	λ_4		
$E_1(0,0,0,0)$	0	U	+	+	Constraints cannot be met	Unstable
$E_2(1,0,0,0)$	0	U	+	+	Constraints cannot be met	Unstable
$E_3(1,1,0,0)$	U	U	U	U	$T_r<Q; C+\omega_1 R_1<V+T_r; F<S_{ub}; F+(1-\tau)V+(1-\tau)T_r+(1-\tau)T_r\ \ xy<\omega_2 R_2+T_o$	*ESS*
$E_4(1,1,1,0)$	U	U	U	U	$T_r-Q<P_{un};\ V+S_{ub}+T_r>C+\omega_1 R_1; S_{ub}<F; (1-\delta)F+(1-\tau)V+(1-\tau)T_r<T_o+\omega_2 R_2$	*ESS*
$E_5(1,1,1,1)$	U	U	U	U	$T_r-Q<P_{un};\ \tau V+S_{ub}+\tau T_r>C+\omega_1 R_1; S_{ub}<\delta F; \omega_2 R_2+T_o<(1-\delta)F+(1-\tau)V+(1-\tau)T_r$	*ESS*
$E_6(0,1,0,0)$	U	U	U	U	$Q<T_r; C+\omega_1 R_1<V; F+P_{un}<S_{ub}; F+(1-\tau)V<\omega_2 R_2+T_o$	*ESS*
$E_7(0,1,1,0)$	U	U	U	U	$P_{un}+Q<T_r; V+S_{ub}>C+\omega_1 R_1: S_{ub}<F+P_{un}; (1-\delta)F+(1-\tau)V<T_o+\omega_2 R_2$	*ESS*
$E_8(0,1,1,1)$	U	U	U	U	$P_{un}+Q<T_r;\ C+\omega_1 R_1<\tau V+S_{ub}; S_{ub}<\delta F+P_{un}; \omega_2 R_2+T_o<(1-\delta)F+(1-\tau)V$	*ESS*
$E_9(0,0,1,0)$	0	U	–	+	Constraints cannot be met	Unstable
$E_{10}(0,0,1,1)$	0	U	–	–	Constraints cannot be met	Unsure
$E_{11}(0,0,0,1)$	0	U	+	–	Constraints cannot be met	Unstable
$E_{12}(1,0,0,1)$	0	U	+	–	Constraints cannot be met	Unstable
$E_{13}(1,1,0,1)$	U	U	U	U	$T_r<Q;\ C+\omega_1 R_1<\tau(V+T_r); \delta F<S_{ub}; \omega_2 R_2+T_o<F+(1-\tau)V+(1-\tau)T_r$	*ESS*
$E_{14}(1,0,1,1)$	0	U	–	–	Constraints cannot be met	Unsure
$E_{15}(1,0,1,0)$	0	U	–	+	Constraints cannot be met	Unsure
$E_{16}(0,1,0,1)$	U	U	U	U	$Q<T_r;\ C+\omega_1 R_1<\tau V; \delta F+P_{un}<S_{ub}; \omega_2 R_2+T_o<(1-\tau)V+F$	*ESS*

point, when the four subjects choose positive strategies, that is, pure strategy point $E_5(1, 1, 1, 1)$, the government needs to give a higher penalty for exceeding the limit. At the same time, the economic benefits of marine carbon sink products' derived value, government subsidies, and marine carbon sink trading volume obtained by relevant practitioners are higher than their risks and development costs, and image enhancement and the equilibrium point can be established only when the amount of marine carbon sink transactions and the derivative value of marine carbon sink products are greater than their investment amount and risk expenditure. By comparing the stable point and unstable point, it can be seen that if the system wants to maintain a stable state, relevant practitioners must participate in the marine carbon sink project; otherwise, the system will fall into instability. The system will remain stable even when the other three parties are not involved and only relevant practitioners are involved, while the decisions of the other three parties cannot make the system stable or unstable.

3.3 Simulation analysis

According to the above analysis, the choice of the marine carbon sink demanders, relevant practitioners, the government, and investors in the process of evolutionary game will affect each other. In this paper, MATLAB 2020a software is used to simulate the strategy choice of each player in different situations to directly show the influence of the key elements in the replication dynamic system on the evolution process and results of the multi-party game. Refer to the existing research results (Wan et al., 2020; Wan et al., 2021; Wang et al., 2022; Giulia et al., 2023; Karol, 2023), and make the initial value $\omega_{1\ =}\ 0.2$, $\omega_{2\ =}\ 0.2$, $\delta = 0.5$, $\tau = 0.85$, $C = 25$, $S_{ub} = 10$, $P_{un} = 35$, $Q = 9$, $T_o = 19$, $F = 45$, $V = 6$, $T_r = 25$, $R_{1\ =\ 32}$ and $R_{2\ =}\ 12$.

Starting from different combinations of initial strategies, we evolve over time 60 times to obtain the initial array evolution path result in Figure 2. It can be seen from the results that under the condition of low risk coefficient, when the government's decision is stable to 1, that is, the government chooses the subsidy or adjusts the overlimit penalty, the system can reach a stable point $E_5(1, 1, 1, 1)$ when the demander, relevant practitioners, and investors of marine carbon sink all choose active strategies. At this time, the marine carbon sink demander has the demand to purchase marine carbon sink. Relevant practitioners adjust their strategies to develop marine carbon sink according to the changes in the supply and demand relationship of the carbon sink market so as to obtain more economic benefits. Investors are willing to invest based on the good prospects and great potential of the carbon sink market.

3.3.1 The impact of risk

(1) ω_1 impact on the marine carbon sink demander, relevant practitioners, the government, and investors

The remaining initial values remain unchanged, with $\omega_1 = 0.1$, $\omega_1 = 0.3$, $\omega_1 = 0.6$, and $\omega_1 = 0.9$, respectively, to obtain the influence of the risk coefficient change of the relevant practitioners on the square (Figure 3). According to Figure 3A when the risk coefficient borne by relevant practitioners changes from 0.1 to 0.9, the rate of the marine carbon sink demander to stabilize decisions gradually slows down. When the risk coefficient is 0.1, 0.3, and 0.6, the marine carbon sink demander will eventually choose to buy marine carbon sink. However, when the risk coefficient reaches 0.9, that is, when the relevant practitioners may choose not to develop the marine carbon sink, the final decision of the marine carbon sink demanders to trade the marine carbon sink is not to purchase the marine carbon sink. It can be seen that the risks faced by the relevant practitioners will significantly affect the decisions of the marine carbon sink demander. According to Figure 3B, when the risk

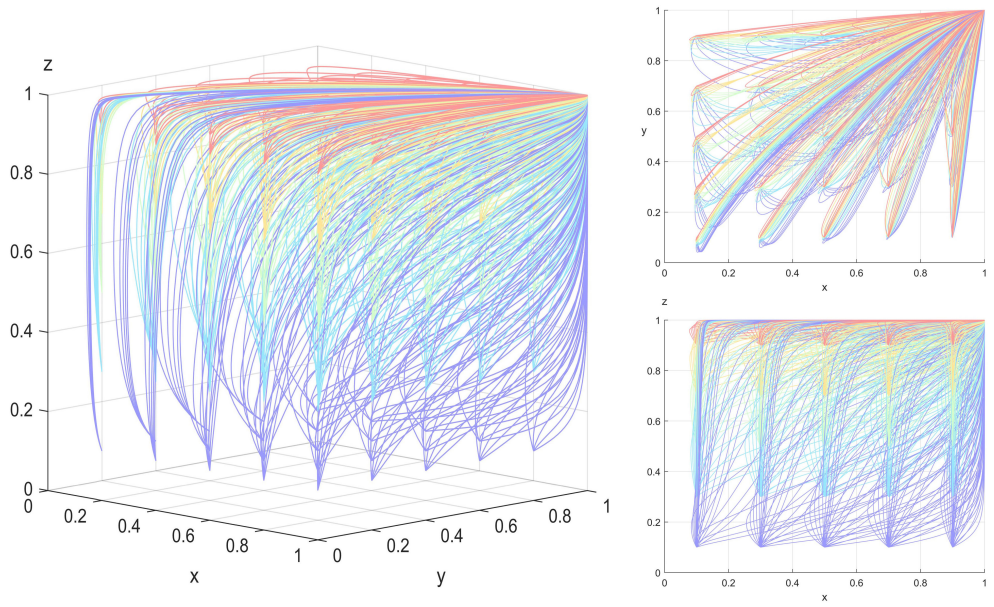


FIGURE 2
Initial array evolution path results.

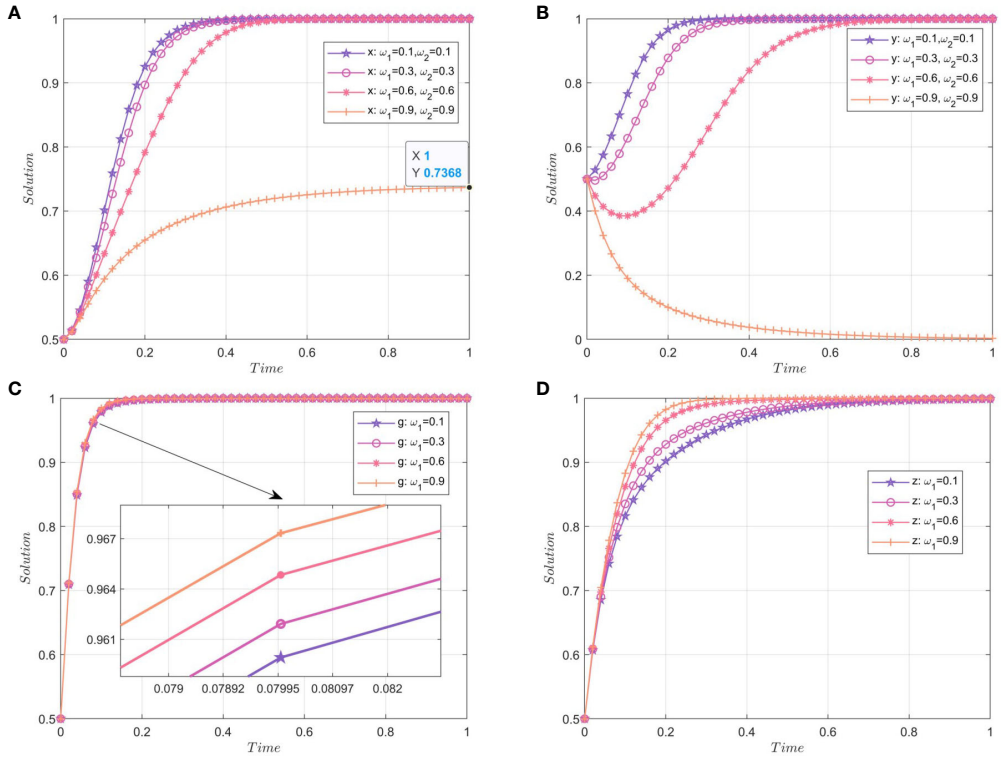


FIGURE 3
ω_1 impact on of marine carbon sink demander **(A)**, relevant practitioners **(B)**, government **(C)** and investors **(D)**.

coefficient of relevant practitioners is 0.6, the choice of their decision willingness fluctuates, with a gradual decrease followed by a steady increase to 1. If the risk coefficient increases again, the relevant practitioners will not develop the marine carbon sink. At this time, for the relevant practitioners, the cost (including risk and loss cost) of the development of the marine carbon sink is likely to be higher than the benefit. From Figure 3C regardless of the risk coefficient of the relevant practitioners, the government always makes the choice of incentive, unlike other cases; the higher the risk, the greater the probability of the government choosing the incentive. This may be because the government mainly plays a supervisory and management role in the development of marine carbon sinks. The willingness of relevant practitioners to develop marine carbon sinks will decrease due to the increased risk and damage to interests. For environmental protection considerations, the government increases subsidies to encourage relevant practitioners to develop marine carbon sinks. As can be seen from Figure 3D, because of the game of interest distribution with relevant practitioners, investors will make investments at all risk levels. In particular, the greater the risk coefficient is, the lower the development willingness of relevant practitioners, and investors are more willing to invest in order to obtain more direct economic income.

(2) ω_2 impact on relevant practitioners, governments, and investors

The remaining initial values remain unchanged, with ω_2 = 0.1, ω_2 = 0.3, ω_2 = 0.6, and ω_2 = 0.9, respectively, to obtain the impact of the risk coefficient of investors on relevant practitioners, governments, and investors (Figure 4). For the relevant practitioners (Figure 4A) and the government (Figure 4B), although the respective decisions are contrary to the change in the investor risk coefficient, they eventually stabilize. Among them, compared with the low risk coefficient of investors, the government shows more positive incentive willingness in the case of high risk coefficient of investors, which is exactly the same relationship with the risk coefficient of related practitioners. In order to actively promote the development of marine carbon sink to combat climate change, the government wants to encourage them to cope with the risks when relevant practitioners and investors shake their decisions due to risks. The decision-making willingness of relevant practitioners to develop marine carbon sinks is negatively correlated with the risk of investors, because of the competitive relationship between the two in the distribution of interests. The smaller the risk, the greater the probability that relevant practitioners will obtain a stable investment, and thus the willingness to develop marine carbon sinks is also higher. For relevant practitioners, having a stable source of funds can help deal with the risk of price fluctuations of factors of production such as labor, and provide a stronger guarantee for the development of marine carbon sink projects. In contrast, when the risk coefficient reaches 0.6, investors will still choose the strategy of investing in marine carbon sink projects for the sake of higher image and income. Once the risk coefficient is as high as 0.9, although a high image improvement income can be obtained in the short term, it will take decades for marine carbon sink projects from development to completion (Yang et al., 2021). In the long term, the loss caused by the risk may be

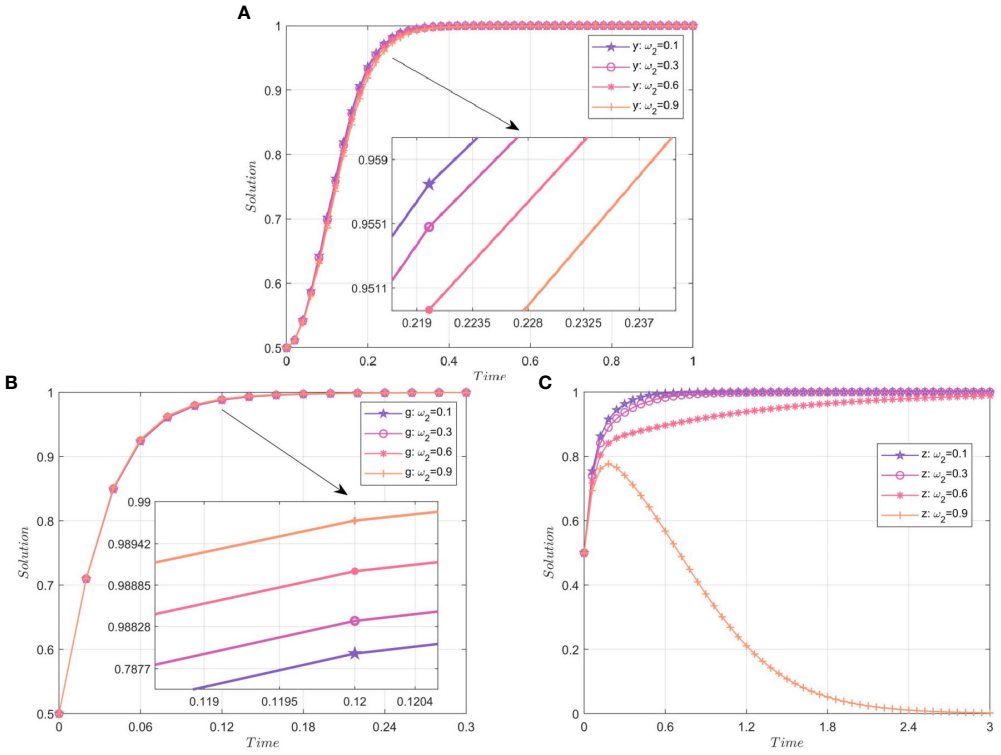


FIGURE 4
ω_2 impact on relevant practitioners **(A)**, government **(B)** and investors **(C)**.

greater. Therefore, investors finally choose to avoid risk, that is, not to invest in marine carbon sink projects.

(3) Impact of ω_1 and ω_2 synchronous changes on marine carbon sink demanders, relevant practitioners, and investors

The remaining initial values remain unchanged, making ω_1 and ω_2 change synchronously to 0.1, 0.3, 0.6, and 0.9, respectively, and obtaining the impact of the risk coefficient on marine carbon sink demanders, relevant practitioners, and investors (Figure 5). For the whole system, it is more often a situation where multiple risks coexist and the risks change at the same time. As can be seen from the group of figures in Figure 5, when the two risk coefficients change simultaneously, the marine carbon sink demanders (*a*), relevant practitioners (*b*), and investors (*c*) show different decision choices, but the decision change trend is similar to that of Figure 3. The situation is slightly different when the risk coefficient is high, because then, the marine carbon sink demander is less willing to purchase marine carbon sinks under the synchronous change of two risk coefficients. This may be because the demander considers the possibility of smooth carbon trading to be low, and the high risk makes them hesitant, but they still have other types of carbon sinks to choose from and so they purchase other carbon sinks with a lower risk. If investors believe that the project risk is not high after evaluation, and relevant practitioners believe that the project risk is high, and the development willingness decreases, investors will increase their investment intensity and move towards a stable strategy faster in order to allocate more economic returns and obtain higher social status than the relevant practitioners.

3.3.2 The impact of subsidies

Under risk conditions, the government always shows the willingness to actively subsidize, and government subsidies become one of the benefits of relevant practitioners, demanders, and investors. In order to further explore the impact of subsidies on each subject, the remaining initial values remained unchanged, i.e., $S_{ub} = 10$, $S_{ub} = 20$, $S_{ub} = 40$, and $S_{ub} = 60$, and obtained the impact of government subsidies on marine carbon sink demanders (a), relevant practitioners (b), the government (c), and investors (d) (Figure 6). It can be seen that when the risk coefficient is low, the increase in the amount of subsidies helps relevant practitioners bear more development costs. Within a certain range, the higher the amount of subsidies, the greater the willingness of relevant practitioners to choose to develop marine carbon sinks. However, when the amount of subsidies is high ($S_{ub} > 40$), the willingness of government incentives is reduced, falling into long-term unstable decision-making fluctuations, which will affect the decision-making of relevant practitioners. Once the decision of relevant practitioners to develop marine carbon sink becomes unknown, in order not to be punished by the government, the marine carbon sink demander will shift its purchase focus to terrestrial carbon sink, and the willingness to buy marine carbon sink may even be reduced to zero. At this time, only the investor's investment willingness is always nearly stable, and the higher the subsidy amount, the faster the stabilization policy is because investors focus more on the effectiveness of behavior than whether to take action. In other words, even if the relevant practitioners do not develop marine carbon sink, investors can obtain certain image improvement income

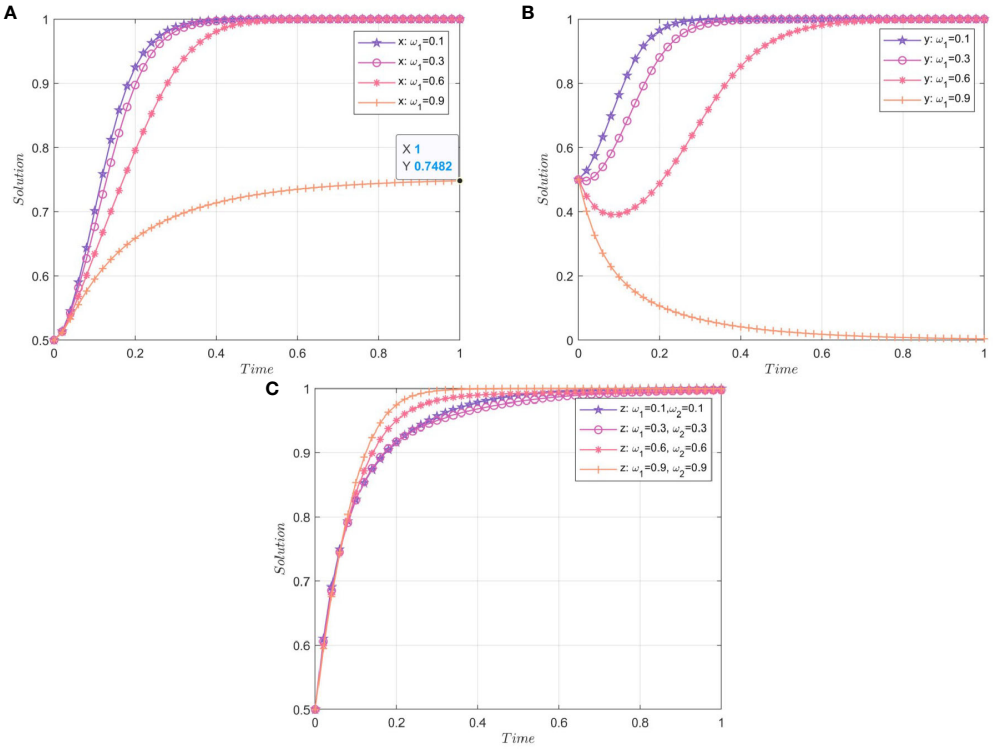


FIGURE 5
Impact of ω_1 and ω_2 synchronous changes on marine carbon sink demander **(A)**, relevant practitioners **(B)** and investors **(C)**.

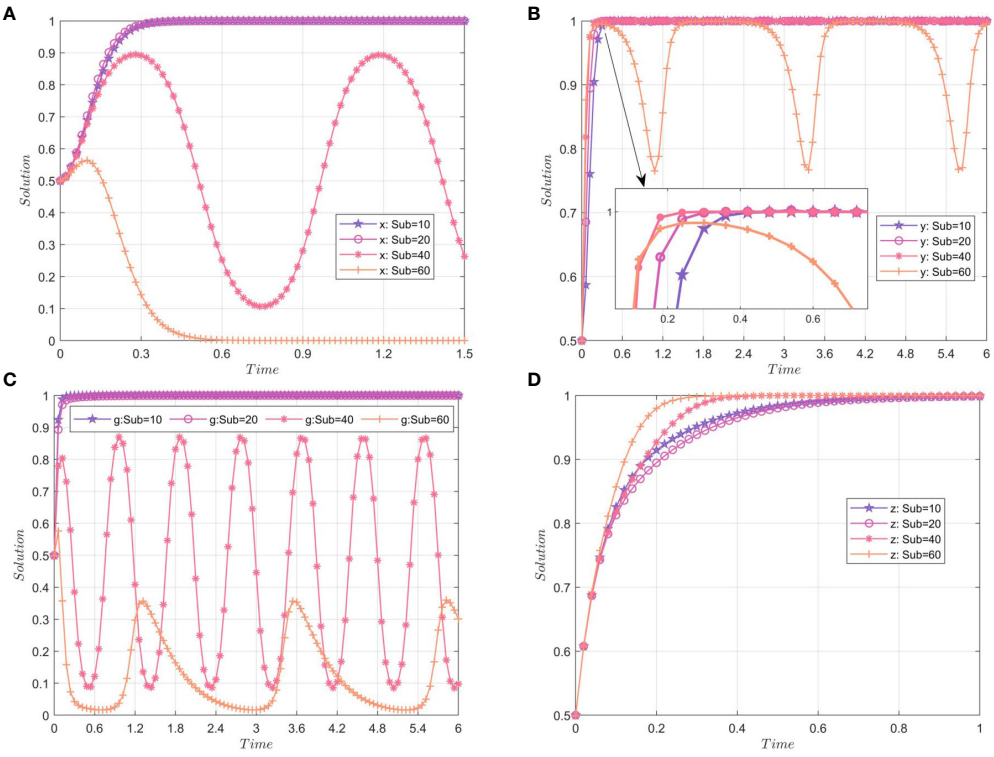


FIGURE 6
The impact of subsidies on the marine carbon sink demander **(A)**, relevant practitioners **(B)**, government **(C)** and investors **(D)**.

as long as they invest; thus, choosing investment is the most favorable decision.

3.3.3 The impact of image improvement

Under the risk condition, image improvement is an important income for the government, the demander, and investors to develop marine carbon sink projects, which affects their willingness to act. In order to further study the impact of image improvement on each subject, the rest of the initial values remain unchanged, i.e., δ = 0.3, δ = 0.5, and δ = 0.9, to get the impact of image improvement on relevant practitioners, the government, and investors (Figure 7). It can be seen that when the risk coefficient is low, with the image enhancement coefficient increasing, the investment willingness of investors gradually decreases, and the incentive willingness of the government gradually increases. When the distribution coefficient is 0.3 and 0.5, the investment enthusiasm of investors is still high, because at this time, the government and investors have not shown a very big difference in the distribution of income from image improvement. Even if there is a difference, it is still within an acceptable range, so the strategies of both tend to be stable in the end. However, when the image income allocated by the government is much higher than that of the investors, that is, the government allocates 90% of the image income, the investor's investment willingness drops to zero and he chooses not to invest. In the setting of this article, the relevant practitioners have no need for image improvement, only the pursuit of economic benefits, and so the change of image improvement coefficient has little impact on the relevant practitioners, and their decisions tend to be stable.

3.3.4 The impact of development costs

Under the risk condition, the income of each subject is closely related to the development cost, and when the income is greater than or far greater than the development cost, the subject will choose to develop the marine carbon sink project. In order to explore the impact of development cost on each subject, the remaining initial values remain unchanged, i.e., C = 25, C = 30, and C = 40, to obtain the impact of cost on relevant practitioners, government, and investors (Figure 8). It can be seen that when the risk coefficient is low, the increase in development cost means that the profits of relevant practitioners in developing marine carbon sinks are reduced. As a rational economic man, the willingness of relevant practitioners to develop marine carbon sinks is reduced from 0.2 to 0, indicating that it is more beneficial for relevant practitioners not to develop marine carbon sinks at this time. Because the carbon storage time of the marine carbon sink is longer than that of the general land carbon sink, based on the consideration of the carbon sink effect, the government will tend to make the decision of developing the marine carbon sink regardless of the development cost. Similarly, the development cost will not directly affect the economic return of investors. Thus, generally, investors will choose to make positive decisions, but the decision of relevant practitioners not to develop marine carbon sinks will reduce the economic return that some investors can obtain from the project, which has a small impact on investors' decisions.

In order to further explore the impact of economic income distribution on the three parties in the case of high cost, this paper selects the special case of C = 30, keeping the rest of the initial values unchanged, making τ = 0.1, τ = 0.5, and τ = 0.9 to get the impact of economic income distribution on relevant practitioners, the government, and investors (Figure 9). Under this cost setting, both the government and investors choose to make active decisions, and the relevant practitioners have a low willingness to develop. If the τ is small, investors can get more economic returns from the marine carbon sink projects. At this time, the relevant practitioners not only will face the considerable pressure of development cost, but also cannot get enough economic benefits. In order to avoid too much loss, the probability of choosing not to develop is greater. If the τ is large, the relevant practitioners can allocate more economic benefits and have more confidence and motivation to develop marine carbon sinks. Investors make up for the low distribution of economic returns by improving their higher image status, and the total returns still drive investors closer to positive strategies.

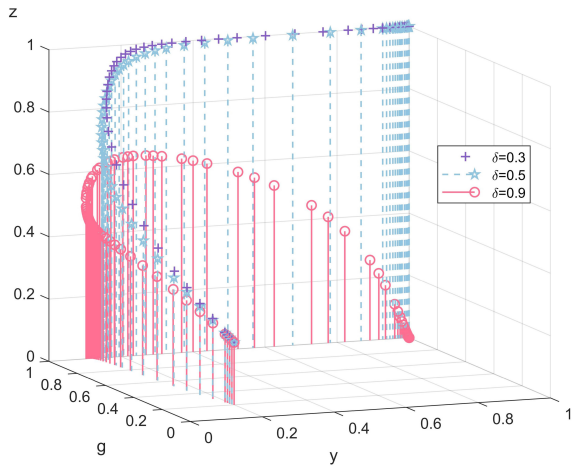


FIGURE 7
The impact of image improvement on relevant practitioners, government and investors.

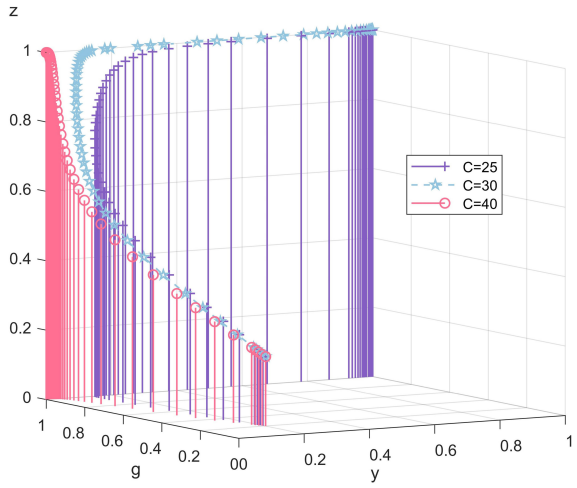


FIGURE 8
The impact of costs on relevant practitioners, government and investors.

4 Conclusions and countermeasures

4.1 Conclusions

This paper adopts the evolutionary game method to explore the game relationship and behavior mechanism of relevant practitioners, the government, investors, and demanders. After simulation and analysis, the influencing factors of the decision-making behavior of marine carbon sink project subjects under risk conditions are analyzed through feedback and adjustment. The willingness of each subject to take positive decisions and the impact of changes in various factors on their probability of behavior are analyzed. The main conclusions are as follows: (1) Government subsidies can promote the development of marine carbon sink projects, but when the subsidy amount is too large, the government is less willing, and even chooses not to subsidize, which may lead to significant changes in the decisions of relevant practitioners. (2) The government is not sensitive to the impact of risk changes, and always actively encourages relevant practitioners and investors. From the simulation results, it can be seen that the government pays more attention to the benefits of image improvement. Economic interests are the main driving force for the behavior of relevant practitioners and investors. When the risk poses a greater threat to the income, both parties will determine their own behavior strategies that can obtain more income according to the behavior decisions of the other party. (3) The strategies of relevant practitioners and investors will directly affect the behavior of the demander. Among them, the behavior choice of relevant practitioners, when faced with risks, has a greater impact on the demander, and the high risk increases the probability of the demander not buying marine carbon sink.

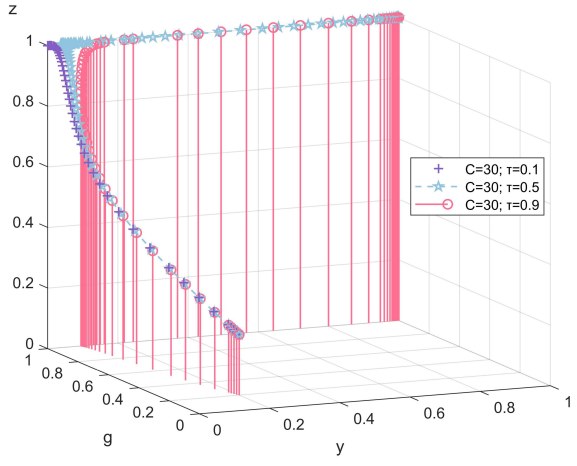


FIGURE 9
The impact of economic income distribution on relevant practitioners, government and investors in special circumstances.

4.2 Countermeasures

The results of this research and simulation show that the risk has a great impact on the behavior choice of the subjects of a marine carbon sink project, and the subjects will adjust their behavior to deal with the risk. Accordingly, in order to ensure the smooth development of marine carbon sink projects, this paper puts forward the following relevant suggestions:

(1) Given that subsidies can partially make up for the losses caused by risks and significantly increase relevant practitioners' willingness to participate in marine carbon sink projects, and since the behavior decisions of relevant practitioners affect the behavior of other subjects, the government should implement precise subsidies and differentiated subsidies. The government should pay attention to the adaptability and flexibility of the subsidy mechanism, and make dynamic adjustments based on the different types of marine carbon sink practitioners and the different output of marine carbon sink. Basic subsidies and incentive subsidies for a unit of marine carbon sink should be set, and the subsidy amount should be flexibly adjusted according to the effectiveness of project development, in order to improve the development willingness of practitioners (Shen et al., 2018). In addition, subsidies can help relevant practitioners share costs, indirectly reduce development costs to a certain extent, and enhance their confidence in responding to risks. Thus, the government can better play the role of subsidies by improving carbon market trading, formulating laws and regulations in the field of marine carbon sink, and improving the quality of professionals to further reduce the development costs of relevant practitioners.

(2) In order to encourage investors to choose positive strategies, the social influence of the development of marine carbon sink projects should be increased. Since most investors are banks and financial institutions, as the public recognition of marine carbon sink projects increases, they will be more inclined to handle savings, loans, and other businesses in these institutions participating in the development of marine carbon sink projects. In order to improve the public's attention and recognition of marine carbon sink, we can rely on holding offline- and online-related activities to strengthen the publicity of marine carbon sink-related knowledge, and increase the proportion of marine carbon sink in carbon inclusion. In addition, the government also needs to provide some policy incentives to investors, with the goal of promoting the stability of the funding chain in project development progress and strengthening cooperation with investors.

(3) Because of the significant impact of risks faced by practitioners due to demander's behavior choices in purchasing marine carbon sinks, it is necessary to reduce the risks faced by practitioners and thereby increase the willingness of the demander to buy marine carbon sinks. During the development process of marine carbon sink projects, relevant practitioners may face various risks such as invasion of diseases, pests, and alien species; natural disasters such as storm surge; inadequate government support policies; and high project development costs (He et al., 2023a). In this regard, the government should further improve the construction of a network system of marine climate observation, form a comprehensive observation and monitoring capacity of key elements of marine carbon sink development, and carry out an in-depth observation, early warning, a comprehensive investigation, and an evaluation of storm surge, waves, red tide, and other disasters, so as to provide technical support for effectively preventing natural risks of marine carbon sink. At the same time, it is necessary to clarify the work responsibilities of relevant management departments, establish a sound and efficient negotiation mechanism, and form a close multi-departmental and multi-level cooperative governance mechanism to reduce the impact of policy risks. In addition, it is necessary to optimize the management process of marine carbon sink projects, coordinate the services and management of the entire process of marine carbon sink projects, and strengthen the connection and coordination between resource development and market mechanisms, thereby reducing obstacles to market risks.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

YH: Conceptualization, Supervision, Writing – review & editing. YW: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was supported by the National Social Science Foundation of China (Grant No. 23BJY197).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Bañolas, G., Fernández, S., Espino, F., Haroun, R., and Tuya, F. (2020). Evaluation of carbon sinks by the seagrass Cymodocea nodosa at an oceanic island: Spatial variation and economic valuation. *Ocean Coast. Manage.* 187, 105112–105112. doi: 10.1016/j.ocecoaman.2020.105112

Cao, Y. M., Kang, Z. Q., Bai, J. D., Cui, Y., Chang, I.-S. H., and Wu, J. (2022). How to build an efficient blue carbon trading market in China? - A study based on evolutionary game theory. *J. Clean. Prod.* 367, 132867. doi: 10.1016/J.JCLEPRO.2022.132867

Chen, G. C. (2021). China has successfully traded the first "blue carbon". *carbon sink project. J. Appl. Oceanography* 40, 555–556. (in Chinese).

Chen, J. L., Huang, G. R., and Chen, W. J. (2021). Towards better flood risk management: Assessing flood risk and investigating the potential mechanism based on machine learning models. *J. Environ. Manage.* 293, 112810–112810. doi: 10.1016/j.jenvman.2021.112810

Fan, W., Wang, S., Gu, X., Zhou, Z., Zhao, Y., and Huo, W. (2021). Evolutionary game analysis on industrial pollution control of local government in China. *J. Environ. Manage.* 298, 113499–113499. doi: 10.1016/j.jenvman.2021.113499

Friedman, D. (1998). On economic applications of evolutionary game theory. *J. Evol. Econ.* 8, 15–43. doi: 10.1007/s001910050054

Giulia, M. Z., Angela, B., Claudia, R., Alessandro, P., and Renata, A. (2023). Traditional vs. novel approaches to coastal risk management: A review and insights from Italy. *J. Environ. Manage.* 346, 119003–119003. doi: 10.1016/j.jenvman.2023.119003

He, Y. X., Hu, Y. B., Xie, S. M., Li, C. L., Xu, M., and Chen, X. Y. (2022b). Risk and impacts associated with marine carbon sink projects: an example from Guangdong, China. *J. Coast. Res.* 39, 246–256. doi: 10.2112/JCOASTRES-D-22-00041.1

He, Y. X., Wang, Y. W., and Xie, S. M. (2023b). Study on the risk measurement and evaluation of the whole life cycle of mangrove carbon sink project from the perspective of the supply subject: Take the Zhanjiang mangrove afforestation project as an example. *Mar. Sci. Bull.* 43, 248–264. (in Chinese).

He, Y. X., Wang, Y. W., Xie, S. M., and Luo, W. L. (2022a). Research progress of marine carbon sink in China : Literature analysis based on CNKI(2006-2021). *Mar. Economy* 12, 1–16. doi: 10.19426/j.cnki.cn12-1424/p.20220630.002

He, Y. X., and Zhang, F. X. (2023). A game study on the implementation of marine carbon sink fisheries in the context of carbon neutrality – Analysis of the tripartite behavior of fishery practitioners, research institutions, and the government. *Mar. Policy* 147, 105365. doi: 10.1016/j.marpol.2022.105365

He, Y. X., Zhang, F. X., and Wang, Y. W. (2023a). How to facilitate efficient blue carbon trading? A simulation study using the game theory to find the optimal strategy for each participant. *Energy* 276, 127521. doi: 10.1016/j.energy.2023.127521

Karol, M. (2023). Sharing risk to avoid tragedy: Informal insurance and irrigation in village economies. *J. Dev. Econ.* 161, 103030. doi: 10.1016/J.JDEVECO.2022.103030

Li, X. Q., Dong, Z. F., and Li, X. L. (2022). International experiences and enlightenment of climate legislation towards carbon neutrality. *Environ. pollut. Control* 44, 261–265. doi: 10.15985/j.cnki.1001-3865.2022.02.021

Li, J., Li, M. D., Gong, P. H., and Guan, C. T. (2022). Research progress on fishery carbon sinking associated with marine ranching. *Prog. Fishery Sci.* 43, 142–150. doi: 10.19663/j.issn2095-9869.20220118002

Li, M. X., Xu, C. C., Wang, T., and Hu, J. (2022). Progress, challenges and development strategies of China's marine carbon sink trading under the goal of carbon neutrality and emission peak. *Sci. Technol. Manage. Res.* 43, 193–200. (in Chinese).

Li, X. N., Yi, S. Y., Cundy, A. B., and Chen, W. P. (2022). Sustainable decision-making for contaminated site risk management: A decision tree model using machine learning algorithms. *J. Clean. Prod.* 371, 133612. doi: 10.1016/j.jclepro.2022.133612

Lyapunov, A. M. (2007). The general problem of the stability of motion. *Int. J. Control* 55, 531–534. doi: 10.1080/00207179208934253

Masud, M. M., Sackor, A. S., Alam, A. S. A. F., Al-Amin, A. Q., and Ghani, A. B. A. (2018). Community responses to flood risk management – An empirical Investigation of the Marine Protected Areas (MPAs) in Malaysia. *Mar. Policy* 97, 119–126. doi: 10.1016/j.marpol.2018.08.027

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., et al. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Front. Ecol. Environ.* 9. doi: 10.1890/110004

Nellemann, C., Corcoran, E., Duarte, C., Valdes, L., and Grimsditch, G. (2009). *Blue carbon. A rapid response assessment* (GRID-Arendal, Norway: United Nations Environment Programme).

Ritzberger, K., and Weibull, W. J. (1995). Evolutionary selection in normal-form games. *Econometrica* 63, 1371–1399. doi: 10.2307/2171774

Sabine, C. L., Feely, R. A., Gruber, N., Key, R. M., Lee, K., and Bullister, J. L. (2004). The oceanic sink for anthropogenic CO2. *Science* 305, 367–371. doi: 10.1126/science.1097403

Shen, J. S., Wang, Z. P., and Wang, X. Q. (2018). A study on incentive subsidy of blue carbon in marine ranch. *J. Ocean Univ. China(Social Sciences)* 16-21, 1747–1748. doi: 10.16497/j.cnki.1672-335x.2018.02.003

Wan, X. L., Li, Q. Q., Qiu, L. L., and Du, Y. W. (2021). How do carbon trading platform participation and government subsidy motivate blue carbon trading of marine ranching? A study based on evolutionary equilibrium strategy method. *Mar. Policy* 130, 104567. doi: 10.1016/J.MARPOL.2021.104567

Wang, S., Liu, C., Hou, Y. T., and Xue, X. Z. (2022). Incentive policies for transboundary marine spatial planning: an evolutionary game theory-based analysis. *J. Environ. Manage.* 312, 114905. doi: 10.1016/j.jenvman.2022.114905

Wan, X. L., Xiao, S. W., Li, Q. Q., and Du, Y. W. (2020). Evolutionary policy of trading of blue carbon produced by marine ranching with media participation and government supervision. *Mar. Policy* 312, 104302. doi: 10.1016/J.MARPOL.2020.104302

Watanabe, K., Yoshida, G., Hori, M., Umezawa, Y., Moki, H., and Kuwae, T. (2020). Macroalgal metabolism and lateral carbon flows can create significant carbon sinks. *Biogeosciences* 17, 2425–2440. doi: 10.5194/bg-17-2425-2020

Wei, Z. H. H., Jang, X. Z. H., Zhao, Z. H. B., Xu, W. L., Guo, L. Y., and Zheng, Q. Y. (2023). Can ocean carbon sink trading achieve economic and environmental benefits? Simulation based on DICE-DSGE model. *Environ. Sci. pollut. Res. Int.* 30, 72690–72709. doi: 10.1007/s11356-023-27435-x

Yang, Z. (2022). Quadripartite evolutionary game of public participation in interactivetransboundary pollution control compensation. *Chin. J. Manage. Sci.*, 1–14. doi: 10.16381/j.cnki.issn1003-207x.2021.1416

Yang, Y., Chen, L., and Xue, L. (2021). Top design and strategy selection of blue carbon market construction in China. *China Population, Resources Environ.* 31, 92–103. (in Chinese).

Yu, L. H., Zhen, S., and Gao, Q. (2023). Independent or collaborative management? Regional management strategy for ocean carbon sink trading based on game theory. *Ocean Coast. Manage.* 235, 106484. doi: 10.1016/j.ocecoaman.2023.106484

Zhang, F. X., He, Y. X., Wang, Y. W., Xie, S. M., Liu, R. Z., and Xu, M. (2023b). Incentive effects of marine carbon sink on carbon emission disclosure: Ananalysis considering purchase price from a game-theoretic perspective. *China Environ. Sci.* 43, 4975–4987. doi: 10.19674/j.cnki.issn1000-6923.20230316.001

Zhang, F. X., He, Y. X., Xie, S. M., Shi, W. T., Zheng, M. X., and Wang, Y. W. (2023a). Research on the game of fishermen's cooperative behavior in developing marine carbon sink fisheries from a complex network perspective. *Ocean Coast. Manage.* 244, 106832. doi: 10.1016/j.ocecoaman.2023.106832

Zhang, C., Shi, T., Liu, J., He, Z., Thomas, H., Dong, H., et al. (2022). Eco-engineering approaches for ocean negative carbon emission. *Sci. Bull.* 67, 2564–2573. doi: 10.1016/j.scib.2022.11.016

Zhang, K. X., Zhang, X. T., and Ding, L. (2023). How to incentivize bank credit development in blue carbon projects? A study of refinancing mechanisms with evolutionary game. *Ocean Coast. Manage.* 241, 106671. doi: 10.1016/j.ocecoaman.2023.106671

Zhang, X. X., Zheng, S., and Yu, L. H. (2020). Green efficiency measurement and spatial spillover effect of China's marine carbon sequestration fishery. *Chin. Rural Economy*, 91–110. (in Chinese).

Zhao, T., Liu, Z., and Tooraj, J. (2022). Developing hydrogen refueling stations: An evolutionary game approach and the case of China. *Energy Economics* 115, 106390. doi: 10.1016/j.eneco.2022.106390

Zhou, J. X., Huang, L. J., Shen, G. Q., Wu, H. Q., and Luo, L. Z. (2023). Modeling stakeholder-associated productivity performance risks in modular integrated construction projects of Hong Kong: A social network analysis. *J. Clean. Prod.* 423, 138699. doi: 10.1016/j.jclepro.2023.138699

Zhuang, W., Song, X. C., Liu, M., Wang, Q., Song, J. M., Duan, L. Q., et al. (2023). Potential capture and conversion of CO2 from oceanwater through mineral carbonation. *Sci. Total Environ.* 867, 161589. doi: doi: 10.1016/J.SCITOTENV.2023.161589

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 04 July 2024
DOI 10.3389/fmars.2024.1429781

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Shih-Ming Kao,
National Sun Yat-sen University, Taiwan
Mehran Idris Khan,
University of International Business and Economics, China
Maruf M.,
Dalian Maritime University, China
Hongyun Huang,
Shandong University, China

*CORRESPONDENCE
Yinxiao Xu
761011309@qq.com

RECEIVED 08 May 2024
ACCEPTED 17 June 2024
PUBLISHED 04 July 2024

CITATION
Mao S and Xu Y (2024) Manufacturing maritime firms' environmental behaviors: theory and practice.
Front. Mar. Sci. 11:1429781.
doi: 10.3389/fmars.2024.1429781

COPYRIGHT
© 2024 Mao and Xu. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Manufacturing maritime firms' environmental behaviors: theory and practice

Shuling Mao[1] and Yinxiao Xu[2]*

[1]School of Law and Politics, Liaoning Normal University, Dalian, China, [2]Law School, East China University of Political Science and Law, Shanghai, China

Analyzing the factors that influence maritime manufacturing firms' environmental behavior is of significant theoretical and practical importance, particularly from a managerial cognition perspective. This study applies the regulatory focus theory to examine the complex relationship between environmental quality, regulation, and firms' environmental actions. Our findings reveal a U-shaped relationship between regional environmental quality and local firms' environmental consciousness. In regions with either better or poorer environmental conditions, firms demonstrate higher environmental consciousness. Specifically, firms in regions with better environmental quality exhibit a "promotion focus" on environmental issues, leading to proactive engagement in green innovation. Conversely, firms in regions with poor environmental quality adopt a "prevention focus" by pursuing ISO 14001 certification to maintain legitimacy and mitigate penalties. Moreover, we find that incentive regulations are more effective at stimulating green innovation among firms operating in regions with good environmental quality. In contrast, mandatory regulations drive higher ISO 14001 certification rates among firms located in areas with poor environmental quality. This study offers insights into the internal and external motivators of firms' environmental behavior, contributing to the literature on corporate environmental responsibility. Additionally, it provides policy recommendations to encourage active participation in environmental initiatives among maritime manufacturing firms.

KEYWORDS

manufacturing maritime firms, environmental quality, marine environmental consciousness, Environmental behavior, environmental regulation, regulatory focus theory

1 Introduction

Currently, approximately 97% of international trade is conducted via sea (Chang and Khan, 2023), implying that the shipping industry significantly contributes to carbon emissions and environmental pollution. Over the past decade, as global warming and climate change have accelerated, there has been a growing focus on environmental

management. This has led to increased interest in Green Supply Chain Management (GSCM) among businesses, governments, and consumers (Shang et al., 2010; Wu et al., 2012). Similarly, growing pressure for sustainable socio-economic development has led to increased attention from various sectors regarding environmental protection and sustainable development. Shipping firms are confronting new opportunities and challenges in the contemporary global economy. Specifically, there is a growing public awareness and concern about environmental issues such as resource depletion and pollution associated with shipping activities, spurred by the globalization of business operations (Lai et al., 2011). Business and political leaders have extensively deliberated on the topics of environmental conservation and sustainable resource management (Obama, 2009). In 2020, China committed to global climate and ecological preservation by announcing its goal to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. Strengthening management and control at the "emission source" is essential to achieving this goal. Firms, acting as emission entities, play a pivotal role in achieving the "30–60 dual carbon goals."

Currently, environmental pollution and ecological destruction resulting from production and daily activities are still at a high level. In addition to factors such as delayed legislation and funding challenges, a crucial factor is the perception of ecological resources as free public goods in the traditional mindset of individuals, particularly profit-driven entrepreneurs. Moreover, the impact on the marine environment is particularly significant. Marine ecosystems face unique challenges due to pollution, overfishing, habitat destruction, and climate change. The degradation of marine resources not only threatens biodiversity but also affects industries reliant on healthy oceans, such as fisheries, tourism, and maritime transportation. Many top managers in enterprises lack a sense of responsibility and willingness to foster an ecological civilization, resulting in their reluctance to allocate resources to environmental protection. Consequently, understanding the complicated antecedents of firms' environmental consciousness is a crucial direction for analyzing their environmental behaviors (Bansal and Roth, 2000; Bianchi et al., 2022).

In assessing environmental consciousness within business contexts, it is important to analyze the specific behaviors and attitudes of maritime manufacturing firms towards ecological civilization and environmental protection (Chen and Zheng, 2020; Nazir et al., 2024). The maritime sector, encompassing industries such as shipbuilding, marine equipment manufacturing, and shipping logistics, faces unique challenges and opportunities related to environmental sustainability. Maritime manufacturing firms play a significant role in global trade and transportation, but they also have a substantial impact on marine ecosystems and coastal environments (Chen and Zheng, 2020; Tan et al., 2022). Despite growing awareness of environmental issues, studies suggest that many maritime manufacturing firms still face obstacles in adopting environmentally friendly practices due to factors such as cost concerns, regulatory complexities, and perceived conflicts between profitability and sustainability goals (Tan et al., 2022; Li et al., 2023).

It is crucial to recognize that the external environment, encompassing natural and institutional aspects, plays a significant role in shaping corporate environmental consciousness. However, prior research frequently treats executive environmental consciousness as a predetermined factor, focusing on its impact on firm behavior and performance (Chang, 2011), but neglects the process of environmental consciousness formation. The natural development of environmental consciousness is inherently challenging, and individuals' perception and appreciation of the natural environment are significantly influenced by the feedback they receive from both natural and social realms. Furthermore, while certain studies have observed changes in individual environmental consciousness influenced by a combination of natural and social factors (Franzen and Meyer, 2010), they have not thoroughly examined or deconstructed the concept of "environmental consciousness." There is an important dimension of consciousness — the regulatory focus.

Significantly, there are divergent focuses in terms of environmental consciousness. Specifically, some firms prioritize the "costs of pollution," while others prioritize the "benefits of green initiatives" (Wright and Nyberg, 2017). Various external environmental factors catalyze the emergence of different focuses, which in turn cause firms to prioritize environmental behavior in varying ways. Therefore, a comprehensive understanding of the notable differences in specific environmental behaviors among firms is elusive unless a specific analysis of the causes of environmental consciousness is conducted, and the regulatory focus of environmental consciousness is classified and discussed. Furthermore, enterprises are increasingly opting to implement environmental initiatives voluntarily, based on the belief that these actions will enhance environmental conditions and support economic growth (Lai et al., 2010). However, a recent study investigating green practices across various industrial sectors discovered that firms often do not align closely with this "win-win" mindset (Zhu et al., 2008). One prominent reason underlying this discrepancy is the absence of compelling incentives to justify the investment of time and resources required to embrace green practices.

Second, research on environmental consciousness often establishes a direct, linear relationship between environmental consciousness and behavior (Harris, 2008). Most studies assume that firms will engage in more environmental behaviors if their top managers have environmental consciousness. However, it is often observed that heavily polluting firms, despite having greater sensitivity and understanding of pollution emissions and environmental information than others, often lack the motivation to engage in environmental behavior proactively. Therefore, what is the true relationship between firms' environmental consciousness and their environmental behavior? The paper argues that there is currently no convincing answer to this question due to two key factors. One reason is that previous studies failed to consider varying dimensions of environmental consciousness specially in maritime manufacturing sector. The other is the absence of an examination of how managers' environmental consciousness impacts corporate environmental behavior across various situations such as marine manufacturing sector.

Third, existing research also indicates that firms' environmental behavior depends on the intervention of environmental regulations. The relationship between environmental regulations and maritime firms' environmental behavior has consistently been a crucial research topic (Reid and Toffel, 2009; Rennings and Rammer, 2011). Although, firm's policy and procedure (FPP) involves a corporate dedication to a sustainability vision or culture within a shipping firm. This includes commitments from senior managers to GSPs, backing for GSPs from mid-level managers, collaboration across departments for green initiatives, environmental compliance and auditing programs, ISO 14001 certification, environmental policy establishment, and system implementation. For example, Maersk prioritizes environmental protection and integrates this commitment into its business management. Maersk's environmental policy emphasizes minimizing environmental impact through resource conservation, operational optimization, and waste management, while continuously striving to enhance environmental performance and prevent pollution across all activities (Lai et al., 2011). Similarly, from a regulatory perspective, the adoption of Environmental Compliance (2007) developed by the International Chamber of Shipping and International Shipping Federation (available at www.marisec.org/environmental-compliance) imposes pressure on shipping companies to embrace GSPs.

Furthermore, the "Porter hypothesis" posits that while strict environmental policies may increase costs in the short term, they can stimulate firms to pursue technological innovations, leading to the adoption of more efficient production technologies and ultimately enhancing industrial competitiveness in the long run (Wubben, 2000; Chygryn et al., 2021). Since the Porter hypothesis was proposed, scholars have been involved in vigorous debates about its validity (Andersson and Börjesson, 2021). However, these debates have resulted in inconsistent research conclusions (Ford et al., 2014; Currie and Walker, 2019).

Although these studies have presented evidence for or against the Porter hypothesis from their respective perspectives, they have overlooked a crucial premise: the significance of well-designed environmental regulations. Environmental regulations can be classified into different types, including mandatory regulations and incentive regulations. The reasonable combination and design of different types of environmental regulations can often lead to favorable outcomes. Therefore, this study posits that selecting appropriate environmental regulations is vital for effectively guiding maritime firms' environmental behavior.

In the context of maritime ecosystems, the impact of environmental regulations is particularly important. Marine ecosystems face significant threats from pollution, overfishing, habitat destruction, and climate change, which can disrupt the delicate balance of marine life. Likewise, within maritime manufacturing, environmental behavior plays a critical role in minimizing the ecological footprint of shipbuilding, marine equipment manufacturing, and shipping logistics. By aligning environmental regulations with the unique challenges of maritime ecosystems and the environmental behavior of maritime manufacturing firms, policymakers can foster sustainable practices that promote the health and resilience of marine environments while supporting responsible industrial activities. Effective incentivization of firms' environmental efforts occurs when environmental regulations are tailored to the specific needs and focus of maritime stakeholders, promoting positive environmental outcomes across the maritime sector.

Hence, Firms that adopt a long-term orientation prioritize future-oriented strategies and investments, as opposed to short-term oriented firms that aim for immediate low-cost returns. Long-term oriented firms are more inclined to prioritize reducing their greenhouse gas (GHG) emissions, as they tend to allocate resources towards environmental efforts even when the benefits are not immediate or directly advantageous to the firm (Wang, 2016; Sternad and Kennelly, 2017).

To sum up, the existing literature has laid a foundation for studying the antecedents of maritime firms' environmental behavior, yet certain gaps remain. This study aims to address the following three research questions: First, what is the relationship between regional environmental quality and firms' environmental consciousness, particularly within the context of maritime manufacturing firms and their interactions with the marine environment? Second, how does the environmental consciousness of maritime manufacturing firms influence their environmental behaviors, especially concerning marine ecosystem sustainability? Third, how can the alignment of environmental regulations and the regulatory focus of environmental consciousness better incentivize maritime manufacturing firms' environmental behaviors towards marine ecosystem protection and sustainability?

This study aims to conduct an empirical analysis of maritime manufacturing firms, utilizing regulatory focus theory to explore how managers' orientations towards environmental issues impact their firms' environmental behaviors, particularly in relation to the marine environment. By examining the influence of managers' regulatory focus—whether promotion-focused, which emphasizes aspirations and accomplishments, or prevention-focused, which prioritizes safety and responsibility—the study seeks to understand how these orientations shape environmental practices within these firms. Additionally, the research investigates the effects of various types of environmental regulations, including command-and-control, market-based, and voluntary approaches, on the environmental behaviors of maritime manufacturing firms. By identifying the incentives created by different regulatory frameworks, the study aims to align these frameworks with the environmental consciousness of maritime manufacturing firms to promote sustainable practices. Ultimately, the objective is to provide insights into effective regulatory strategies that foster responsible stewardship of the marine environment and advance environmental sustainability in the maritime manufacturing sector.

2 Literature review

2.1 Environmental quality and maritime firms' environmental consciousness

Sustainable development is defined as the process of fulfilling current needs without jeopardizing the ability of future generations

to satisfy their own requirements. This concept has garnered universal endorsement and has progressively been enshrined in national and international legal frameworks and policies, such as the 1992 Rio Declaration, Agenda 21, and the Johannesburg Declaration. A fundamental aim of sustainable development is to reconcile resource utilization with environmental stewardship, ensuring that they are neither contradictory nor antagonistic, but rather mutually reinforcing. Environmental preservation is imperative for achieving sustainable resource exploitation, while the economic gains derived from resource use can create the conditions most conducive to effective environmental protection (Zou and Chang, 2021).

Environmental consciousness encompasses societal concern, attention, and understanding of environmental knowledge. Only when people have awareness and concern about environmental problems will they engage in environmental protection behaviors (Franzen and Meyer, 2010). Likewise, within firms, active guidance towards environmental protection activities is only possible when managers possess environmental responsibility, environmental consciousness, or environmentalist beliefs (Chang, 2011). Consequently, numerous studies grounded in environmental psychology have thoroughly examined the environmental consciousness of executives (Boiral et al., 2018). However, existing research often treats individual environmental consciousness as a static factor, focusing on its impact on firm behavior and performance while overlooking the complex antecedents that shape it. This oversight makes it challenging to fully understand the factors contributing to the variations in specific environmental behaviors observed among maritime firms.

Therefore, it is crucial to explore the environments in which individuals within the maritime sector exhibit heightened environmental consciousness and prioritize environmental issues. Drawing from a synthesis of existing research and practical experience in the maritime industry, this study emphasizes that individuals in maritime contexts tend to exhibit heightened environmental consciousness in environments characterized by distinct environmental qualities. As the International Maritime Organization (IMO) confronts governance challenges in today's context—exacerbated by climate change and technological advancements, such as artificial intelligence—initiatives like scoping exercises, the Sulphur 2020 regulations, and GHG emissions controls represent ambitious measures. These efforts are aimed at integrating new technologies and mitigating air pollution from ships, thereby navigating the complexities of contemporary maritime environmental management (Mukherjee et al., 2020; Khan et al., 2023).

The first situation follows the "pollution driving hypothesis," indicating that in regions with compromised environmental quality and escalated pollution levels, pollution will have significant adverse impacts on regional productivity and livelihoods (Franzen and Meyer, 2010). Thus, public environmental consciousness will be enhanced. For example, severe air pollution has had detrimental effects on residents' health. Additionally, water pollution and soil degradation have caused a scarcity of resources crucial for supporting regional economic development. In this situation, residents will gradually prioritize environmental protection and pollution control, fostering the motivation of individuals to bring about favorable changes in the environment. This effect influences managers in the region by directly altering their attitudes. Besides, it affects the attitudes of local stakeholders, such as the government, the community, and employees. Stakeholders' heightened demands on the environment compel managers to prioritize environmental protection and strive for energy conservation and emission reduction. Consequently, shipping materials (SM) focuses on recovering and repurposing used shipping resources to reduce costs and enhance operational efficiency. This includes activities such as selling surplus equipment and facilities, marketing used shipping materials like packaging and cartons, and collecting and reselling used oil. For instance, Maersk has implemented a thorough company policy regarding vessel recycling. This policy necessitates rigorous inspections of vessels prior to delivery to a recycling yard. These inspections ensure that recycled ships are free from oil spills, toxic water discharge, and other harmful environmental impacts associated with shipping material disposal. The procedures involve conducting radiation surveys and auditing hazardous materials to minimize environmental impacts during vessel recycling. Additionally, Maersk prioritizes designing and constructing new vessels with a high recycling ratio in mind (Lai et al., 2011).

However, the "pollution-driven hypothesis" suggests a positive linear relationship between pollution levels and public environmental consciousness. In fact, this research overlooks another situation: residents' value environmental protection in areas with high environmental quality. They are sensitive to non-compliant pollution emissions and environmental damage. They have higher demands and are concerned about potential environmental pollution (Bickerstaff and Walker, 2001), resulting in a positive response to environmental issues. Additionally, given the rising awareness of environmental issues across society, residents in areas with better environmental quality perceive "greenness" as a valuable resource for local socio-economic development (Porter and Kramer, 2019), representing a highly significant development advantage compared to other areas affected by pollution. Likewise, this will directly and indirectly affect the level of environmental concern among managers and shape firms' environmental consciousness.

In contrast, environmental issues may not attract significant attention from residents in maritime areas with relatively moderate environmental quality. Stakeholders in these regions may also place relatively low emphasis on environmental protection and pollution control. Therefore, environmental issues within the maritime sector may go unnoticed by managers whose primary goal is to maximize profits. Based on the above analysis within the maritime context, this study presents the baseline hypothesis: There is a U-shaped relationship between regional environmental quality and maritime firms' environmental consciousness. However, shipping design and compliance (SDC) entails sophisticated strategies aimed at minimizing the environmental impact of shipping activities throughout their lifecycle while ensuring compliance with regulatory standards. This involves implementing innovative approaches such as designing shipping activities and equipment to optimize material and energy usage, integrating practices that promote reuse, recycling, and material recovery, and developing

advanced equipment that reduces reliance on polluting energy sources (Lai et al., 2011). One key aspect of SDC is optimized voyage planning, which plays a crucial role in achieving fuel savings and environmental efficiency. For instance, Maersk has introduced the Voyage Efficiency System (VES), a sophisticated tool designed to identify the most fuel-efficient routes and implement a just-in-time steady running strategy. Additionally, initiatives like the Los Angeles Harbor Commission's Vessel Speed Reduction (VSR) Program, which encourages vessels to voluntarily reduce speed to a 12-knot limit within specific zones, demonstrate the commitment to environmental stewardship. Maersk actively participates in such programs, like the Ports of Los Angeles/Long Beach Vessel Speed Reduction Program, contributing to sustainable shipping practices (Lai et al., 2011).

Furthermore, Borja and colleagues explore the definition of Good Environmental Status (GES) as outlined by the European Union (EU) Marine Strategy Framework Directive (MSFD). GES is defined as the condition where marine waters provide ecologically diverse and dynamic oceans and seas which are clean, healthy, and productive. They emphasize the importance of operationalizing this concept by establishing clear, measurable indicators and targets. They discuss the 11 descriptors provided by the MSFD, which include biodiversity, fish populations, eutrophication, sea floor integrity, and contaminants, among others. They underscore the challenges in achieving GES, particularly due to the complexity and variability of marine ecosystems and the pressures exerted by human activities (Borja et al., 2013). Similarly, Cochrane and colleagues focus on the biological diversity descriptor of the MSFD. It details the criteria and methodological standards necessary for assessing biodiversity to achieve GES. They provide a comprehensive approach to monitoring and assessing marine biodiversity, including species, habitats, and ecosystems. They highlight the importance of maintaining ecosystem structure and functions and stress the need for coordinated monitoring efforts across EU member states. The report serves as a guideline for implementing biodiversity assessments and emphasizes the role of scientific research in informing policy decisions (Cochrane et al., 2010).

In addition, the foundational legal document of the MSFD outlines its objectives to protect and preserve the marine environment, prevent its deterioration, and, where practicable, restore marine ecosystems in areas where they have been adversely affected. The directive aims to achieve GES of the EU's marine waters by 2020 and ensure the sustainable use of marine goods and services. It mandates member states to develop Marine Strategies that include an initial assessment of their marine waters, determination of GES, establishment of environmental targets and monitoring programs, and the implementation of measures designed to achieve or maintain GES (European Commission, 2008). Likewise, Mee and colleagues examine the human values underlying the concept of GES and the implications for the MSFD. They discuss the difficulty of defining "good" environmental status due to the subjective nature of human values and perceptions. They argue that achieving GES requires balancing ecological, economic, and social objectives, which can sometimes be conflicting. The authors advocate for a participatory approach in the decision-making process, involving stakeholders from various sectors to ensure that the measures taken are equitable and reflect societal values (Mee et al., 2008).

2.2 Regulatory focus theory and maritime firms' environmental consciousness

Emerging issues in ocean governance encompass a wide range of concerns, including plastic pollution, blue carbon, ocean acidification, deep-sea mining, large marine protected areas, biodiversity conservation in international waters, aquaculture, and small-scale fisheries (Chang, 2023). Addressing these issues, alongside other scientific endeavors, necessitates the development of appropriate rules and regulations to manage their impacts while upholding the rule of law. Consequently, it is crucial to establish a timely and robust link between marine sciences, ocean governance, and the rule of law (Chang, 2023). Similarly, the complexities surrounding fuel supply, safety, regulation, and climate governance while exploring implications of low-Sulphur oil and alternative fuels (Chang, 2023). Furthermore, this paper aims to deconstruct the concept of "environmental consciousness" and analyze the different regulatory focus of firms' environmental consciousness based on the regulatory focus theory.

The basic assumption of psychology regarding the motivation of human behavior has been "the pursuit of pleasure and the avoidance of pain" (Sprigge, 1999). This principle suggests that seeking benefits and avoiding harm are inherent in human nature and explain the source and essence of human behavioral decision motivation. Building on this foundation, Higgins argued that "seeking benefits" and "avoiding harm" are two distinct motivational orientations that require further differentiation (Higgins, 1997). In his study, Higgins proposed the concept of two regulatory foci that individuals possess and explained how these foci are formed and achieved through distinct means. The regulatory focus theory, proposed by Higgins and further discussed by Higgins and Pinelli, suggests that individuals exhibit diverse goal orientations and pursue objectives through varying approaches (Higgins, 1998; Higgins and Pinelli, 2020). They commonly demonstrate two distinctive self-regulatory tendencies, referred to as "regulatory focus". One is promotion focus, which emphasizes positive outcomes, growth, progress, achievement, and long-term development. It entails a focus on higher levels of performance and an expectation of greater rewards and returns. The other is prevention focus, which emphasizes negative outcomes, the importance of fulfilling responsibilities and obligations, the pursuit of "legitimacy strategies," the avoidance of punishment and the achievement of security. An individual's regulatory focus can manifest as a stable, long-term personal trait or as a temporary state influenced by diverse external factors (Manczak et al., 2014).

In strategic management research, this perspective is often used to analyze how managers' different regulatory focuses influence their strategic decision-making (Ma et al., 2022). Moreover, this perspective has found application in the corporate environmental and green strategy literature. For example, in the context of

corporate sustainable transformation, managers driven by a promotion focus will emphasize the positive effects of environmental behavior and actively seek solutions to improve and enhance environmental governance throughout all industries and especially maritime sector. Conversely, managers with a prevention focus will primarily concentrate on avoiding punishment from the government and stakeholders due to non-compliance with environmental standards, as their primary motivation for decision-making is to enhance legitimacy.

Furthermore, an increasing body of literature has highlighted that a limited emphasis on individuals' regulatory focus and the application of this focus to anticipate decision outcomes often fail to yield consistent research findings (Neubert et al., 2008; De Cremer et al., 2009). Therefore, Higgins proposed the regulatory fit theory (Higgins, 2000), suggesting that individual regulatory focus should align with the decision situation to have its desired effects. This perspective can also be extended to analyzing organizational strategic behaviors within the maritime sector: managers are more likely to make sound strategic decisions when the external environment aligns with their regulatory focus (Lee et al., 2019; Huang and Zheng, 2022). Therefore, in addition to analyzing how different regulatory focuses influence maritime firms' environmental behaviors, it is also important to discuss how the institutional context (such as environmental regulations) aligns with the regulatory focus of managers (Lee et al., 2019; Huang and Zheng, 2022). Understanding this alignment can shed light on how managers navigate and respond to regulatory frameworks within the maritime sector, influencing strategic decisions that impact environmental outcomes and sustainability initiatives within maritime operations (Lee et al., 2019). This holistic approach considers both the internal cognitive factors of managers and the external institutional factors shaping environmental behaviors and strategic orientations in the maritime industry.

Building upon the regulatory focus theory, we aim to further analyze and explore the concept of "environmental consciousness" by examining the variations in managerial focus. We have noted that firms in regions characterized by both good and poor environmental quality have a certain level of environmental consciousness. However, is there a distinction in the regulatory focus of these firms between regions with good or poor environmental quality? We suggest that under conditions of poor environmental quality within the maritime sector, managers of maritime manufacturing firms are more likely to adopt a prevention focus when facing environmental issues. This means they have little incentive or willingness to proactively respond to environmental problems or make investments in green technologies (Aragòn-Correa et al., 2020; Wang et al., 2020, 2023). Their primary goal is to avoid punishment and maintain legitimacy in the face of regulatory pressures (Vourdachas, 2018; Wang et al., 2023). Although high pollution levels compel maritime firms to become environmentally conscious and recognize the urgency of addressing environmental issues, firms in highly polluted maritime areas may not always consider their emissions as "significant" compared to more severely affected regions. This mindset can lead to a reactive approach to environmental challenges rather than proactive initiatives aimed at improving environmental performance and sustainability within the maritime sector (Wang et al., 2023).

Consequently, understanding these dynamics is essential for developing targeted interventions and policies that encourage maritime firms to adopt more sustainable practices and contribute to environmental quality improvement. Instead, what they need to do is to ensure that their emissions are not significantly higher than those of other firms in order to avoid penalties, maintain legitimacy, and fulfill their environmental responsibilities and obligations appropriately (Bansal and Clelland, 2004; Shu et al., 2016). Therefore, when it comes to environmental issues, firms mainly emphasize legitimacy and obligations, making it easier for them to adopt a prevention focus.

In contrast, within the maritime sector and among maritime manufacturing firms operating in regions with better environmental quality, managers are more likely to adopt a promotion focus when addressing environmental issues. They proactively seek solutions to improve environmental performance, reduce emissions, employ technological advancements to address environmental problems, and emphasize the positive impacts of environmental protection (Li et al., 2020; Mulaessa and Lin, 2021). Residents in low-pollution maritime areas are highly sensitive to environmental and ecological damage, considering any pollution resulting from production and daily activities as "significant" and drawing the attention of the local community. Consequently, regional maritime firms should strive to improve and optimize their production methods, prioritize energy conservation, and focus on emission reduction to uphold environmental quality standards (Li et al., 2020; Mulaessa and Lin, 2021). This proactive approach not only helps in maintaining the ecological balance but also aligns with the local community's expectations and regulatory frameworks, fostering a culture of sustainability and responsible environmental stewardship within the maritime industry.

Moreover, in regions with higher environmental quality within the maritime sector, regional maritime manufacturing firms facing environmental issues still pay attention to maintaining their legitimacy. However, compared to firms in regions with poorer environmental quality, these maritime firms can leverage the region's overall "green advantage" to attain better growth. They view "green" practices not only as a means to avoid penalties but also as a strategic resource and pathway to gain a competitive advantage within the maritime industry (Li et al., 2020; Mulaessa and Lin, 2021). This strategic mindset underscores the importance of sustainable practices and environmental consciousness among maritime manufacturing firms operating in regions with varying environmental conditions.

3 Hypotheses

3.1 Firms' environmental behavior under varying regulatory focus in the maritime sector

This study aims to discuss whether and how environmental consciousness stimulates firms' environmental behavior

(Harris, 2008). Prior research usually neglects the gap between "consciousness" and "behavior," assuming a straightforward linear association between environmental consciousness and environmental behavior. This study posits that despite sharing similar levels of environmental consciousness, firms may have varying regulatory focuses on environmental issues, which changes their motivations for environmental behaviors. Therefore, based on regulatory focus theory, this study investigates the different environmental behaviors that firms may engage in under diverse regulatory focuses of their environmental consciousness.

In general, four types of environmental behavior have gained significant attention across various sectors. The first is environmental information disclosure. In March 2008, with the establishment of China's Ministry of Environmental Protection, firms' environmental behavior received further guidance and regulation at the policy level (Wang et al., 2018). Subsequently, Chinese listed firms have been progressively obligated to disclose their environmental actions and fulfill environmental responsibilities in their annual reports, corporate social responsibility reports, environmental reports, and other relevant documents. The implementation of the "Guidelines for the Preparation of Corporate Environmental Reports" on October 1, 2011, further standardized the process of preparing corporate environmental reports and clarified the obligation of firms to disclose environmental information. While the current regulatory requirements for environmental information disclosure are already well-defined and strict, firms have maneuverable space regarding how and when to disclose, along with the authenticity, accuracy, and completeness of the disclosed information (Reid and Toffel, 2009; Li et al., 2018, p. 100).

The second is firms' environmental investment. It encompasses investments in purchasing and operating environmental equipment and facilities, treating pollution and wastewater, emitting waste gases and solid waste, ecological shipbuilding, and organizing social activities related to the environment (Wang et al., 2018). However, because such investment does not always result in direct economic output, traditional corporate social responsibility research typically regards this investment as either a social responsibility investment or a cost to society.

The third is adopting and implementing environmental management systems (EMS) and associated management practices, as exemplified by ISO 14001 certification. Firms seeking ISO 14001 certification must obtain a "certificate of compliance" from the environmental protection department, adhere to national standards for environmental labeling of their products or technical requirements, maintain emissions within specified limits, and keep their environmental performance at a high level. Wuisan, van Leeuwen, and van Koppen investigated the Clean Shipping Project (CSP) and proposed that a key strategy to promote environmental awareness in the shipping industry is to encourage cargo owners or shippers to demand that their shipping suppliers or carriers adopt green practices (Wuisan et al., 2012). ISO 14001 mandates rigorous subcontractor management, encompassing adherence to green transport supplier criteria. Additionally, the CSP advocates for the use of the Clean Shipping Index as a supportive tool in the procurement process (Lirn et al., 2014). At present, ISO 14001 certification has established itself as a mature environmental management approach for firms and plays a crucial role in demonstrating their environmental legitimacy and responsibility to external stakeholders. Apart from ISO 14001, certain industries also have their own certification standards. For example, in the construction industry, Leadership in Energy and Environmental Design (LEED) is a green shipbuilding certification program (York et al., 2018).

The fourth is green innovation - Green innovation is a more proactive environmental action, providing more environmental and economic benefits. Developing an environmental policy – green policy is essential for establishing an effective environmental management system (Roy et al., 2001). The concept of a greener policy involves the adoption of environmental policies to cultivate a culture or vision of environmental protection (Lai et al., 2011). In the maritime sector, green innovation encompasses the development and adoption of new technologies, processes, or products aimed at reducing environmental pollution and minimizing the use of raw materials and energy. This includes innovations such as green product design tailored for maritime applications, advancements in environmentally friendly manufacturing processes specific to maritime operations, and the implementation of green management practices within maritime firms. Green innovation in the maritime sector plays a crucial role in promoting sustainability, enhancing resource efficiency, and mitigating the environmental impact of maritime activities on marine ecosystems. By fostering green innovation across these domains, the maritime industry can contribute to a more sustainable and environmentally responsible approach to maritime operations and marine resource management.

Green product innovation directly reflects the progress of green technology and has profound implications for the environment and ecology (Rehfeld et al., 2007). It helps firms optimize production methods, improve efficiency, and reduce the environmental burden caused by production (Chen and Chang, 2013). Moreover, green innovation brings long-term competitive advantages to firms (Frempong et al., 2021; Dai and Xue, 2022). Firms can not only gain a "green premium" by selling their green products and technologies but also occupy the green market, seize green opportunities, and establish unique green competitive advantages (Chen et al., 2006). However, it should be noted that green product innovation requires significant financial resources and exhibits dual externalities (Rennings, 2000) with high research and development costs. Therefore, strong motivation and incentives are often necessary for firms to engage in green innovation.

We focus on two types of environmental behaviors within maritime manufacturing firms: the certification of the environmental management system (ISO 14001) and green product innovation. On the one hand, these two types of environmental behaviors are driven by voluntary and proactive motivations of maritime firms, rather than passive responses to policies or pressures from stakeholders. On the other hand, these environmental behaviors substantially change maritime firms' overall management practices and production operations. Embracing ISO 14001 certification and engaging in green product innovation reflect a strategic commitment to sustainability within the

maritime sector, leading to improvements in environmental performance and the adoption of eco-friendly practices throughout maritime manufacturing processes and product development cycles.

As previously mentioned, individuals make different decisions and exhibit different behaviors based on varying regulatory focuses. In our research context, managers in areas with good or poor environmental quality possess a high level of environmental consciousness, which implies that they have a specific regulatory focus on environmental issues. However, their regulatory focus differs in these two types of areas. Consequently, their environmental behaviors will be different. Firms driven by a prevention focus are more inclined to adopt mature environmental management methods and obtain certification standards to maintain legitimacy and prevent penalties resulting from "illegitimacy." Hence, firms in areas with poorer environmental quality are more prone to adopting and certifying ISO14001 standards. Conversely, in areas with better environmental quality, firms are more inclined to embrace proactive green production practices, implement technological innovations, and engage in additional green product innovations, aiming to gain distinct competitive advantages through green innovation.

However, for firms located in areas with relatively moderate environmental quality, due to their insufficient environmental consciousness, managers cannot develop a regulatory focus on environmental protection and, therefore, will not engage in further protective behaviors.

Based on this, we propose the following hypotheses:

Hypothesis 1: Compared to firms in other regions, firms located in regions with better environmental quality initiate more green innovation.

Hypothesis 2: Compared to firms in other regions, firms located in regions with poorer environmental quality have higher ISO14001 certification rates. The relationship of "environmental quality-environmental consciousness-regulatory focus-environmental behavior" is summarized in Table 1.

TABLE 1 Relationship between environmental quality, environmental consciousness, regulatory focus, and environmental behavior.

Environmental Quality	Good	Moderate	Poor
Environmental consciousness	High	Low	High
Regulatory Focus	Promotion Focus	No Focus	Prevention Focus
Environmental behavior	Green product innovation	× ×	Certified ISO14001 standard

3.2 The moderating effect of environmental regulations

Moreover, firms' environmental behaviors heavily depend on the incentives offered by environmental regulations. In emerging economies like China, the institutional environment strongly influences the strategic choices made by firms. Nevertheless, environmental regulations may not always achieve the desired effectiveness. The regulatory fit theory posits that to optimize the impact of individual regulatory focus, it should be aligned with the decision-making context. This study posits that effective environmental regulations should align with the varying environmental consciousness influenced by different regulatory focuses of firms. Environmental behaviors of firms are effectively incentivized only when the objectives and means of environmental regulations align with the regulatory focus of managers.

Overall, environmental regulations can be divided into two types. The first is mandatory regulation, which focuses on enforcing firms' environmental actions and binding firms through administrative laws and regulations. The underlying rationale behind mandatory regulation is to deter firms from causing environmental harm by imposing penalties for such actions (Dowell and Muthulingam, 2017). This approach aims to urge firms to adopt specific environmental standards in their production practices. The second type is incentive regulation, which focuses on utilizing market incentives to encourage firms to invest in environmental activities. Incentive regulations stimulate firms' environmental behaviors through supporting and optimizing the development of green markets (Huang et al., 2019). Mandatory regulation emphasizes punishing environmental destruction, whereas incentive regulation emphasizes supporting the benefits derived from environmental protection.

Based on the framework of the regulatory focus theory and the regulatory fit theory, when a specific regulatory context emphasizes the benefits of environmental protection and provides increased encouragement and support for positive aspects of environmental behaviors, it aligns with the logic of a promotion focus. This alignment further reinforces the promotion focus of managers. Consequently, for maritime firms located in regions with better environmental quality, incentive regulations are more effective in stimulating environmental behaviors and promoting green innovation.

Conversely, for maritime firms situated in high-pollution areas with a prevention focus, mandatory regulations are more effective. This is because mandatory regulations align with the basic logic of the prevention focus, given their emphasis on the costs incurred by non-compliance. As a result, maritime firms might opt to adopt ISO 14001 standards to maintain legitimacy and avoid being penalized by environmental regulations. This nuanced understanding of regulatory focus and fit helps elucidate how different types of environmental regulations can influence maritime firms' behavior and strategic decision-making within varying environmental contexts.

This study derives the 2x2 matching framework depicted in Figure 1 and posits the subsequent hypotheses:

Hypothesis 3: For firms in regions with better environmental quality, incentive regulations can enhance their level of green innovation more effectively than mandatory regulations.

Hypothesis 4: For firms in regions with poorer environmental quality, mandatory regulations can increase the certification rate of ISO 14001 more effectively than incentive regulations.

Our theoretical framework is summarized in Figure 2.

	Mandatory regulation	Incentive Regulation
Prevention Focus	√	×
Promotion Focus	×	√

FIGURE 1
Matching of regulatory focus and environmental regulation.

4 Research design

4.1 Data

We constructed our sample with all publicly listed manufacturing firms on China's Shanghai and Shenzhen Stock Exchanges from 2010 to 2019. In 2007, the China Green Companies Public Welfare Project was officially launched, marking that Chinese firms have put "green" on the agenda. With the establishment of the Chinese Ministry of Environmental Protection (formerly known as the State Environmental Protection Administration) in March 2008, enterprises received specific guidance and regulations for their environmental protection activities in terms of policy. Subsequently, Chinese listed firms have been progressively required to disclose their environmental behavior and fulfill their environmental responsibilities through reports such as annual reports, corporate social responsibility reports, and environmental reports. The implementation of the Guidelines for the Compilation of Corporate Environmental Reports on October 1, 2011, played a significant role in standardizing the preparation of these reports. Therefore, starting from 2010 as the initial year, it is possible to observe the activities of firms in environmental protection more comprehensively and in-depth.

The firm-level data utilized in this study are sourced from the China Stock Market and Accounting Research Database (CSMAR) (available at: https://data.csmar.com/), incoPat Shared Global Patent Literature Database available at: https://www.incopat.com/login?locale=en), and annual reports of listed firms. Data on regional air quality, particularly the PM2.5 index, is obtained from the report data provided by the Atmospheric Composition Analysis Group at Dalhousie University in Canada (ResourceWatch, 2024). Information on regional environmental regulations is obtained from various sources, including Peking University Law Information, the China Statistical Yearbook published by the National Bureau of Statistics (NBSC, 2022), Provincial Statistical Yearbooks, and the China Insurance Yearbook.

We match the data obtained from these sources. For observations with incomplete or ambiguous records, additional information is obtained and verified through websites such as "QiChaCha" (available at: https://www.qcc.com/). Ultimately, a total of 17,245 observations were collected from 2,806 manufacturing firms between 2010 and 2019.

4.2 Measurement

(1) Environmental quality and environmental consciousness. Regional environmental quality is typically indicated by the level of pollution in the area. Specifically, air pollution is closely related to the activities of residents and local production. Research has shown that PM2.5, which refers to fine particulate matter with an aerodynamic equivalent diameter of 2.5 micrometers or less in the ambient air, stands out among air pollutants such as PM10, SO2, CO, O3, and API. It is considered the primary pollutant responsible for air pollution and draws significant attention across different sectors of society. Additionally, PM2.5 concentration provides a more accurate and objective measurement of the atmospheric pollution in a region compared to indicators like industrial "three wastes" emissions. Hence, we employ the annual average PM2.5 concentration as a metric to assess regional environmental quality. Using ArcGIS software, this article extracts the layer information of NC from grid data (in NetCDF format) provided by the Atmospheric Composition Analysis Group at Dalhousie University in Canada (available at: sites.wustl.edu/acag/datasets/surface-pm2–5/). Subsequently, the data is matched with China's administrative divisions through zoning statistics to obtain the annual average PM2.5 concentration data at the provincial level.

According to our theoretical framework, we also need to group different environmental qualities (good/poor/average). The specific

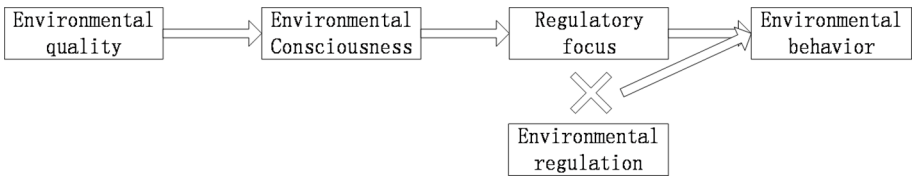


FIGURE 2
Theoretical framework.

grouping method is as follows: "Poor environmental quality" group (1 = the average annual concentration of PM2.5 in the province where the firm is located is the highest 25% among all provinces, 0 = others); "Good environmental quality" group (1 = the average annual concentration of PM2.5 in the province where the firm is located is the lowest 25% among all provinces, 0 = others).

For the construction of environmental consciousness indicators, this study chooses to use text analysis (Graf-Vlachy et al., 2020). We use Python to conduct text mining on the annual reports of listed firms. Based on the environmentally related keywords identified in previous studies (Wang et al., 2018), we counted the word frequency of the following keywords in the firms' annual reports: "ecology," "environmental protection," "green," "pollution," "emission," "energy consumption," "emission reduction," and "low carbon." This study selects and calculates the word frequency of these keywords from the financial reports of firms each year and calculates their proportion in the total word count of the financial reports to measure the focal firm's "environmental consciousness." Most importantly, In the context of improving environmental practices within maritime manufacturing firms and their supply chains, the adoption of ISO 14001 certification emerges as a critical factor. ISO 14001 is an international standard that provides a framework for establishing, implementing, maintaining, and improving environmental management systems. This certification signifies a firm's commitment to managing its environmental impact in a systematic and effective manner.

For instance, Ford Motor Company requires its suppliers, including those in maritime manufacturing, to utilize manufacturing facilities certified to ISO 14001 standards, demonstrating a proactive approach to environmental management (Sroufe and Curkovic, 2008). This requirement not only ensures compliance with environmental regulations but also promotes continuous improvement in environmental performance throughout the supply chain, including maritime manufacturing activities. In the shipbuilding industry, where shipowners increasingly demand environmentally friendly ships and sustainable production processes, ISO 14001 certification can play a crucial role. Maritime manufacturing firms can leverage ISO 14001 to enhance their environmental management practices and demonstrate their commitment to meeting regulatory requirements and customer expectations in the maritime sector. The integration of ISO 14001 into supply chain practices within maritime manufacturing underscores the importance of environmental considerations in modern business operations. By encouraging maritime manufacturing suppliers to adopt ISO 14001 and other green initiatives, lead firms promote sustainability throughout the value chain and mitigate environmental risks associated with maritime manufacturing activities. This proactive approach not only enhances environmental performance but also contributes to the overall competitiveness and reputation of maritime manufacturing firms in environmentally conscious industries.

(2) Green product innovation and ISO 14001 certification. Drawing on Flammer, Hong, and Minor's measurement (Flammer et al., 2019) for green patents and green innovation, this study first identifies green patents from the patents that firms apply for each year. In 2010, the World Intellectual Property Organization (WIPO) launched an online tool called the "International Patent Classification Green Inventory" (available at: www.wipo.int/classifications/ipc/green-inventory), which aims to facilitate the retrieval of environmentally friendly technology-related patent information. Based on the United Nations Framework Convention on Climate Change, this retrieval system classified green patents into seven categories: transportation, waste management, energy conservation, alternative energy production, administrative regulatory or design aspects, agriculture or forestry, and nuclear power generation. Following this classification standard, this article identifies and calculates the number of green patents obtained by firms each year based on the green patent IPC categories provided in the inventory. Finally, we measure firms' green innovation using the number of green patents applied for by firms in a given year (natural logarithm). In addition, the concept of green innovation was evaluated using three items that reflect a firm's innovative actions in relation to green or environmental processes, solutions, and products. These items were adapted from innovation metrics developed by Bell (Bell, 2005) and Wang (Wang, 2008). An example item from this assessment is: "Our firm is at the forefront of adopting new green technologies compared to our competitors." Similarly, following the adoption of the Maritime Labor Convention, 2006 by the ILO, which has become the fourth pillar of the international maritime legal regime, shipping firms should also adhere to the convention's requirements concerning the safety of human resources and the protection of the marine ecosystem (Khan et al., 2024).

For the certification of ISO 14001 in firms, this study measures it by setting a dummy variable (1 = focal firm has obtained ISO 14001 certification; 0 = focal firm has not obtained ISO 14001 certification). The data are obtained from the CSMAR Environmental Research Database.

Incentive regulation: We measure incentive regulation through the green finance index of the province where the company is located. Drawing on related research, the green finance index is calculated using the entropy method based on four dimensions: green credit (interest expenses of the six major high-energy-consuming industries/total industrial interest expenses), green investment (investment in environmental pollution control/GDP), green insurance (agricultural insurance income/total agricultural output value), and government support (environmental protection expenditure/total general budget expenditure).

(4) Control Variables: This study also controls for firm age, firm size (total number of employees in the current year), firm research and development intensity (proportion of R&D investment to total sales), as well as the firm's financial performance in the current year (difference between Tobin's Q value of the firm and the industry average). Additionally, we believe that the motivation for environmental efforts in heavily polluting industries differs from that of clean industries in manufacturing firms, and their sensitivity to environmental regulations is higher. Therefore, based on the 16 categories of heavily polluting industries summarized in the "Guidelines for Environmental Information Disclosure of Listed Firms" published by the Ministry of Environmental Protection in

2010, this study classifies the samples and controls for heavily polluting industries. At the same time, this study also controls for regional factors. First, we control for the level of industrial pollution control in each province, which was measured by the proportion of investment in industrial pollution control to the value added by the secondary industry. Second, we control for the original value of pollution levels in each province (in the model of grouped regression). Finally, this study sets year and industry fixed effects and controls for them.

In order to maintain the consistency of variable dimensions, this study standardized all variables (except for dummy variables).

4.3 Sampling: propensity score matching analysis (PSM)

It is important to note that the research design of this study is affected by a confounding factor, namely selection bias in sample selection. Specifically, the allocation of firms' locations is not random and is influenced by issues of self-selection and endogeneity in the choice of location. For instance, high energy-consuming and heavily polluting firms often cluster together to manipulate pollution levels to appear insignificant. Additionally, there is a close relationship between environmental quality and the level of industrial development in a region, leading to a larger accumulation of manufacturing firms in regions with higher levels of development. Despite the inclusion of some control variables at the regional level, this study does not fully address the aforementioned issues. To mitigate these issues, this study employs the one-to-one nearest neighbor method of propensity score matching [38] to better control for the selection bias. The goal is to achieve approximate equality among three groups of firms categorized as having good, medium, and poor environmental quality, by matching and controlling for individual-level heterogeneity based on important indicators.

This study conducts a two-step process to match three groups of samples based on their environmental quality, categorized as good, medium, and poor. Initially, this paper individually selects two groups of enterprises from the complete sample, specifically those categorized as having "poor environmental quality" and "good environmental quality". Subsequently, it considers various factors, including company size (revenue), age, research and development intensity, innovation ability (proportion of invention patents to total patents), financial performance (Tobin's Q), and industry (represented as an industry dummy variable). Utilizing these variables, the paper employs profit regression to calculate the propensity scores, which represent the likelihood of firms being situated in areas characterized by good or poor environmental quality. Following the acquisition of propensity scores, the paper utilizes a one-to-one nearest neighbor matching method to group observations with identical scores into the corresponding categories of good and poor environmental quality. Additionally, given that the samples are collected over multiple years, this study conducts the matching procedure on an annual basis. The specific econometric model is outlined as follows:

$$C(P_i) = \min_j \| P_i - P_j \|, j \in I_0$$

In this study, P_i and P_j represent propensity scores of participants in the intervention group (with poor environmental quality) and the control group (with good environmental quality), respectively. I_0 refers to the set of participants in the control group, where j is a participant in the control group. C (P_i) represents a set of "neighbor" relationships. When a match between j and i is found, j is removed from I_0 and not returned. Since a one-to-one matching approach is used, for each i, only a single j is found that falls into C P_i).

After the aforementioned matching process, we achieved no significant differences among each observation on important individual factors between the two groups of samples, namely "poor environmental quality" and "good environmental quality." Moving on, the second step is carried out, where the matched groups of "good and poor environmental quality" are matched with the two groups of samples from the original data on "moderate environmental quality." The matching process is consistent with the previous step. After completing this matching step, the complete sample for subsequent analysis is obtained in this study. In this sample, the number of observations in the three groups is also effectively controlled, with each group representing 25% of the total sample for "good environmental quality" and "poor environmental quality," and the "moderate environmental quality" observations accounting for 50% of the total sample. This further facilitates a better comparison of the behaviors of firms in different areas with varying environmental qualities in this research.

After PSM analysis and matching, and excluding observations with missing values in relevant variables, the final sample size used for the subsequent empirical analysis in this study is 7,118 observations from 2,075 manufacturing firms from 2010 to 2019. To evaluate the quality of matching, this study further tested whether there are significant differences between the "poor environmental quality" group and the "good environmental quality" group in terms of relevant variables. Table 2 shows the statistical characteristics of each group of firms before and after matching on important variables. Descriptive statistical analysis and correlation coefficient analysis of each variable in the matched sample are presented in Tables 3, 4, respectively.

5 Results

5.1 Regression results

Before conducting empirical analysis, we first perform Variance Inflation Factor (VIF) diagnostics on all explanatory variables and control variables included in the model. The results show that all VIF values are below 10, indicating no multicollinearity issues. Table 5 presents the regression results. Different regression models are used for different dependent variables. Specifically, for models (1–4) with environmental consciousness and green innovation (in natural logarithm) as the dependent variables, panel data OLS regression is employed. For models (5–7) with ISO 14001 certification as the dependent variable, panel data logit regression is used. We conduct our analyses using Stata 15.0.

In the regression results of Table 5, Model (1) tests the basic hypothesis of this study: there is a U-shaped relationship between

TABLE 2 Basic statistical characteristics of the two groups of observations of poor/good environmental quality before and after matching.

Before PSM matching					
	Poor environmental quality group (N=5784)		Good environmental quality group (N=4100)		
Variable	Average value	Standard deviation	Average value	Standard deviation	T-test for the difference between the two
Tobin's Q	-0.057	2.922	0.063	2.959	1.961**
Operating income	1.42e+10	1.16e+11	6.83e+09	2.14e+10	-3.991***
Heavy polluting industries	0.326	0.469	0.293	0.455	-3.531***
After PSM matching					
	Poor environmental quality group (N=2195)		Good environmental quality group (N=2174)		
Variable	Average value	Standard deviation	Average value	Standard deviation	T-test for the difference between the two
Tobin's Q	-0.082	1.110	-0.051	1.121	0.920
Operating income	6.13e+09	1.45e+10	6.65e+09	1.95e+10	1.015
Heavy polluting industries	0.391	0.488	0.352	0.478	-2.668***

*p< 0.1, **p< 0.05, ***p< 0.01.

regional environmental quality and firms' environmental consciousness. The results of Model (1) show that the coefficient of the first-order term for regional environmental quality (pollution level) (PM2.5) is significantly negative (β=-0.259, p<0.01), and the coefficient of the second-order term for regional environmental quality (pollution level) (PM2.52) is significantly positive (β=0.135, p<0.05). Moreover, the turning point of the U-shape (PM2.5 = 0.959) falls within the range of PM2.5 values (PM2.5 has been standardized), thus supporting the basic hypothesis of this study, that regional environmental quality and firms' environmental consciousness have a U-shaped relationship.

Model (2) is used to test hypothesis 1: firms located in regions with better environmental quality have higher levels of green innovation compared to firms in other regions. Model (2) shows that the coefficient for good regional environmental quality (low PM2.5) is positively significant (β=0.190, p<0.01), thus supporting hypothesis 1. Hypothesis 2 suggests that firms located in regions with poorer environmental quality have higher ISO14001

TABLE 3 Descriptive statistics of main variables.

Variable	Average value	Standard deviation	Maximum value	Minimum value
green innov.	0.320	0.737	6.026	0
ISO14001	0.287	0.452	1	0
PM2.5	39.362	12.123	85.629	9.566
PM2.5 high	0.254	0.436	1	0
PM2.5 low	0.240	0.427	1	0
env. penalty	2647.993	3674.678	17449	0
green finance	0.265	0.135	0.793	0.071
size	5082.854	10219.21	229154	50
age	9.248	6.958	28	0
RDintensity	4.179	3.700	76.35	0
tobin	-0.087	1.144	-3.023	12.843
dirty industry	0.582	0.493	1	0
prov. govern.	0.002	0.002	0.025	0.000

TABLE 4 Correlation matrix of main variables.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1.*PM2.5*													
2.*size*	-0.004												
3.*age*	0.001	0.258***											
4.*RDintensity*	-0.047***	-0.120***	-0.216***										
5.*tobin*	-0.034***	-0.107***	-0.027**	0.133***									
6.*dirty industry*	0.030**	0.022*	0.082***	-0.291***	-0.018								
7.*prov. govern.*	0.231***	0.037***	0.067***	-0.124***	-0.032***	0.106***							
8.*env. penalty*	-0.256***	0.045***	-0.071***	0.119***	0.025**	-0.111***	-0.212***						
9.*green finance*	-0.008	0.022*	-0.068***	0.164***	0.023*	-0.121***	-0.281***	0.396***					
10.*PM2.5 low*	-0.579***	0.051***	-0.028**	0.034***	0.016	-0.051***	-0.082***	0.171***	-0.103***				
11.*PM2.5 high*	0.695***	-0.009	-0.018	-0.010	0.003	0.007	0.087***	-0.002	0.024**	-0.328***			
12.*green innov.*	0.063***	0.299***	0.051***	0.022*	-0.060***	-0.145***	0.007	-0.049***	-0.009	0.045***	0.004		
13.*ISO14001*	-0.028**	0.044***	0.023**	-0.018	-0.027**	-0.015	-0.013	0.049***	0.023*	-0.002	0.007	0.043***	

N=7118; *p< 0.1, **p< 0.05, ***p< 0.01.

TABLE 5 Regression results.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	full sample	full sample	full sample	poor regional environmental quality subsample	full sample	full sample	good regional environmental quality subsample
	env. orientation	green innov.	green innov.	green innov.	ISO14001	ISO14001	ISO14001
size	0.009	0.183***	0.183***	0.201***	0.083	0.088	0.589***
	(0.014)	(0.011)	(0.011)	(0.018)	(0.064)	(0.064)	(0.206)
age	0.025***	-0.002	-0.001	-0.001	0.001	-0.000	-0.018
	(0.002)	(0.002)	(0.002)	(0.004)	(0.011)	(0.011)	(0.025)
RDintensity	-0.003	-0.000	-0.000	-0.003	-0.033*	-0.033*	-0.061
	(0.003)	(0.003)	(0.003)	(0.005)	(0.019)	(0.019)	(0.048)
tobin	-0.020**	-0.015**	-0.015**	-0.023	-0.088*	-0.087*	0.091
	(0.008)	(0.007)	(0.007)	(0.017)	(0.049)	(0.049)	(0.110)
dirty industry	0.506***	-0.199***	-0.196***	-0.110	-0.327	-0.319	-0.287
	(0.058)	(0.042)	(0.042)	(0.097)	(0.264)	(0.264)	(0.546)
prov. govern.	-0.042***	0.012	0.015*	0.034*	0.060	0.055	-0.055
	(0.010)	(0.009)	(0.009)	(0.019)	(0.056)	(0.056)	(0.194)
industry FE	YES	YES	YES	YES	YES	YES	YES
year FE	YES	YES	YES	YES	YES	YES	YES
env. penalty	0.022**	-0.059***	-0.048***	-0.100***	0.112**	0.090*	0.562**
	(0.009)	(0.008)	(0.013)	(0.020)	(0.049)	(0.050)	(0.230)

(Continued)

TABLE 5 Continued

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	full sample	full sample	full sample	poor regional environmental quality subsample	full sample	full sample	good regional environmental quality subsample
green finance	0.039**	0.001	-0.008	0.166***	0.060	0.050	-0.076
	(0.018)	(0.013)	(0.014)	(0.064)	(0.081)	(0.082)	(0.206)
PM2.5	-0.259***	0.113***	0.107***	0.129**	-0.268***	-0.227**	-0.103
	(0.060)	(0.013)	(0.013)	(0.062)	(0.093)	(0.096)	(0.287)
$PM2.5^2$	0.135**						
	(0.058)						
PM2.5 low		0.190***	0.214***				
		(0.026)	(0.028)				
low*penalty			-0.043**				
			(0.019)				
low*greenfin			0.128***				
			(0.042)				
PM2.5 high					0.344**	0.245	
					(0.174)	(0.180)	
high*penalty						0.296**	
						(0.140)	
high*greenfin						0.102	
						(0.133)	
_cons	-0.506***	0.305***	0.302***	0.507***	-1.568***	-1.561***	-1.508**
	(0.058)	(0.044)	(0.044)	(0.112)	(0.285)	(0.285)	(0.661)
N	7114	7118	7118	1709	7118	7118	1798
Wald chi2	1 630.92***	957.77***	969.27***	330.84***	98.78***	103.77***	46.42***

Standard errors are shown in parentheses. *p< 0.1, **p< 0.05, ***p< 0.01.

certification rates compared to firms in other regions. The results of Model (5) show that the coefficient for poor regional environmental quality (high PM2.5) is positively significant (β=0.344, p<0.05), thus providing support for hypothesis 2.

Next, we analyze how different types of environmental regulations influence the environmental behaviors of firms in regions with different environmental quality. First, models (3) and (4) are used to test hypothesis 3: for firms in regions with poor environmental quality, incentive regulations are more effective in improving their level of green innovation compared to mandatory regulations. Next, we test the moderating role of environmental regulations by introducing interaction terms. In model (3), the interaction term (*lowpenalty*) between good regional environmental quality (PM2.5 low) and mandatory regulations (env. penalty) is significantly negative (β=-0.043, p<0.05), indicating that mandatory regulations not only fail to promote green innovation among firms in regions with better environmental quality but also inhibit their green innovation. Conversely, the interaction term (*lowgreenfin*) between good regional environmental quality (PM2.5 low) and incentive regulations (green finance) is significantly positive (β=0.128, p<0.01), indicating that incentive regulations can promote green innovation among firms in regions with better environmental quality, supporting hypothesis 3. Second, we conduct separate regression analysis for all firms in regions with good environmental quality. The results of model (4) show that, under the sample of good regional environmental quality, the coefficient of mandatory regulations (env. penalty) is significantly negative (β=-0.100, p<0.01), while the coefficient of incentive regulations (green finance) is significantly positive (β=0.166, p<0.01), further indicating that only incentive regulations stimulate green innovation among firms in regions with better environmental quality, whereas mandatory regulations only have an inhibitory effect. Therefore, hypothesis 3 is supported.

Based on the same logic, this study tests Hypothesis 4: For businesses in regions with poor environmental quality, mandatory regulation is more effective in improving the certification rate of ISO 14001 than incentive regulation. First, this study sets up an interaction term to test the moderating effect of environmental regulation. In Model (6), the interaction term (*highpenalty*) between poor environmental quality (PM2.5 high) and mandatory regulation (env. penalty) is positively significant (β=0.296, $p<0.05$), indicating that mandatory regulation can indeed increase the ISO 14001 certification rate in regions with poor environmental quality. Conversely, the interaction term (*highpenalty*) between poor environmental quality (PM2.5 high) and incentive regulation (green finance) is not significant (β=0.102, $p>0.1$), suggesting that incentive regulation does not incentivize firms in regions with poor environmental quality to obtain ISO 14001 certification, which is consistent with Hypothesis 4. Similarly, this study conducts a separate regression analysis for all firms in regions with poor environmental quality. The results of Model (7) show that under the sample of poor environmental quality, the coefficient of mandatory regulation (env. penalty) is positively significant (β=0.562, $p<0.05$), while the coefficient of incentive regulation (green finance) is not significant (β=-0.076, $p>0.1$). This further indicates that only mandatory regulation can increase the ISO 14001 certification rate for firms in regions with poor environmental quality, while incentive regulation does not have an effect. Therefore, Hypothesis 4 is supported.

5.2 Robustness check

We tested the robustness of our results. First, we changed the measurement and grouping methods of environmental quality. In the previous model, the grouping of environmental quality was based on the mean concentration of PM2.5 in the province where the company is located, which was either the highest or lowest 25% among all provinces in the same year. In this study, two additional criteria, 20% and 30%, were used for grouping, and the regression analysis was performed with these criteria substituted into the original model. The results were consistent with the previous findings, indicating the robustness of the research results. Furthermore, another air pollution index (API index) was used as a proxy variable to measure environmental quality, and the results were still consistent with the previous findings.

Moreover, this study also changed the measurement of firms' environmental consciousness. In the previous model, this study used text analysis to measure the ratio of keyword frequencies related to "environmental protection/environment" in firms' financial reports. To eliminate ambiguity and subjectivity that may exist in text analysis and enhance the accuracy and objectivity of the research, we replaced it with two dummy variables (whether the firm disclosed environmental targets in its current annual report and whether the firm disclosed environmental protection concepts in its current annual report) to measure firms' "environmental consciousness". The new regression results remain consistent with the previous ones, further confirming the robustness of our research findings.

5.3 Supplementary analysis

Eco-innovation encompasses the creation of novel products and processes that serve the dual purpose of benefitting the environment while promoting environmental sustainability (Rennings and Zwick, 2002). Strategic investments in eco-innovation activities have been shown to optimize resource utilization within firms, ultimately leading to significant cost savings (Triguero et al., 2013). This proactive approach not only drives environmental progress but also enhances economic efficiency, underscoring the business case for embracing eco-innovation within organizational strategies. The previous analysis did not discuss the specific situation of the "medium environmental quality" group of firms but directly compared it with the other two groups as a control group. In order to make the research conclusions clearer, we need to supplement the analysis of this group, that is, to discuss whether the firms in the "medium environmental quality" area lag behind the other two groups of firms in terms of environmental consciousness and environmental behavior. Therefore, we set a new dummy variable "PM2.5 middle" for this group of firms, which takes the value 1 when the company does not belong to the poor environmental quality group or the good environmental quality group, and 0 otherwise. The regression results are shown in Table 6. The results show that in the model with environmental consciousness as the dependent variable (Model 1), the coefficient of medium environmental quality (PM2.5 middle) is negatively significant (β=-0.045, $p<0.1$), indicating that firms in the medium environmental quality areas indeed have weaker environmental consciousness. In the model with green innovation as the dependent variable (Model 2), the coefficient of medium environmental quality (PM2.5 middle) is still negatively significant (β=-0.041, $p<0.05$), indicating that firms in the medium environmental quality areas also have lower levels of green innovation. Finally, in the model with ISO14001 certification as the dependent variable (Model 3), the coefficient of medium environmental quality (PM2.5 middle) is not significant (β=0.109, $p>0.1$), indicating that firms in the medium environmental quality areas do not have higher ISO14001 certification rates. In summary, we further confirm that firms in the medium environmental quality areas are relatively lagging behind in terms of environmental consciousness and environmental behavior compared to the other two groups of firms.

6 Discussion

This study presents a meticulous examination of the intricate interplay among environmental quality, regulatory frameworks, and corporate environmental behavior, focusing on Chinese listed manufacturing firms. Grounded in both theoretical analysis and empirical investigation, it aims to illuminate the multifaceted relationships between these pivotal elements. The research embarks on a thorough theoretical inquiry, meticulously scrutinizing existing frameworks and theories to cultivate a nuanced comprehension of how environmental quality interfaces with corporate behavior. This theoretical foundation lays the groundwork for a rigorous empirical

TABLE 6 Regression results for the medium pollution level group.

	(1)	(2)	(3)
	env. orientation	green innov.	ISO14001
size	0.009	0.186***	0.082
	(0.014)	(0.011)	(0.064)
age	0.026***	-0.003*	0.002
	(0.002)	(0.002)	(0.011)
RDintensity	-0.003	-0.000	-0.032*
	(0.003)	(0.003)	(0.019)
tobin	-0.020**	-0.015**	-0.084*
	(0.008)	(0.007)	(0.049)
dirty industry	0.506***	-0.194***	-0.325
	(0.058)	(0.042)	(0.264)
prov. govern.	-0.044***	0.015*	0.040
	(0.010)	(0.009)	(0.055)
industry FE	YES	YES	YES
year FE	YES	YES	YES
PM2.5	-0.129***	0.072***	-0.148*
	(0.016)	(0.012)	(0.077)
env. penalty	0.021**	-0.054***	0.137***
	(0.009)	(0.008)	(0.050)
green finance	0.040**	-0.012	0.039
	(0.018)	(0.013)	(0.083)
PM2.5 middle	-0.045*	-0.041**	0.109
	(0.023)	(0.019)	(0.119)
_cons	-0.485***	0.366***	-1.530***
	(0.059)	(0.045)	(0.288)
N	7114	7118	7118
Wald chi2	1 628.94***	898.47***	95.65***

Standard errors are shown in parentheses. *p< 0.1, **p< 0.05, ***p< 0.01.

exploration. Drawing from comprehensive empirical findings, the study discerns the profound impact of environmental quality on firms' environmental consciousness. It delineates how variations in environmental conditions catalyze differential levels of environmental awareness and commitment among firms.

Moreover, the research delves into the consequential role of this environmental consciousness in shaping firms' regulatory orientation. It elucidates how firms prioritize compliance and adaptation to environmental regulations commensurate with their degree of environmental consciousness. Furthermore, the study probes into the nuanced responses of firms to diverse environmental regulations, elucidating how their regulatory behavior is intricately linked to their internal environmental priorities. It scrutinizes firms' proactive engagement with regulations, their propensity for innovation to meet compliance standards, and their propensity to exploit regulatory loopholes, all contingent upon their environmental consciousness.

Key findings from this research include:

U-Shaped Relationship Between Regional Environmental Quality and Firms' Environmental Consciousness: The analysis conducted in this study unveils a nuanced U-shaped relationship between regional environmental quality and firms' environmental consciousness, adding depth to our understanding of the complex interplay between environmental contexts and corporate behaviors. Remarkably, our findings suggest that firms located in regions characterized by either poor or excellent environmental quality exhibit heightened levels of environmental consciousness. This phenomenon underscores the significance of extreme environmental conditions in catalyzing a proactive environmental stance among corporations. Specifically, firms situated in regions with subpar environmental quality demonstrate a pronounced inclination towards environmental consciousness. Such adverse conditions likely necessitate heightened awareness and proactive measures to mitigate environmental risks and sustain business operations. Conversely, firms operating in regions renowned for their pristine environmental conditions exhibit a similar propensity towards environmental consciousness. Here, the imperative may lie in preserving the environmental integrity of the area, aligning with broader societal expectations and regulatory frameworks.

Intriguingly, our analysis also reveals a contrasting trend among firms situated in regions characterized by moderate environmental quality. Surprisingly, these firms exhibit comparatively lower levels of environmental awareness. These finding challenges conventional assumptions and suggests that moderate environmental conditions may not exert a sufficiently compelling influence to stimulate robust environmental consciousness among corporations. The observed U-shaped relationship underscores the nuanced nature of environmental responsiveness within the corporate landscape. It highlights the critical role of environmental extremities—whether detrimental or advantageous—in prompting firms to prioritize environmental concerns. Moreover, it raises pertinent questions regarding the efficacy of regulatory interventions and industry initiatives in fostering environmental stewardship amidst moderate environmental contexts.

Regulatory Focus Based on Environmental Quality: In dissecting the regulatory comportment of firms *vis-à-vis* the backdrop of varying regional environmental qualities, our research unveils a subtle interplay of strategic orientations nuanced by environmental contexts. Specifically, firms situated in regions endowed with superior environmental quality exhibit a discernible "promotion focus" in their environmental endeavors. This proactive stance manifests through deliberate investments in green innovation initiatives, leveraging their favorable environmental milieu to augment their ecological footprint positively. Such strategic positioning not only underscores a commitment to advancing environmental stewardship but also serves as a strategic lever to harness competitive advantage amidst

a landscape increasingly attuned to sustainability imperatives. Conversely, an intriguing departure emerges among firms navigating regions marked by ecological adversity. Here, a pronounced "prevention focus" takes root, steering organizational imperatives towards the preservation of legitimacy and reputational integrity amidst challenging environmental terrains. In lieu of pioneering innovation, these firms prioritize defensive maneuvers, with a pronounced emphasis on regulatory compliance and legitimacy-seeking behaviors. Notably, the pursuit of ISO 14001 certification emerges as a salient manifestation of this regulatory orientation, symbolizing a concerted effort to fortify organizational resilience against environmental exigencies.

This dichotomous regulatory orientation underscores the adaptive ingenuity of firms in tailoring strategic responses to the idiosyncratic demands of their environmental contexts. While firms in regions of environmental abundance leverage their advantageous position to spearhead proactive environmental initiatives, counterparts contending with ecological constraints pivot towards defensive strategies aimed at mitigating operational vulnerabilities. By unraveling these divergent trajectories, our study offers nuanced insights into the intricate interplay between environmental quality and corporate regulatory postures.

Effectiveness of Incentive Versus Mandatory Regulations: Our study delves into the comparative effectiveness of incentive-based and mandatory regulations in driving environmental compliance and innovation across regions characterized by varying environmental qualities. Our findings reveal a nuanced interplay between regulatory approaches and firms' strategic orientations, shedding light on differential responses shaped by environmental contexts. In regions boasting high environmental quality, incentive-based regulations emerge as potent catalysts for fostering green innovation among firms. Aligned with the promotion-focused mindset prevalent in such environments, these regulations leverage rewards and positive reinforcement to motivate firms towards enhancing their environmental practices. By offering tangible incentives for eco-friendly initiatives, such regulations not only stimulate proactive engagement but also cultivate a culture of continuous improvement, wherein firms strive to capitalize on their environmental advantages to gain competitive edge through innovation.

Conversely, in regions grappling with lower environmental quality, mandatory regulations exhibit greater efficacy, particularly in driving ISO 14001 certification rates among firms. This resonance with the prevention-focused ethos prevalent in such contexts underscores the significance of compulsory measures in ensuring compliance and bolstering legitimacy. Faced with environmental challenges, firms prioritize adherence to regulatory mandates as a means to fortify their organizational image and navigate reputational risks associated with environmental non-compliance. Mandatory regulations, characterized by their enforceability, serve as pivotal instruments for instilling discipline and ensuring conformity to prescribed environmental standards, thereby mitigating operational vulnerabilities and safeguarding organizational standing. This dichotomy in regulatory effectiveness underscores the importance of tailoring regulatory strategies to suit the specific environmental conditions and strategic orientations of firms. While incentive-based regulations thrive in stimulating innovation and proactive environmental engagement in regions endowed with favorable environmental conditions, mandatory regulations emerge as pragmatic tools for promoting compliance and legitimacy in regions confronting environmental adversities. By elucidating these differential dynamics, our research contributes valuable insights to policy formulation and strategic decision-making aimed at fostering enduring environmental sustainability and corporate responsibility across diverse environmental landscapes.

Further to explain, these insights underscore the imperative for managers within the manufacturing maritime sector to adopt a forward-thinking orientation. Such an orientation is crucial as it directly impacts their firms' environmental initiatives, particularly in green innovation and strategy. This is especially significant in the maritime sector, which faces unique and pressing sustainability challenges. While a long-term perspective indirectly supports the prioritization of emission reduction, the research suggests that managers can effectively achieve emission reductions through strategic green initiatives, even in the absence of a strong long-term outlook. The findings highlight that merely possessing a long-term perspective is insufficient for achieving emission reduction goals within the manufacturing maritime context. Instead, the cultivation of robust green strategies and innovation capabilities is paramount. This necessity underscores the need to prioritize these capabilities irrespective of temporal orientation, particularly in industries like maritime manufacturing that require sustained investments for substantial environmental impact.

Moreover, the analysis reveals a positive correlation between green strategy and green innovation within the maritime manufacturing sector. Firms that implement proactive green strategies are more likely to foster innovation in environmental practices. This suggests that organizations embracing sustainability are better equipped to develop and adopt innovative solutions tailored to the specific challenges of maritime manufacturing. While our model underscores the pivotal role of green innovation in emission reduction, it cautions against a narrow focus on innovation alone. Instead, we advocate for a comprehensive approach that integrates green strategy with innovative environmental initiatives, finely attuned to the complexities of maritime manufacturing operations.

Last but not least, the research provides significant policy implications for encouraging firms to proactively engage in environmental behaviors and implementing suitable environmental regulations. Effective environmental governance necessitates a sophisticated understanding of how regional environmental quality influences corporate environmental consciousness and behavior. Policy mechanisms must be designed to align with these insights, ensuring that both incentive-based and mandatory regulations are deployed strategically to maximize their impact on fostering sustainable practices within the manufacturing maritime sector. Furthermore, these findings underscore the importance of coordinated policy efforts and collaborative governance to achieve regional green and high-quality development, aligning the environmental efforts of both policymakers and firms to ensure genuine improvements in environmental performance.

7 Conclusion

The research offers significant policy implications for encouraging firms to proactively engage in environmental behaviors and implementing suitable environmental regulations:

Cultivating Firms' Environmental Consciousness: It is essential to help manufacturing firms understand the significance of environmental behavior. Effective allocation of limited resources to maximize benefits has always been a primary concern for managers. However, investing in environmental behavior is often perceived as a social cost that may conflict with managers' economic benefits, hindering many firms from engaging in such behaviors. This study suggests that, beyond considerations of corporate image, reputation, and stakeholder relationships, firms' perspectives on environmental issues may involve proactive engagement in green technological innovation to attain greater environmental benefits within relevant environmental and institutional contexts. Hence, cultivating and guiding environmental consciousness among firms is vital. This would enable managers to reassess the strategic significance of environmental protection and emphasize the technological value of environmental practices, ultimately facilitating firms in acquiring and accumulating green technologies and knowledge.

Targeted Environmental Regulation: Effective environmental regulation should be more targeted and "prescribe the right medicine." This study suggests that proper guidance of firms' environmental behavior through environmental regulation depends on selecting the appropriate regulations. Government environmental regulation should align with firms' understanding of environmental issues to enhance their motivation to protect the environment. For instance, incentive regulations can reward and support firms that proactively engage in environmental management, strive to optimize production processes, and improve production technology, thereby significantly enhancing environmental performance. Such regulations can further encourage increased investments in research and development of green technologies. Differentiated and targeted environmental regulation is more effective than a one-size-fits-all approach across all regions, as it fosters environmentally friendly and high-quality development of firms in different sectors, thereby enhancing the overall effectiveness of environmental regulation.

Effective and Collaborative Governance: Establishing effective and collaborative governance between policies and firms is crucial for addressing environmental issues, necessitating a careful balance between incentive and mandatory regulations. The research indicates that regional green and high-quality development can be achieved through the joint efforts of policy and firms. On the one hand, it is essential to identify the factors influencing corporate environmental consciousness. A comprehensive understanding of how managers' environmental consciousness influences firms' environmental strategies, particularly in varying contexts, can shed light on the mechanisms that motivate firms to proactively participate in environmental actions. On the other hand, analyzing the alignment between various types of environmental regulations and the motivation and consciousness of firms' environmental behavior is crucial for ensuring the effectiveness of the regulations. Genuine improvement in the region's environmental performance is only possible when the environmental efforts of policymakers and firms are effectively aligned and coordinated.

Furthermore, policy mechanisms such as technology push through public development contracts and market pull via public procurement play vital roles in accelerating sustainability within manufacturing maritime firms. These mechanisms are crucial for transitioning towards lower emission levels at sea, aligning with broader efforts to promote environmental responsibility in maritime operations. While firms should be encouraged to actively participate in this transition, effective policy changes are essential to inspire and incentivize innovative projects and the adoption of green strategies at organizational levels. Stakeholder involvement and coordinated actions across government and industry are crucial for successful policy implementation. In addition to these policy measures, the implementation of environmental management systems such as ISO 14001 within firms can significantly enhance their environmental behaviors. ISO 14001 is an internationally recognized standard that provides a framework for establishing, implementing, maintaining, and improving environmental management systems. By adopting ISO 14001, manufacturing maritime firms can systematically manage their environmental impact, improve resource efficiency, and demonstrate a commitment to sustainability to stakeholders and regulatory bodies. Achieving considerable sector-wide reductions requires a multifaceted approach with various policies and regulations. A transition to more sustainable business operations at sea demands clear and concise policy regulations from governments at both national and international levels. While sector ambition is a positive step forward, sustained long-term support from policymakers is essential for driving technology and market development that leads to significant emission reductions over time (Bouman et al., 2017).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

SM: Writing – review & editing, Writing – original draft. YX: Writing – review & editing, Formal Analysis, Data curation.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Andersson, Ö., and Börjesson, P. (2021). The greenhouse gas emissions of an electrified vehicle combined with renewable fuels: Life cycle assessment and policy implications. *Appl. Energy* 289, 116621. doi: 10.1016/j.apenergy.2021.116621

Aragòn-Correa, J. A., Marcus, A. A., and Vogel, D. (2020). The effects of mandatory and voluntary regulatory pressures on firms' Environmental strategies: A review and recommendations for future research. *Acad. Manage. Ann.* 14, 339–365. doi: 10.5465/annals.2018.0014

Bansal, P., and Clelland, I. (2004). Talking trash: legitimacy, impression management, and unsystematic risk in the context of the natural environment. *Acad. Manage. J.* 47, 93–103. doi: 10.5465/20159562

Bansal, P., and Roth, K. (2000). Why companies go green: A model of ecological responsiveness. *Acad. Manage. J.* 43, 717–736. doi: 10.5465/1556363

Bell, G. G. (2005). Clusters, networks, and firm innovativeness. *Strateg. Manage. J.* 26, 287–295. doi: 10.1002/(ISSN)1097-0266

Bianchi, G., Testa, F., Boiral, O., and Iraldo, F. (2022). Organizational learning for environmental sustainability: internalizing lifecycle management. *Organ. Environ.* 35, 103–129. doi: 10.1177/1086026621998744

Bickerstaff, K., and Walker, G. (2001). Public understandings of air pollution: the 'localisation' of environmental risk. *Glob. Environ. Change* 11, 133–145. doi: 10.1016/S0959-3780(00)00063-7

Boiral, O., Raineri, N., and Talbot, D. (2018). Managers' Citizenship behaviors for the environment: A developmental perspective. *J. Bus. Ethics* 149, 395–409. doi: 10.1007/s10551-016-3098-6

Borja, A., Elliott, M., H. Anderson, J., C. Cardoso, A., Carstensen, J., G. Ferreira, J., et al. (2013). Good Environmental Status of marine ecosystems: What is it and how do we know when we have attained it? *Mar. pollut. Bull.* 76, 16–27. doi: 10.1016/j.marpolbul.2013.08.042

Bouman, E. A., Lindstad, E., Rialland, A. I., and Strømman, A. H. (2017). State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review. *Transp. Res. Part Transp. Environ.* 52, 408–421. doi: 10.1016/j.trd.2017.03.022

Chang, C.-H. (2011). The influence of corporate environmental ethics on competitive advantage: the mediation role of green innovation. *J. Bus. Ethics* 104, 361–370. doi: 10.1007/s10551-011-0914-x

Chang, Y.-C. (2023). Editorial: Rule of law in the governance of new frontiers of the marine environment. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1277409

Chang, Y.-C., and Khan, M. (2023). The Maritime Labour Convention 2006 in human rights context: An appraisal. *Mar. Policy* 154, 105688. doi: 10.1016/j.marpol.2023.105688

Chen, Y.-S., and Chang, C.-H. (2013). The determinants of green product development performance: green dynamic capabilities, green transformational leadership, and green creativity. *J. Bus. Ethics* 116, 107–119. doi: 10.1007/s10551-012-1452-x

Chen, Y.-S., Lai, S.-B., and Wen, C.-T. (2006). The influence of green innovation performance on corporate advantage in Taiwan. *J. Bus. Ethics* 67, 331–339. doi: 10.1007/s10551-006-9025-5

Chen, X., and Zheng, J. (2020). Countermeasures for marine environmental pollution governance: an ecological civilization perspective. *J. Coast. Res.* 106, 355–358. doi: 10.2112/SI106-082.1

Chygryn, O., Rosokhata, A., Rybina, O., and Stoyanets, N. (2021). Green competitiveness: the evolution of concept formation. *E3S Web Conf.* 234, 4. doi: 10.1051/e3sconf/202123400004

Cochrane, S., Connor, D., Nilsson, P., Mitchell, I., Reker, J., Franco, J., et al. (2010). Marine strategy framework directive - task group 1 report biological diversity. *JRC Publ. Repos.* doi: 10.2788/86653

Currie, J., and Walker, R. (2019). What Do Economists Have to Say about the Clean Air Act 50 Years after the Establishment of the Environmental Protection Agency? *J. Econ. Perspect.* 33, 3–26. doi: 10.1257/jep.33.4.3

Dai, D., and Xue, Y. (2022). The impact of green innovation on a firm's value from the perspective of enterprise life cycles. *Sustainability* 14, 1226. doi: 10.3390/su14031226

De Cremer, D., Mayer, D. M., van Dijke, M., Schouten, B. C., and Bardes, M. (2009). When does self-sacrificial leadership motivate prosocial behavior? It depends on followers' prevention focus. *J. Appl. Psychol.* 94, 887–899. doi: 10.1037/a0014782

Dowell, G. W. S., and Muthulingam, S. (2017). Will firms go green if it pays? The impact of disruption, cost, and external factors on the adoption of environmental initiatives. *Strateg. Manage. J.* 38, 1287–1304. doi: 10.1002/smj.2603

European Commission (2008). Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance). Available online at: https://eur-lex.europa.eu/eli/dir/2008/56/oj (Accessed June 9, 2024).

Flammer, C., Hong, B., and Minor, D. (2019). Corporate governance and the rise of integrating corporate social responsibility criteria in executive compensation: Effectiveness and implications for firm outcomes. *Strateg. Manage. J.* 40, 1097–1122. doi: 10.1002/smj.3018

Ford, J. A., Steen, J., and Verreynne, M.-L. (2014). How environmental regulations affect innovation in the Australian oil and gas industry: going beyond the Porter Hypothesis. *J. Clean. Prod.* 84, 204–213. doi: 10.1016/j.jclepro.2013.12.062

Franzen, A., and Meyer, R. (2010). Environmental attitudes in cross-national perspective: A multilevel analysis of the ISSP 1993 and 2000. *Eur. Sociol. Rev.* 26, 219–234. doi: 10.1093/esr/jcp018

Frempong, M. F., Mu, Y., Adu-Yeboah, S. S., Hossin, M. A., and Adu-Gyamfi, M. (2021). Corporate sustainability and firm performance: the role of green innovation capabilities and sustainability-oriented supplier–buyer relationship. *Sustainability* 13, 10414. doi: 10.3390/su131810414

Graf-Vlachy, L., Bundy, J., and Hambrick, D. C. (2020). Effects of an advancing tenure on CEO cognitive complexity. *Organ. Sci.* 31, 936–959. doi: 10.1287/orsc.2019.1336

Harris, P. G. (2008). Green or brown? Environmental attitudes and governance in greater China. *Nat. Cult.* 3, 151–182. doi: 10.3167/nc.2008.030202

Higgins, E. T. (1997). Beyond pleasure and pain. *Am. Psychol.* 52, 1280–1300. doi: 10.1037/0003-066X.52.12.1280

Higgins, E. T. (1998). "Promotion and Prevention: Regulatory Focus as A Motivational Principle," in *Advances in Experimental Social Psychology*. Ed. M. P. Zanna (Academic Press, Elsevier), 1–46. doi: 10.1016/S0065-2601(08)60381-0

Higgins, E. T. (2000). Making a good decision: Value from fit. *Am. Psychol.* 55, 1217–1230. doi: 10.1037/0003-066X.55.11.1217

Higgins, E. T., and Pinelli, F. (2020). Regulatory focus and fit effects in organizations. *Annu. Rev. Organ. Psychol. Organ. Behav.* 7, 25–48. doi: 10.1146/annurev-orgpsych-012119-045404

Huang, Z., Liao, G., and Li, Z. (2019). Loaning scale and government subsidy for promoting green innovation. *Technol. Forecast. Soc Change* 144, 148–156. doi: 10.1016/j.techfore.2019.04.023

Huang, C., and Zheng, W. (2022). CEO regulatory focus, analysts' Optimism bias, and firm strategic change: evidence from Chinese-listed companies. *Front. Psychol.* 13. doi: 10.3389/fpsyg.2022.813920

Khan, M., Butt, M. J., and Chang, Y.-C. (2023). Maritime Law in Motion: Book Review. *China Oceans Law Rev.* Available online at: https://heinonline.org/HOL/LandingPage?handle=hein.journals/cholr2023&div=29&id=&page.

Khan, M., Chang, Y.-C., and Bibi, A. (2024). Navigating Pakistan's Maritime Industry potential in context of blue economy: An analysis of the necessity for ratification of maritime labour convention 2006. *Mar. Policy* 165, 106150. doi: 10.1016/j.marpol.2024.106150

Lai, K.-H., Cheng, T. C. E., and Tang, A. K. Y. (2010). Green retailing: factors for success. *Calif. Manage. Rev.* 52, 6–31. doi: 10.1525/cmr.2010.52.2.6

Lai, K.-H., Lun, V. Y. H., Wong, C. W. Y., and Cheng, T. C. E. (2011). Green shipping practices in the shipping industry: Conceptualization, adoption, and implications. *Resour. Conserv. Recycl.* 55, 631–638. doi: 10.1016/j.resconrec.2010.12.004

Lee, P. T.-W., Kwon, O. K., and Ruan, X. (2019). Sustainability challenges in maritime transport and logistics industry and its way ahead. *Sustainability* 11, 1331. doi: 10.3390/su11051331

Li, D., Huang, M., Ren, S., Chen, X., and Ning, L. (2018). Environmental legitimacy, green innovation, and corporate carbon disclosure: evidence from CDP China 100. *J. Bus. Ethics* 150, 1089–1104. doi: 10.1007/s10551-016-3187-6

Li, S., Qiao, J., Cui, H., and Wang, S. (2020). Realizing the environmental benefits of proactive environmental strategy: the roles of green supply chain integration and relational capability. *Sustainability* 12, 2907. doi: 10.3390/su12072907

Li, Y., Tang, Y.-T., Tan-Mullins, M., and Ives, C. D. (2023). Exploring the potential opportunities of China's environmental agenda, ecological civilization, on global sustainable development. *Sustainability* 15, 5135. doi: 10.3390/su15065135

Lirn, T.-C., Lin, H.-W., and Shang, K.-C. (2014). Green shipping management capability and firm performance in the container shipping industry. *Marit. Policy Manage.* 41, 159–175. doi: 10.1080/03088839.2013.819132

Ma, R., Hou, W., Priem, R., and Wright, P. (2022). Does restricted stock turn CEOs into risk-averse managers? Insights from the regulatory focus theory. *Long Range Plann.* 55, 102165. doi: 10.1016/j.lrp.2021.102165

Manczak, E. M., Zapata-Gietl, C., and McAdams, D. P. (2014). Regulatory focus in the life story: Prevention and promotion as expressed in three layers of personality. *J. Pers. Soc Psychol.* 106, 169–181. doi: 10.1037/a0034951

Mee, L. D., Jefferson, R. L., Laffoley, D.d'A., and Elliott, M. (2008). How good is good? Human values and Europe's proposed Marine Strategy Directive. *Mar. pollut. Bull.* 56, 187–204. doi: 10.1016/j.marpolbul.2007.09.038

P. K. Mukherjee, M. Q. Mejia and J. Xu (Eds.) (2020). *Maritime law in motion* (Cham: Springer International Publishing). doi: 10.1007/978–3-030–31749-2

Mulaessa, N., and Lin, L. (2021). How do proactive environmental strategies affect green innovation? The moderating role of environmental regulations and firm performance. *Int. J. Environ. Res. Public. Health* 18, 9083. doi: 10.3390/ijerph18179083

Nazir, S., Zhaolei, L., Mehmood, S., and Nazir, Z. (2024). Impact of green supply chain management practices on the environmental performance of manufacturing firms considering institutional pressure as a moderator. *Sustainability* 16, 2278. doi: 10.3390/su16062278

NBSC (2022). China Statistical Yearbook. Available online at: https://www.stats.gov.cn/sj/ndsj/2022/indexeh.htm (Accessed June 6, 2024).

Neubert, M. J., Kacmar, K. M., Carlson, D. S., Chonko, L. B., and Roberts, J. A. (2008). Regulatory focus as a mediator of the influence of initiating structure and servant leadership on employee behavior. *J. Appl. Psychol.* 93, 1220–1233. doi: 10.1037/a0012695

Obama, B. (2009). President Barack Obama at UN Climate Change Summit. Available online at: https://www.osti.gov/sciencecinema/biblio/1045440 (Accessed May 6, 2024).

Porter, M. E., and Kramer, M. R. (2019). ""Creating Shared Value,"," in *Managing Sustainable Business: An Executive Education Case and Textbook*. Eds. G. G. Lenssen and N. C. Smith (Springer Netherlands, Dordrecht), 323–346. doi: 10.1007/978–94-024–1144-7_16

Rehfeld, K.-M., Rennings, K., and Ziegler, A. (2007). Integrated product policy and environmental product innovations: An empirical analysis. *Ecol. Econ.* 61, 91–100. doi: 10.1016/j.ecolecon.2006.02.003

Reid, E. M., and Toffel, M. W. (2009). Responding to public and private politics: corporate disclosure of climate change strategies. *Strateg. Manage. J.* 30, 1157–1178. doi: 10.1002/smj.796

Rennings, K. (2000). Redefining innovation — eco-innovation research and the contribution from ecological economics. *Ecol. Econ.* 32, 319–332. doi: 10.1016/S0921-8009(99)00112-3

Rennings, K., and Rammer, C. (2011). The impact of regulation-driven environmental innovation on innovation success and firm performance. *Ind. Innov.* 18, 255–283. doi: 10.1080/13662716.2011.561027

Rennings, K., and Zwick, T. (2002). Employment impact of cleaner production on the firm level: empirical evidence from a survey in five european countries. *Int. J. Innov. Manage.* 06, 319–342. doi: 10.1142/S1363919602000604

ResourceWatch Air Quality: Surface Fine Particulate Matter (PM2.5) Concentrations (RESSOURCEWATCH). (2024). Available online at: https://resourcewatch.org/data/explore/cit031rw1-Air-Quality-Surface-Fine-Particulate-Matter-PM25-Concentrations (Accessed June 6, 2024).

Roy, M.-J., Boiral, O., and Lagacé, D. (2001). Environmental commitment and manufacturing excellence: a comparative study within Canadian industry. *Bus. Strategy Environ.* 10, 257–268. doi: 10.1002/bse.304

Shang, K.-C., Lu, C.-S., and Li, S. (2010). A taxonomy of green supply chain management capability among electronics-related manufacturing firms in Taiwan. *J. Environ. Manage.* 91, 1218–1226. doi: 10.1016/j.jenvman.2010.01.016

Shu, C., Zhou, K. Z., Xiao, Y., and Gao, S. (2016). How green management influences product innovation in China: the role of institutional benefits. *J. Bus. Ethics* 133, 471–485. doi: 10.1007/s10551-014-2401-7

Sprigge, T. L. S. (1999). The relation between jeremy bentham's psychological, and his ethical, hedonism. *Utilitas* 11, 296–319. doi: 10.1017/S0953820800002521

Sroufe, R., and Curkovic, S. (2008). An examination of ISO 9000:2000 and supply chain quality assurance. *J. Oper. Manage.* 26, 503–520. doi: 10.1016/j.jom.2007.06.006

Sternad, D., and Kennelly, J. J. (2017). The sustainable executive: antecedents of managerial long-term orientation. *J. Glob. Responsib.* 8, 179–195. doi: 10.1108/JGR-04-2017-0026

Tan, K., Siddik, A. B., Sobhani, F. A., Hamayun, M., and Masukujjaman, M. (2022). Do environmental strategy and awareness improve firms' Environmental and financial performance? The role of competitive advantage. *Sustainability* 14, 10600. doi: 10.3390/su141710600

Triguero, A., Moreno-Mondéjar, L., and Davia, M. A. (2013). Drivers of different types of eco-innovation in European SMEs. *Ecol. Econ.* 92, 25–33. doi: 10.1016/j.ecolecon.2013.04.009

Vourdachas, A. (2018). Overview of the recent regulatory framework in maritime industry (SAFETY4SEA). Available online at: https://safety4sea.com/overview-of-the-recent-regulatory-framework-in-maritime-industry/ (Accessed June 6, 2024).

Wang, C. L. (2008). Entrepreneurial orientation, learning orientation, and firm performance. *Entrep. Theory Pract.* 32, 635–657. doi: 10.1111/j.1540-6520.2008.00246.x

Wang, T. (2016). Long-term orientation, marketing and technological capabilities, and social responsibility in new ventures. *World Scientific. World Scientific*. 249–273. doi: 10.1142/9789813220614_0010

Wang, L., Li, W., and Qi, L. (2020). Stakeholder pressures and corporate environmental strategies: A meta-analysis. *Sustainability* 12, 1172. doi: 10.3390/su12031172

Wang, R., Wijen, F., and Heugens, P. P. M. A. R. (2018). Government's green grip: Multifaceted state influence on corporate environmental actions in China. *Strateg. Manage. J.* 39, 403–428. doi: 10.1002/smj.2714

Wang, L., Yao, J., Zhang, H., Pang, Q., and Fang, M. (2023). A sustainable shipping management framework in the marine environment: Institutional pressure, eco-design, and cross-functional perspectives. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.1070078

Wright, C., and Nyberg, D. (2017). An inconvenient truth: how organizations translate climate change into business as usual. *Acad. Manage. J.* 60, 1633–1661. doi: 10.5465/amj.2015.0718

Wu, G.-C., Ding, J.-H., and Chen, P.-S. (2012). The effects of GSCM drivers and institutional pressures on GSCM practices in Taiwan's textile and apparel industry. *Int. J. Prod. Econ.* 135, 618–636. doi: 10.1016/j.ijpe.2011.05.023

Wubben, E. F. M. (2000). *The Dynamics of the Eco-efficient Economy: Environmental Regulation and Competitive Advantage* (UK: Edward Elgar Publishing, Glos). doi: 10.4337/9781782543978

Wuisan, L., van Leeuwen, J., and Kris) van Koppen, C. S. A. (2012). Greening international shipping through private governance: A case study of the Clean Shipping Project. *Mar. Policy* 36, 165–173. doi: 10.1016/j.marpol.2011.04.009

York, J. G., Vedula, S., and Lenox, M. J. (2018). It's not easy building green: the impact of public policy, private actors, and regional logics on voluntary standards adoption. *Acad. Manage. J.* 61, 1492–1523. doi: 10.5465/amj.2015.0769

Zhu, Q., Sarkis, J., and Lai, K. (2008). Confirmation of a measurement model for green supply chain management practices implementation. *Int. J. Prod. Econ.* 111, 261–273. doi: 10.1016/j.ijpe.2006.11.029

Zou, K., and Chang, Y.-C. (Eds.). (2021) "Climate Change and Fisheries Regulation: What We Should Consider for the Future?," in *Preserving Community Interests in Ocean Governance towards Sustainability*, vol. 2 (MDPI, Basel, Switzerland). Available at: https://core.ac.uk/download/pdf/520262239.pdf.

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 10 July 2024
DOI 10.3389/fmars.2024.1438690

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
M. Jahanzeb Butt,
Shandong University, China
Hongyun Huang,
Shandong University, China
I. Gusti Ngurah Parikesit Widiatedja,
Udayana University, Indonesia

*CORRESPONDENCE
Weihai Li
weihaili@cupl.edu.cn

RECEIVED 26 May 2024
ACCEPTED 28 June 2024
PUBLISHED 10 July 2024

CITATION
Li W (2024) Building the rule of law for maritime security in China: a domestic law perspective. *Front. Mar. Sci.* 11:1438690. doi: 10.3389/fmars.2024.1438690

COPYRIGHT
© 2024 Li. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Building the rule of law for maritime security in China: a domestic law perspective

Weihai Li*

School of Law, China University of Political Science and Law, Beijing, China

Maritime security is an essential component of national security, and the effective maintenance of China's maritime security urgently needs a complete guarantee of the rule of law. Since the founding of the People's Republic of China in 1949, the construction of domestic law on maritime security has undergone three phases: slow development, formation and refinement. Although the rule of law in the seas has been constantly improved, it has provided essential safeguards for maintaining China's maritime sovereignty, security, and rights and interests. It has facilitated the development of maritime undertakings. However, it still faces problems such as the lack of an explicit constitutional basis, the law of the sea is not an independent departmental law, the absence of the fundamental law of the sea, the lack of operability of marine legislation, and the existence of some gaps in marine laws. Given the problems with the current domestic law on maritime security, it is necessary to make improvements in the following areas: adding marine provisions to the *Constitution*, formulating the fundamental law of the sea and other marine laws, improving local marine laws, and introducing implementing regulations.

KEYWORDS

the rule of law, maritime security, the domestic law, problems, improvements

1 Introduction

Maritime security can be understood as a concept referring to the security of the maritime domain and as a set of policies, regulations, measures and actions to ensure the security of the maritime domain. Maritime security is geopolitical, as it involves projecting public power beyond external boundaries within the global maritime domain (Germond, 2015). Maritime security involves all aspects of human security, peace and stability, economic prosperity, environmental health, social equity and security, and the pursuit of maritime security calls for the global community, States, communities, groups and individuals to work together, contribute their wisdom and unite their efforts to provide a sustainable path to maritime security (Li, 2023). Maritime security is also a popular term in current international relations (Bueger, 2015). This term attracts extensive academic discussion, covering security studies, international trade, environmental protection,

climate change, and global governance. The term's popularity reflects an emerging consensus in the international community that recognizes the growing challenges facing the world's seas and the urgent need for serious efforts to address them.

It is as old as human interaction with the sea, whether as fishermen, traders, or in any other capacity. Maritime security has a long history (Amirell, 2016). Over the past few decades, research on criminal activities, illegal acts and violence at sea (e.g., illegal fishing, piracy and robbery at sea, arms and drug smuggling, and human trafficking) has increasingly explored the interplay between economic, social, political and geopolitical factors that have transformed maritime security (Germond and Mazaris, 2019). The international maritime security order is shifting from a hegemonic pattern dominated by the United States and its allies to a multinational pattern. As a rising maritime power, China's continued strengthening of its economy and maritime power is a significant influence on the future maritime security environment in Asia, and its increased maritime power will inevitably have an impact on the existing maritime security order (Bateman, 2015; Sun et al., 2021). The United States and Japan have linked the East and South China Seas in their maritime strategies to prevent China from continuing to expand its offshore presence (Odgaard, 2017). China is facing problems in the East China Sea, the South China Sea, and port disputes along the Belt and Road Initiative. The situation will likely become even more critical (Sun et al., 2021). Threats from the sea include non-traditional issues such as piracy, terrorism, environmental protection and natural disasters. There are also traditional security threats, including military aggression, the maintenance of sovereignty and sovereign rights, and the security of sea lines of communication. Maritime security is the basis for regional economic development and national security (Joshi, 2023). Peaceful coexistence and active defense are China's main principles for maintaining maritime security (Odgaard, 2017).

As a large country with both land and sea resources, China is one of the countries with the longest borders, the largest number of neighboring countries and the most complex border situation in the world (Zhu, 2015, p. 103). For a long time, China's maritime security has faced complex challenges, especially since the Opium War, when many large-scale invasions by foreign enemies came from the sea. After founding the People's Republic of China in 1949, the Chinese government has increasingly emphasized the rule of law on the sea. Especially after the reform and opening-up, China's marine legislation has developed rapidly, and many maritime laws and regulations have been formulated. Since entering the 21st century, in the face of the complex changes in the maritime security situation, China has strengthened the construction of maritime military forces, enhanced its ability to defend its national sovereignty and territorial integrity, and actively improved the legal system of the seas to provide a solid domestic rule of law for the effective maintenance of maritime security. In the era of building a strong maritime country, the realization and maintenance of national maritime security interests are undoubtedly inseparable from the guarantee and support of legal norms (Tao and Wang, 2019). China's experience shows that it is vital to ensure that the domestic rule of law is in line with trends in global governance (Xing et al., 2022).

Although the rule of law plays an extremely important role in the construction of China's maritime security, there is a lack of systematic research on China's domestic law on maritime security. Therefore, from the perspective of China's domestic law, this paper first combs through the current literature on maritime security research, then reviews the history of the construction of domestic law on maritime security, including the three phases of slow developing, forming and refining. On this basis, it analyzes the issues existing in China's domestic law on maritime security and further proposes recommendations to improve the domestic law on maritime security, hoping to provide inspiration and guidance for the construction of domestic law on maritime security.

2 Literature review

Scholars of international relations have argued that the idea of maritime security should guide the construction of a legal system for maritime security. Scholars introduce the schools of international relations on security issues and the main contemporary national security concepts and sort out the vein of the maritime security concept (Liu and Xv, 2011; Zhang Y., 2022). In *On China's Maritime Power*, the author discusses China's maritime security ideology from the perspectives of the characteristics of China's maritime power and the principles of the expansion of China's maritime power, and puts forward countermeasure proposals for China's maritime security in the first half of the 21st century (Zhang, 2014). In 2014, China put forward the Overall National Security Outlook (ONSO). National security has both traditional and non-traditional security. China faces the challenge of the interplay of traditional maritime security and non-traditional maritime security risks, and the maintenance of maritime security is an important content and basic embodiment of the ONSO (Qing, 2015; Zhang H. W., 2022). China needs to change its traditional thinking on maritime security, implement the concept of a maritime community based on mutual consultation and sharing, and establish comprehensive national security and common security for humankind (Sun et al., 2021).

Scholars of the law of the sea have made analyses from the perspective of the rule of law for maritime security. Firstly, recognizing the situation and challenges facing maritime security is a prerequisite for improving the rule of law system for maritime security. Based on a systematic analysis of traditional and non-traditional maritime security challenges, the scholar distilled the new challenges to China's maritime security, focused on analyzing some of the deficiencies in the current domestic marine legislation, and put forward some constructive suggestions (Zhang H. W., 2022). Scholars have analyzed the situation of China's maritime security and the causes of threats from the perspective of globalization and explained why they chose to apply the rule of law to safeguard maritime security through specific cases such as piracy on the high seas and military surveying activities (Jin, 2010; Man, 2014). Scholars have proposed a path for legalizing the marine national strategy, discussing how to achieve the rule of law for the sustainable development of the seas in terms of institutional mechanisms (Man, 2014; Zhai, 2015). In the above representative

literature, although the complex situation and challenges facing China's maritime security have been analyzed from different perspectives, the conclusion that "the rule of law is the best measure to deal with maritime security" has been put forward.

Secondly, scholars have introduced the stages of development that China's maritime strategy has gone through, the core concepts embodied in its maritime strategy, and the specific manifestations of its promotion of innovation in the international law of the sea system, which is of great significance to the understanding of its maritime strategy and marine legislation, and provides China with helpful experience in promoting international maritime security legislation (Yao, 2021). *United Nations Convention on the Law of the Sea* (*UNCLOS*) is the charter of the international law of the sea, and a fair and reasonable interpretation of *UNCLOS* is a prerequisite for its accurate application and the safeguarding of rights and interests. It provides theoretical guidance for China to safeguard its maritime security under the framework of international law, build up a system for interpreting the rules, and strengthen its capacity for discourse. It also contributes to promoting the fundamental role of *UNCLOS* in the international governance of the seas (Zhang, 2021; Yang, 2022).

Thirdly, the seas are open to all humankind and require the joint participation of all countries in their governance. Maritime security is an essential component and a strong guarantee of ocean governance (Aarstad, 2017). Ocean governance and maritime security translate into a practice of controlling ocean space, leading to a certain territorialization of the seas, not so much from the point of view of sovereignty and jurisdiction as from the point of view of function and norms (Germond and Germond-Duret, 2016). Scholars comprehensively introduce the generative background, connotation, characteristics, starting point and foothold, important role, and basic methodology of the rule of law relating to foreign affairs in the seas, which theoretically supports the construction of the rule of law for China's maritime security to the international level and provides a Chinese program for global ocean governance (Wang G., 2022; Wang L., 2022; Yang, 2023). The rule of law relating to foreign affairs is an integral part of China's rule of law system for maritime security, and it is a crucial way to promote the fair and reasonable distribution of maritime rights and interests by the international community, and to build a harmonious global ocean governance system. However, the current research on China's foreign-related marine rule of law is insufficient (Yao, 2022; Bai and Li, 2024). Scholars have introduced the main problems in constructing China's marine legal system, which are highlighted by the lack of a fundamental law on the seas, insufficient coordination among laws, and insufficient forward-looking legislation (Yang, 2021; Chu and Guo, 2023).

The above literatures have expressed their views on the construction of domestic laws on maritime security more from specific areas and macro perspectives, without sorting out and analyzing the specific problems that exist in them, and without putting forward systematic recommendations. Scholars have introduced the purpose, basic features, and essential connotations of China's maritime security policy and strategy, which provide a basis for understanding the construction of China's maritime security legal system, noting that China does not seem to have a long-term marine policy (Ji, 2022). The global nature of the maritime domain has led to the transnational nature of many current maritime security threats (immigration, drug smuggling, piracy) (Germond, 2015). The maritime security order is an integral part of the international security order (Sun et al., 2021). The future global maritime strategy is under the rule of law and implemented under *UNCLOS*. Countries should develop the seas peacefully, participate in ocean governance harmoniously, deal with sea-related disputes more through consultation, and create a community of destiny in the seas. China must start with sound marine security laws if it wants to realize the sustainable and stable development of its marine strategy.

3 Review of domestic law

Since the founding of the People's Republic of China in 1949, the construction of China's marine rule of law has continued to improve, and is an essential element in the construction of China's rule of law; in particular, it has made great strides in the more than forty years since the reform and opening up, and has provided a kind of institutionalized legal safeguard for maintaining China's maritime sovereignty, security and rights and interests in the seas, and has contributed to the promotion of maritime undertakings. China has not yet introduced the *Maritime Safety Law*, and provisions on maritime safety are scattered in other maritime laws. The development of domestic maritime security laws can be divided into the following three stages.

3.1 Slow development stage (from 1949 to 1979)

In this stage, there was a gap in China's marine laws. There was no formal legislation on the seas, but rather statements, ordinances and regulations issued by the Chinese government declared and defended the country's sovereignty, security and rights and interests. The Chinese government issued only a small number of sea-related regulations and rules in individual areas, such as the *Interim Regulations Harbor Management* in 1954, the *Order on the Closed Areas of the Bohai Sea, the Yellow Sea, and the East China Sea for Machine Trawl Fisheries* in 1955, the *Provisions on the Passage of Merchant Vessels through the Old Tieshan Waterway* in 1956, the *Rules on Investigation Settlement of Average Accidents* in 1959, the *Rules for the Control of Non-Military Vessels of Foreign Origin Passing Through the Qiongzhou Strait* in 1964, and the *Provisions on Port Navigation* in 1976 (Jia, 2007).

During this period, one of the most important documents of the Chinese government relating to maritime security was the *Declaration on China's Territorial Sea*, issued in 1958. This was the first time that China made a clear statement on maritime rights and interests and maritime security, and its core contents include: first, determining the width of the territorial sea of 12 nautical miles; second, adopting a straight line baseline; third, all foreign aircraft and military vessels are not allowed to enter China's territorial sea and airspace without the permission of the Chinese government. Its main

purpose was to ensure China's maritime security. Article 1 of *Rules for the Control of Non-Military Vessels of Foreign Origin Passing Through the Qiongzhou Strait* once again reiterated China's basic position on the territorial sea system, emphasizing that the rules for passage through the territorial sea had a bearing on the sovereignty of the coastal States and maritime security. However, since China did not publish the baselines of its territorial sea at that time, the territorial sea system was still very imperfect.

3.2 Formative stage (from 1980 to 1999)

3.2.1 Incorporating the relevant *UNCLOS* rules into domestic legislation

UNCLOS was promulgated in 1982, and China ratified its accession to *UNCLOS* in 1996, using its relevant provisions as a template for its marine legislation, with some of the provisions of its domestic legislation drawing entirely on the content of the relevant provisions of *UNCLOS*. China promulgated the *Law on the Territorial Sea and the Contiguous Zone* in 1992. This law stipulates China's territorial sea and contiguous zone regime based on the *Declaration on China's Territorial Sea*. This law emphasizes the two fundamental elements of the State's sovereignty over the territorial sea, its right to control the contiguous zone, and the spatial extent of China's territorial sea and contiguous zone. Since this law was drafted based on the principles of international law, in particular *UNCLOS*, the basic contents of this law are consistent with the principles and relevant provisions of *UNCLOS*. This law contains 17 articles, which are 75% similar to the applicable provisions of *UNCLOS* (Gao, 2004, p. 6).

The 1998 *Law on the Exclusive Economic Zone and the Continental Shelf* established the legal regime for China's 200-nautical-mile exclusive economic zone, as well as the legal regime for the continental shelf based on the 200-nautical-mile distance and the natural extension of China's land territory. This law was also drafted based on *UNCLOS*, and attention was paid to its convergence with the relevant provisions of *UNCLOS* (Gao, 2004, pp. 3-18). However, this law does not contain specific provisions on some of the interpretative and operational provisions of *UNCLOS* relating to the exclusive economic zone and continental shelf. In order to ensure that China enjoys all the rights provided for in *UNCLOS* and international law, Article 13 specifically provides that the rights China enjoys in its exclusive economic zone and continental shelf shall be exercised in accordance with international law and other relevant Chinese laws and regulations. This law contains 16 articles, 80% of which are similar to those of *UNCLOS* (Gao, 2004, p. 7). These two laws are the most fundamental marine laws and are essential in safeguarding maritime sovereignty, security and interests (Jia, 2019).

3.2.2 Building a domestic legal system for the seas

During this stage, China issued a series of laws, regulations and government statements to regulate various types of marine activities, gradually forming the basic framework for the rule of law in China's seas. Laws and regulations on the development, management and protection of marine resources include the *Interim Regulation on Fishery Administrative Work* in 1979, the *Regulation on the Exploitation of Offshore Petroleum Resources in Cooperation with Foreign Enterprises* in 1982, the *Fisheries Law* in 1986, and the *Mineral Resources Law* in 1986.

Laws and regulations on navigation safety include the *Regulations Governing Supervision and Control of Foreign Vessels* in 1979, the *Regulation on the Administration of Navigable Waterways* in 1987, and the *Regulations for Navigation Marks* in 1995. The 1983 *Maritime Traffic Safety Law* makes legal provisions for supervising maritime traffic safety and ensuring the safety of ships, facilities, persons and property (The State Oceanic Administration, 2012, p. 49).

Laws and regulations on marine ecological security. The 1982 *Marine Environmental Protection Law* established a system for managing sources of marine pollution, assessing the marine environment, and imposing penalties for marine pollution. This law is one of the earliest, most direct and most significant marine environmental protection laws in China, laying a legal foundation for protecting the marine environment and playing a pivotal role in constructing a marine ecological civilization (Zou, 1999). In accordance with this law, the State Council also formulated the *Regulations on the Control over Prevention of Pollution by Vessels in Sea Waters* and the *Regulations Concerning Environmental Protection in Offshore Oil Exploration and Exploitation* in 1983, the *Regulations on the Control over Dumping Wastes into the Sea Waters* in 1985, the *Administrative Regulation on the Prevention of Environmental Pollution by Ship Breaking* in 1988, the *Administrative Regulations on the Prevention and Control of Pollution Damage to the Marine Environment by Land-sourced Pollutants*, and the *Administrative Regulation on the Prevention and Control of Pollution Damages to the Marine Environment by Coastal Engineering Construction Projects* in 1990.

In addition, the State Council has promulgated many other sea-related administrative laws and regulations, such as the *Provisions Governing the Laying of Submarine Cables and Pipelines* in 1989, the *Administrative Measures on Foreign Participation in Salvaging Shipwrecks and Sunken Objects in China's Coastal Waters* in 1992, the *Regulations on Nature Reserves* in 1994, and the *Provisions on Administration of Foreign-related Marine Scientific Research* in 1996. The *Interim Provisions on the Administration of Use of National Sea Waters*, jointly issued by the Ministry of Finance and the State Oceanic Administration in 1993, clearly stated that a system of sea area use rights and compensated use should be established, initially setting up a sea area management system (Jia, 2019).

3.3 Refinement stage (from 2000 to the present)

3.3.1 Laws

Against the background of the continuous improvement of China's level of marine development and utilization, China has successively introduced a series of marine laws. These new laws not only cover all aspects of the development, utilization and protection

of marine resources but also involve all aspects of marine management and law enforcement, with some of the legislation filling in the gaps in certain areas (see Table 1). Article 3 of the *Law on the Administration of Sea Areas* in 2001 stipulates that the maritime areas are owned by the State, and Article 6 provides for the right to use maritime areas registered in accordance with the law is legally protected, which strengthens the rational development, sustainable utilization and effective management of internal waters and territorial seas. The *Ports Law* promulgated in 2003 is a law regulating the planning, construction, maintenance, operation and management of ports, and Article 3 stipulates that the scope of application shall be a specific range of waters and land areas. The *Island Protection Law* in 2009 establishes a new legal system for the efficient exploitation and adequate protection of near-shore sea areas and sea islands. The *Law on the Exploration and Development of Resources in Deep Seabed Areas* in 2016 is the first law regulating the exploration and exploitation of deep seabed mineral resources in areas beyond the national jurisdiction of Chinese enterprises, organizations and individuals, and is also the first law to regulate the deep and international seabed, filling a gap in two of China's laws (Xinhua News Agency, 2016).

China has reformed its marine law enforcement system since 2017, incorporating the Coast Guard into the People's Armed Police Force and assuming responsibility for safeguarding the country's maritime rights and interests and maritime law enforcement (see Table 2). China enacted the *Coast Guard Law* in 2021, which stipulates the duties and authorities of the Coast Guard and provides a legal basis for the Coast Guard to carry out maritime rights and law enforcement (Liu and Hu, 2024). Although some scholars have questioned specific provisions of the *Coast Guard Law* as posing a threat to regional maritime security (Kim, 2022), this does not detract from the positive contribution of the *Coast Guard Law* to China's maritime security.

Much of China's existing marine legislation no longer meets the needs of the maritime security situation and the development of the maritime economy, and some of its provisions are inconsistent with the relevant provisions of *UNCLOS* and need to be revised. For example, as the *Fisheries Law* was not compatible with China's economic and social development, it was revised four times in 2000, 2004, 2009, and 2013; to implement the idea of ecological civilization and the new concept of ecological protection, China revised the *Marine Environmental Protection Law* five times in 1999, 2013, 2016, 2017, and 2023 (Liu, 2024); and in accordance with the overall requirements for building a strong maritime country and a strong transportation country, the *Ports Law* was revised three times in 2015, 2017 and 2018; and the *Maritime Traffic Safety Law* was amended twice in 2016 and 2021 to safeguard the safety of people and property at sea, safeguard the rights and interests of the State, and comprehensively enhance the capacity of management of maritime traffic order.

In addition, marine provisions have found their way into an increasing number of non-specialized marine laws. As a result of the growing importance of maritime issues in the country's overall strategy and the expanding field of adjustment of China's laws, more and more laws contain sea-related provisions. In particular, some critical foundational laws also contain sea-related legal provisions. For example, Articles 17 and 23 of the *National Security Law* include territorial sovereignty, maritime rights and interests, and China's interests in the international seabed area as

TABLE 1 Laws related to maritime security in China.

Time	Law Name	Related Article
1992 (Formulation)	Law on the Territorial Sea and the Contiguous Zone	Articles 1, 8, 9, and 13
1998 (Formulation)	Law on the Exclusive Economic Zone and the Continental Shelf	Articles 5, 7, 8, and 9
2001 (Formulation)	Law on the Administration of Sea Areas	Articles 7, 11, 13, 26, 30, and 52
2013 (Amendment)	Fisheries Law	Articles 8, 17, and 46
2015 (Formulation)	National Security Law	Articles 17, 18, and 32
2016 (Amendment)	Waterway Law	Articles 1, 2, 4, 10, 11, 12, 14, 17, 18, 19, 21, 33, 35, and 42
2016 (Formulation)	Law on the Exploration and Development of Resources in Deep Seabed Areas	Articles 1, 7, 9, 11, 12, and 13
2020 (Revision)	National Defense Law	Articles 2, 3, 4, 25, 30, 31, 32, 47, 68, and 69
2021 (Revision)	Maritime Traffic Safety Law	Articles 1, 2, 3, 5, 7, 8, 11, 19, 20, 27, 28, 29, 30, 44, 47, 48, 49, 50, 51, 53, 54, 88, 91, 92, 93, 101, 103, 105, and 117
2021 (Formulation)	Coast Guard Law	Articles 1, 5, 12, 16, 17, 18, 19, 20, 21, 22, 25, and 64
2023 (Revision)	Marine Environmental Protection Law	Articles 1, 55, 73, 81, 84, 87, and 89

TABLE 2 Responsibility of the China coast guard.

Responsibility	Detail
Maintaining maritime security order	Combating illegal and criminal activities such as smuggling, robbery and drug trafficking, organizing patrols and alerts, dealing with emergencies and settling maritime disputes.
Ensuring the safety of maritime traffic	Implementing maritime search and rescue, maintaining maritime shipping safety, and implementing maritime traffic and waterway management.
Protecting the marine environment and marine resources	Supervising ships to comply with laws and regulations on protecting the marine environment and resources, preventing marine pollution, conducting cruise surveillance in fishery waters, and investigating and dealing with violations of fishery laws and regulations.
Assumption of maritime territorial defense	Maintaining the security of ports and waterways, combating terrorist activities at sea, safeguarding national sovereignty, dealing with sea-related disputes with neighbouring countries, serving as a naval reserve in wartime and assisting in completing of wartime mobilization.

essential elements of national security. Articles 247 and 328 of the *Civil Code* stipulate that the State owns maritime areas and uninhabited islands and that the State protects the right to use maritime areas acquired in accordance with the law, explicitly stipulating the ownership of the seas, which is conducive to the safeguarding of China's maritime interests.

3.3.2 Regulations and rules

In order to better implement marine laws, the relevant departments have also formulated a series of supporting measures. For example, after the *Law on the Exploration and Development of Resources in Deep Seabed Areas*, the relevant departments have successively issued the *Interim Measures for the Management of Samples for Exploration and Exploitation of Resources in Deep Seabed Area*s and the *Interim Measures for the Management of Information on Exploration and Exploitation of Resources in Deep Seabed Areas*. In China, it is usually the case that the relevant departments formulate some normative documents before formal legislation is enacted to conduct some preliminary exploration for subsequent legislation. In the case of Antarctic governance, for example, the "*Law on Antarctic Activities and Environmental Protection*" is still in the drafting stage, but provisions on administrative licensing and environmental impact assessment of Antarctic scientific research activities have been introduced one after another. First, it temporarily fills gaps in the law with departmental regulations and rules to regulate and manage Antarctic activities; second, it provides the basis and experience for formal legislation (China National People's Congress, 2024).

4 Problems with domestic law on maritime security

The elements of the seas have not been incorporated into the *Constitution*, nor has China formulated a basic law on the seas that is overarching and fundamental, let alone a law on maritime security. At present, China's legislation on maritime security is scattered in laws and regulations relating to maritime security and rights, maritime ecological and environmental security, maritime transportation security, maritime law enforcement, which runs counter to the comprehensive and sustainable outlook of maritime security (Guo and Yan, 2024).

4.1 Lack of an explicit constitutional basis

At present, 32 countries have marine provisions in their constitutions (Jiang, 1997). To date, China has not included the word "sea" in the *Constitution*, and the *Constitution* does not explicitly protect maritime security. The territorial sea is as essential a part of China's territory as the land territory. However, there is still a big difference between the two in the status of the *Constitution*, and maritime security is only protected by the common law, but not by the fundamental law of the country—the *Constitution*. Article 34 of the *Common Program of The Chinese People's Political Consultative Conference*, which was the provisional *Constitution* of the People's Republic of China in 1949, contains the phrase "coastal fisheries shall be protected and the aquatic products industry shall be developed", which can be said to include sea-related content; the 1954 *Constitution* and the 1975 *Constitution* do not contain any relevant content on the sea; Article 6, paragraph 2 of the 1978 *Constitution* stipulates that "marine and land resources" shall be owned by all people, which is the most direct and explicit provision on the issue of the sea in the *Constitution*. Article 9 of the current 1982 *Constitution* replaces "marine and land resources" in the 1978 *Constitution* with "natural resources", and the *Constitution* still makes no mention of the sea. In the *Constitution*, terms such as "waters" and "beaches" are hardly representative of the seas (Yi, 2014). Although the *Constitution* has been amended several times, there is still no amendment concerning the seas, and the provisions on the seas have not improved. This also shows that China's emphasis on the seas still needs to be improved, that the protection of maritime security has still not been incorporated into the fundamental law of the country, and the status of the law of the sea in the construction of the rule of law in China has not been adequately reflected. This directly leads to the dilemma that China's sea-related legislation often faces a lack of constitutional basis. In China, other departmental laws are generally based on the *Constitution*, and "this Law is developed in accordance with the *Constitution*" is often used. However, there is no similar expression in the laws relating to the seas, which indicates that China's marine legal system lacks a constitutional basis (Xv, 2008).

4.2 The law of the sea is not an independent departmental law

China's marine resources are rich in variety and quantity, and its marine administration is complex and burdensome. There are many sea-related departments in China, from a horizontal perspective, including: marine administration, foreign affairs, fisheries, minerals, transportation, maritime commerce, environmental protection, scientific research, and military institutions; from a vertical perspective, they are divided into national centralized management and local hierarchical management. Managing ocean affairs requires handling a variety of complex administrative, civil, commercial, and criminal social relations. The subjects of legal relations include natural persons, legal persons and governmental agencies at all levels. Therefore, the legal system of the seas utilizes different measures, such as administrative, criminal, civil and economic, to regulate different legal relationships, including those between domestic and international actors (Jia, 2019). The legal system usually refers to the organically linked and unified whole formed by classifying and combining a country's existing legal norms into different legal departments (General Editorial Committee of the Encyclopedia of China, 2002, p. 84). Under China's legal system, there are divisions of departmental law, such as civil, criminal and international law. In contrast, the law of the sea is not an independent departmental law,

but only a part of international law. Each department of law can realize the settlement of disputes under the existing legal system, solve real disputes, and ensure social order as well as the stability of the legal system (Guo, 2022). The fact that the law of the sea, with its different effects and natures, has not become an independent department law makes it difficult to form a coordinated and complete legal system, which is not conducive to the handling of various legal relationships in maritime affairs and makes it difficult to elevate the status of the law on maritime security in the entire China's legal system.

4.3 Failure to introduce the fundamental law of the sea

In order to effectively safeguard maritime security and strive to build a strong maritime country, it is necessary to strengthen the construction of the rule of law, for which a legal basis is a prerequisite. Although China's legal system for the seas has been established, it still needs improvement. There is a lack of the fundamental law of the sea, which plays a fundamental role in leading the construction of the rule of law for China's seas in general and in providing a fundamental legal basis for China's maritime security. Since the 18th CPC National Congress, the reports of all the CPC National Congress have put forward the requirement of building a strong maritime country and made deployments (Liu, 2024). However, from the perspective of the rule of law in the seas, this deployment has yet to be legalized by formulating the fundamental law of the sea. In terms of ocean strategy, China has long used policy documents as a substitute for legislation. Although policy documents such as *China Ocean Agenda 21* and the *Functional Divisions of the Sea of the Whole Country* have been formulated and implemented, they have yet to be able to play their proper guiding roles due to the lack of legally binding force. China's marine legislation is relatively decentralized, with many departments formulating marine laws and regulations with different legislative perspectives and departmental interests. Most of the marine legislation is single-item regulations, which mainly safeguard a particular sea area, department or industry, and the scope of adjustment of each law is relatively homogenous, being mainly confined to a particular area and a particular scope of marine governance. At the same time, because the effectiveness of the various departmental laws is equal and because there is no fundamental law to provide them with basic principles and a systematic framework, it is challenging to create a benign interaction between the formulation and implementation of the laws, which not only leads to certain inconveniences in the implementation and application of the laws, but also adversely affects the safeguarding of maritime rights and interests and maritime security. Therefore, although China has initially established a system of marine laws and regulations, it is still not perfect, and in particular, lacks the fundamental law of the sea, which leads the construction of the rule of law for the seas in general and is capable of providing a fundamental legal basis for the maintenance of maritime security (Gu, 2022).

4.4 Inadequate operationalization of marine legislation

China's current system of rule of law for the seas is not yet sufficiently complete and complementary. Many of the legal provisions are vague, some are abstract and overly principled, and there are no specific regulations and implementation measures to support them after promulgation, nor are there clear implementation standards, and the applicability is poor. Article 58 of the *Civil Procedure Law*, as revised in 2012, adds "the environment public interest litigation", which provides for public prosecution of environmental pollution. However, this law lacks specific provisions for determining the burden of proof and the provision of legal aid in the case of marine environmental pollution.

Article 6 of the *Law on the Territorial Sea and the Contiguous Zone* stipulates that foreign military vessels must obtain prior authorization before entering China's territorial sea. However, since the promulgation in 1992, there have been no corresponding implementing regulations, nor have there been any clear stipulations on the procedures and methods for the declaration of authorization by foreign military vessels, thus rendering the implementation of this provision virtually impossible. The main purpose of this provision is to safeguard national sovereignty and the security of the territorial sea. The political position that foreign warships must be authorized to enter China's territorial sea is not an operational provision.

Many elements of the *Law on the Exclusive Economic Zone and the Continental Shelf* are similarly general and lack operationalization. For example, Article 12 stipulates that China has the right to take measures such as boarding, inspection, arrest, detention and other measures in response to law violations, and may exercise the right of hot pursuit. However, it does not specify the specific department or agency that shall take the measures, in particular, the right of hot pursuit (Yu, 2006), which, in accordance with international law, must be implemented by a specific agency authorized by the law, in strict accordance with the procedures stipulated in the law. Since this law does not specify the specific authorities or institutions that should exercise the right of hot pursuit, it isn't easy to implement it in practice (Xue, 2011, p. 291). Article 8 stipulates that competent authorities are authorized to establish safety zones around artificial islands, installations and structures to ensure the safety of navigation and the installations. However, it is not clear which authorities are the competent authorities, nor is it clear which procedures and specific operational requirements are necessary to establish safety zones. This provision is a direct replica of *UNCLOS*, which merely translates international law into domestic law without formulating specific supporting measures, thus rendering the provision unworkable.

4.5 Some legal gaps in the law of the sea

China's legal norms on the seas are not yet complete, the legal system on the seas is not sound enough, and the system of the rule of law on the seas has not yet been fully established. Although sea-related legislation has been strengthened since the 1980s, and the

coverage of marine legislation is expanding, there are still many gaps and no corresponding legislative programs in some of the blank areas (Xue, 2005). In addition, there is little specialized marine legislation in China, many of which are special industry regulations or ordinances. Only a minimal number of laws and regulations deal with the seas. In some areas, laws and regulations relating to the sea are simply a continuation of land-based legislation, with insufficient consideration given to the characteristics of the sea. Provisions relating to marine activities do not treat the sea as a specific object of application, but are mentioned incidentally in the relevant separate laws, with limited scope for application in practice. For example, the *Agricultural Law*, the *Property Law* and the *Mineral Resources Law*, although they contain sea-related norms, do not take the sea as a specific object of adjustment. At the same time, because of the new changes, situations and problems constantly emerging in the current maritime situation, new laws should be formulated, especially for new industries, to fill the legal gaps and effectively protect China's maritime security and rights and interests.

5 Recommendations for improving domestic law on maritime security

As China is in an important period of building a strong maritime country, facing many challenges to its maritime security, and with a domestic legal system for maritime security that is not yet sound enough to rely on legal measures to safeguard national maritime security effectively, there is an urgent need to take the necessary measures to rapidly improve the capacity to safeguard national maritime security, to promote the rule of law on the seas, and to raise the level of the rule of law in safeguarding national maritime security.

5.1 Incorporating marine provisions into the *Constitution*

The *Constitution* is the fundamental law of China, regulating the basic system and fundamental tasks of the country, occupying the dominant position in China's legal system and having the highest legal authority and effectiveness. The *Constitution*'s status and significance dictate that, for national marine laws to better fulfill their legal basis, safeguard maritime security and rights and interests, and enhance the status of the seas in the country's strategic layout, marine provisions must be incorporated into the *Constitution*. National maritime rights and interests, maritime strategy and marine environmental protection are placed at the level of the country's fundamental law to respond more effectively to the current complex maritime security challenges. In order to realize the rule of the sea in accordance with the law, so that all sea-related industries can have laws to follow and scientific law enforcement, it is necessary to improve the legal system of the sea, which is in line with the strategy of a strong maritime country and consistent with the international law of the sea, and to raise its status in the national legal system. It is necessary to incorporate marine provisions into the *Constitution* as soon as possible and enhance marine laws' effectiveness (Yang, 2024). Since the conditions for a comprehensive constitutional amendment do not exist, the seas can be constitutionalized by drafting a constitutional amendment. The following could be added to the preamble of the *Constitution*: China's territory includes the territorial land, the territorial sea, the internal waters and their upper and lower spaces. The word "sea" could be added to Article 9 of the *Constitution*, thus providing a fundamental legal basis for the protection of marine resources. The explicit provision on the seas in the *Constitution* will be conducive to safeguarding national security, territorial sovereignty and rights and interests in the seas (Yi, 2014).

5.2 Enactment of the fundamental law of the sea

The fundamental law of the sea is at the core of the law of the sea system. It is an indispensable legal foundation for building a strong maritime country, and an urgent task for improving China's law of the sea system. The enactment of the fundamental law of the sea can legally confirm China's basic claims to maritime rights and interests and its basic marine policy, establish a basic maritime institutional framework, rationalize marine legal relations, regulate various types of maritime actions, and provide guidance for China's response to maritime disputes (Cao and Chu, 2016). China should expeditiously promulgate the fundamental law of the sea, which is the overarching legal system on seas, stipulate the overall planning and goals and tasks of the national strategy for a strong maritime country, set up a comprehensive ocean management organization, promote the implementation of the national ocean policy, establish the basic principles, basic institutions and systematic framework of the seas, and harmonize them with other individual laws and norms, so as to form a sound, reasonable and perfect modern ocean legal system, and to safeguard the country's maritime rights and interests in practice (Yang, 2021). In the world, formulating the fundamental law of the sea is a trend in marine legislation. Canada promulgated the *Oceans Act* in 1996, recognizing in the form of domestic law the rights of the seas enjoyed by coastal States as stipulated in *UNCLOS* and providing a legal basis for the adequate protection of marine rights and interests, thus becoming the first country in the international community to formulate a comprehensive law of the sea (Macdonald, 2018). Since then, coastal States have successively promulgated the fundamental law of the sea, and the United States enacted the *Oceans Act of 2000*. Japan adopted the *Basic Act on Ocean Policy* in 2007, and Vietnam enacted the *Vietnam Law of the Sea* in 2012 (Zhang and Ye, 2013). Indonesia also enacted the *Law of the Republic of Indonesia No. 32 of 2014 on Marine Affairs*.

The fundamental law of the sea is located at the top of the marine rule of law system, and it integrates and coordinates the construction and development of the entire marine rule of law system. Under the framework of the fundamental law of the sea, through the revision of existing laws, making up for the legislative deficiencies, promoting the supporting legislative work of the legal system, and summarizing, classifying and integrating the sea-related

norms dispersed in various administrative regulations and departmental rules, a system is formed that is guided by the principles of the *Constitution* and centered on the fundamental law of the sea, and that covers the various levels of the near sea, the far sea, the deep sea, the poles, and is composed of laws, regulations, local legislation, departmental regulations, which together form the legal system of the seas.

5.3 Introducing other marine laws

Coastal areas play an essential role in the development of the entire Chinese economy, and at the same time will be subjected to increased pressure on the environment and resources. Coastal areas are located at the junction of land and sea, where human production and life are the most frequent and active and where human-sea interactions and conflicts are the most intense. The ecological environment is fragile, and the necessity and importance of rational development and utilization, as well as effective protection, through the enactment of relevant laws and regulations. China should introduce the "*Coastal Areas Protection and Management Law*" and the "*Law on the Promotion of Marine Economy and Science and Technology*" at an early date in order to better implement the strategy of Land and Sea Coordination, and to organically combine the needs of coastal defense with the economic development of the coastal areas, to ensure the joint development of coastal defense and coastal economic development (Feng, 2013).

As China's international military cooperation and exchanges with countries around the world become more and more frequent, the number of visiting ships and their accompanying personnel is also increasing. There is no explicit law on the entry and exit border inspection of visiting warships, but it is usually done in accordance with the requirements of superiors, which is not in line with the requirements of professionalization and systematization of border management. Therefore, it is necessary to expeditiously formulate a law on the entry and exit border inspection of foreign military ships and aircraft and their accompanying crews (Feng, 2013). Accelerate the legislative work of the *Crew Law* to realize the effective convergence of international and domestic laws. In addition, relevant laws on Antarctica should be enacted as soon as possible to better fulfill the obligations under the *Antarctic Treaty* and regulate China's increasingly active scientific research activities in the Antarctic. Laws related to the international seabed area should be introduced, balancing exploitation and protection, and domestic legislation should be adopted to effectively fulfill the obligations of the sponsoring countries and exploit the resources in the area in an orderly manner. It is necessary to keep up with the latest developments of science and technology in the marine field and the industrial market, and scientifically carry out forward-looking legislative research, especially to strengthen the legislation of key and emerging fields in the sea, and the new round of development process of marine technology and industry mainly characterized by intelligence and unmanned is at an accelerated stage, and in the research of the "*Shipping Law*" and other relevant legislation, the possible legal effects brought by the changes in science and technology and the industry should be taken into full consideration, and efforts should be made to obtain legislation with forward-looking effects.

5.4 Improving local marine laws

Local marine legislation is an integral part of the construction of China's marine legal system. On the one hand, national marine laws and regulations need to be implemented through local marine legislation. For example, after the promulgation of the *Law on the Administration of Sea Area*, Liaoning, Shandong, Zhejiang, Fujian, and other provinces have issued their regulations or ordinances on the administration of sea area utilization according to local specificities. In addition to the relevant systems stipulated in the *Law on the Administration of Sea Area*, some of the local regulations have also made provisions on issues that are not clearly defined in this law, such as determining the coastline, managing the collection of sea area use fees, managing the right to use the sea area and protecting the ecological environment of the sea area. On the other hand, flexible and innovative local marine legislation can be explored for the national marine legislation and promote the continuous adjustment and development of the national marine legal system, which in turn plays a positive role in the improvement of the national marine legal system (China Institute for Marine Affairs, 2012, p. 43). Although China has not yet formulated a national coastal area management law, the *Jiangsu Province Coastal Area Management Regulation* in 1991 and the *Hainan Special Economic Zone Coastal Area Protection and Development Management Regulation* in 2013 are important references for the formulation of national laws.

At the same time as improving local marine laws, the focus should be on strengthening support and guidance for the relevant industrial departments, improving their legislative level, synthesizing the successful experiences of various coastal areas in marine legislation, and selecting the best ones for inclusion in national legislation. In addition, some of China's coastal provinces, such as Liaoning, Shandong, Guangdong, Shanghai, and Hainan, undertake important foreign exchange tasks, and in China's neighboring sea areas, there are many complex problems, especially involving the attribution of islands and the delimitation of jurisdictional waters, which are directly related to the national maritime security and maritime interests, these local marine laws must be based on the provisions of the international law of the sea, so that they can better resolve conflicts and reduce the risk of conflict.

5.5 Introducing implementing regulations

China's laws usually contain only provisions of principle, and it is necessary to formulate complementary implementation measures and methods to enhance their operability. China should expeditiously formulate corresponding implementing rules or regulations to ensure that the laws are truly implemented. Formulate supporting regulations and implementing rules for the *Law on the Territorial Sea and Contiguous Zone* and the *Law on the Exclusive Economic Zone and the Continental Shelf*, such as the *Measures for the Administration of Innocent Passage of Foreign*

Warships through the Territorial Sea of China, the *Rules for Overflight and Navigation in the Exclusive Economic Zone*, the *Regulations on the Safety of Traffic in the Exclusive Economic Zone*, and the *Regulations on the Construction of Artificial Structures in the Exclusive Economic Zone*. The establishment of a separate navigation system for ships transporting hazardous chemicals or toxic and harmful substances has made the necessary legal preparations to regulate the navigation of foreign ships in waters under China's jurisdiction, prevent foreign enterprises and ships from infringing on the resources of China's exclusive economic zone and continental shelf, and prevent foreign military vessels and aircraft from engaging in unlawful military activities that jeopardize China's national security in China's territorial waters.

Formulate the *Measures for the Implementation of Boarding and Inspection of Illegal Ships*, unify the applicable laws for the right of boarding and the right of hot pursuit, and stipulate the law enforcement agencies and the specific procedures and methods for carrying out boarding, inspection, arrest, to facilitate the implementation of the law by the implementing agencies, and make it easier for foreign ships to comply with the relevant provisions. In the litigation of marine environmental pollution damage, the authority of administrative subjects to claim compensation should be determined, the institutions and organizations entitled to file lawsuits should be clarified, and it should be stipulated that a private subject can file a lawsuit when the state administration is unable or unwilling to perform. At the same time, detailed provisions should be made on the burden of proof and the relationship of causality in lawsuits (Zhang, 2015). In addition, it is necessary to have an accurate grasp of the characteristics and changing patterns of fishery resources to determine the allowable catch of fishery resources based on scientific analysis, take into account economic, social and ecological factors, and allocate the allowable catch of fishery resources in accordance with the type of fishery resources, the time of operation, the location of the sea area, and the current fishery management system.

6 Conclusion

In the course of its rapid rise, China is facing unprecedented opportunities and challenges, particular the increasing prominence of maritime security in China's ONSO. Since the 18th CPC National Congress, China has attached great importance to constructing a strong maritime country. Accelerating the construction of a strong maritime country is a fundamental guarantee for safeguarding national security and maritime rights and interests. China's national security is steady in the land direction, and threats to national security interests come mainly from the maritime direction. The report of the 20th CPC National Congress not only included marine security in the critical areas of national security for the first time, but also put the rule of law system as the first to improve the national security system. China, as a country moving from maritime great to maritime power, with the Belt and Road Initiative and the Maritime Community of Common Destiny, the rule of law has become a priority for safeguarding China's national maritime security. Strengthening research on the rule of law in China's maritime security is not only a critical action to implement the ONSO, but also an important initiative to actively respond to the construction of China under the rule of law. How effective it is will impact the realization of China's strategic goal of becoming a strong maritime country and on the effectiveness of China's participation in global ocean governance and the maintenance of the world's maritime security order.

From China's domestic law perspective, the paper first conducts a literature review to summarize and evaluate the current research on China's maritime security and its rule of law construction. The construction of China's domestic law on maritime security is divided into three stages, namely, the slow development stage from 1949 to 1979, the forming stage from 1980 to 1999, and the refining stage from 2000 to the present, and the construction of the rule of law in each of these stages is introduced and explained respectively. However, it still faces problems such as the lack of an explicit constitutional basis, the law of the sea is not an independent departmental law, the absence of the fundamental law of the sea, the lack of operability of marine legislation, and the existence of some gaps in marine laws. Given the problems with the current domestic law on maritime security, it is necessary to make improvements in the following areas: adding marine provisions to the *Constitution*, formulating the fundamental law of the sea and other marine laws, improving local marine laws, and introducing implementing regulations. The paper mainly focuses on the perspective of domestic law, but in the future, it will also combine with international law and utilize a systematic and comparative approach to comprehensively construct China's maritime security legal system.

Author contributions

WL: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by China's National Social Sciences Foundation (No.17ZDA146).

Conflict of interest

The authors declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Aarstad, Å. K. (2017). Maritime security and transformations in global governance. *Crime Law Soc Change* 67, 313–331. doi: 10.1007/s10611-016-9656-0

Amirell, S. E. (2016). Global maritime security studies: The rise of a geopolitical area of policy and research. *Secur. J.* 29, 276–289. doi: 10.1057/sj.2013.26

Bai, J. Y., and Li, X. Y. (2024). Elements of the maritime law of rule of Xi Jinping Thought on the rule of law. *Hebei Law Sci.* 42, 2.

Bateman, S. (2015). The future maritime security environment in Asia: A risk assessment approach. *Contemp. Southeast Asia* 37, 1. doi: 10.1355/cs37-1c

Bueger, C. (2015). What is maritime security? *Mar. Policy* 53, 159–164. doi: 10.1016/j.marpol.2014.12.005

Cao, X. G., and Chu, B. P. (2016). On the approach of improvement of China's marine legislation under the perspective of systematization. *Pac. J.* 24, 9.

China Institute for Marine Affairs (2012). *China Ocean Development Report, (2012)* (Beijing: Ocean Press).

China National People's Congress (2024). Report of the Committee on Environment and Resource Protection of the National People's Congress on the results of the consideration of the motions proposed by the delegates referred for consideration by the first session of the 14th National People's Congress. Available online at: http://www.npc.gov.cn/c2/c30834/202401/t20240108_434152.html (Accessed January 13, 2024).

Chu, B. P., and Guo, W. J. (2023). The construction of system for maritime law with Chinese characteristics in the new era: Purposes, situations and paths. *Pac. J.* 31, 1.

Feng, J. F. (2013). Some suggestions for improving the legal system of China's maritime defence. *Natl. Def.* 8, 55–57.

Gao, J. J. (2004). *China and the International Law of the Sea: Commemorating the 10 Anniversary of the Entry into Force of the United Nations Convention on the Law of the Sea* (Beijing: Ocean Press).

General Editorial Committee of the Encyclopaedia of China (2002). *Encyclopaedia of China—Law* (Beijing: Encyclopedia of China Publishing House).

Germond, B. (2015). The geopolitical dimension of maritime security. *Mar. Policy* 54, 137–142. doi: 10.1016/j.marpol.2014.12.013

Germond, B., and Germond-Duret, C. (2016). Ocean governance and maritime security in a placeful environment: The case of the European Union. *Mar. Policy* 66, 124–131. doi: 10.1016/j.marpol.2016.01.010

Germond, B., and Mazaris, A. D. (2019). Climate change and maritime security. *Mar. Policy* 99, 262–266. doi: 10.1016/j.marpol.2018.10.010

Gu, X. D. (2022). The nature and positioning and the institutional pathway of China's basic law for the oceans. *Acad. Res.* 7, 60–66.

Guo, H. D. (2022). On the binary interaction between jurisprudence and department law. *J. Sichuan Minzu Coll.* 31, 4.

Guo, P., and Yan, L. C. (2024). On the realistic dilemma and improvement path of the rule of law in China's maritime security. *Acad. Exch.* 1, 63–77.

Ji, Y. (2022). *Deciphering Beijing's maritime security policy and strategy in managing sovereignty disputes in the China seas* (Singapore: S. Rajaratnam School of International Studies). Available at: https://www.jstor.org/stable/pdf/resrep05793.pdf.

Jia, Y. (2007). "Basic ideas on improving China's maritime legal system," in *Collection of Studies on Ocean State Policies*. Eds. Z. Gao and H. Zhang (Ocean Press, Beijing).

Jia, Y. (2019). The development of China's rule of law in oceans in the past 40 years of reform and openning-up. *J. Bound. Ocean Stud.* 4, 4.

Jiang, S. L. (1997). *The World Book of Constitutions* (Qingdao: Qingdao Press).

Jin, Y. M. (2010). On China's maritime security and maritime rule of law. *Orient. Law* 3, 33–43.

Joshi, Y. (2023). Beyond binaries. *Contemp. Southeast Asia* 45, 2. doi: 10.1355/cs45-2f

Kim, S. K. (2022). An international law perspective on the China Coast Guard Law and its implications for maritime security in East Asia. *Int. J. Mar. Coast. Law* 37, 2. doi: 10.1163/15718085-bja10089

Li, L. (2023). Building up a sustainable path to maritime security: an analytical framework and its policy applications. *Sustainability* 15, 8. doi: 10.3390/su15086757

Liu, L., and Xv, Z. B. (2011). A theoretical exploration into the marine security of China. *Pac. J.* 19, 2.

Liu, R. (2024). Revision of China's Marine Environmental Protection Law: History, background and improvement. *Front. Mar. Sci.* 11. doi: 10.3389/fmars.2024.1409772

Liu, R., and Hu, Z. (2024). Controversies and amendment proposals on the China Coast Guard Law. *Mar. Policy* 163, 106115. doi: 10.1016/j.marpol.2024.106115

Macdonald, N. (2018). Canada's Oceans Act: A narrative analysis of Canada's ocean policy. Available online at: https://dspace.library.uvic.ca/items/970b8605-dc87-4ab8-8638-4a01f4193526 (Accessed March 6, 2024).

Man, H. J. (2014). On the construction of the rule of law for maritime security in China. *Acad. Exch.* 9, 77–81.

Odgaard, L. (2017). Maritime security in East Asia: Peaceful coexistence and active defense in China's Diaoyu/Senkaku policy. *J. Contemp. China* 26, 103. doi: 10.1080/10670564.2016.1206283

Qing, Q. (2015). Maintaining maritime security is an inevitable requirement of the Overall National Security Outlook. *People Rule Law* 6, 35.

Sun, Y., Han, Y., Zhang, L., and Chang, Y. C. (2021). The construction and governance of regional maritime security order in the South China Sea: Conference report. *Mar. Policy* 126, 104438. doi: 10.1016/j.marpol.2021.104438

Tao, Y. C., and Wang, H. B. (2019). The connotation and purpose of Xi Jinping's Overall National Security Outlook in the new era and its dialectical methodology. *J. Beijing Police Coll.* 5, 1–7.

The State Oceanic Administration (2012). *Selected Marine Regulations of the People's Republic of China* (Beijing: Ocean Press).

Wang, G. (2022). Development history and intrinsic logic of China's marine governance system. *Frontiers* 17, 42–50.

Wang, L. (2022). China-Japan-ROK maritime cooperation under the new trends of global ocean governance: Opportunities, challenges and paths. *J. Ocean Univ. China (Soc. Sci.)* 6, 11–20.

Xing, H., Cao, X., and Su, Z. (2022). The rule of law for marine environmental governance in maritime transport: China's experience. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.1083420

Xinhua News Agency (2016). Regulating the exploration and exploitation of deep-sea resources for the common interests of all humankind. Available online at: http://big5.www.gov.cn/gate/big5/www.gov.cn/xinwen/2016-02/26/content_5046783.htm (Accessed February 3, 2024).

Xue, G. F. (2005). Proposals for countermeasures to safeguard China's maritime rights and interests under the regime of the United Nations Convention on the Law of the Sea. *J. Ocean Univ. China (Soc. Sci.)* 6, 13–16.

Xue, G. F. (2011). *The United Nations Convention on the Law of the Sea and State Practice* (Beijing: Ocean Press).

Xv, W. A. (2008). Deficiencies in China's law of the sea system and countermeasures. *Ocean Dev. Manage.* 1, 128–133.

Yang, H. (2021). Legislative positioning and institutional structure of the basic law for the oceans. *Orient. Law* 1, 114–127.

Yang, Z. W. (2022). Forty years of China and the United Nations Convention on the Law of the Sea: History, impact and future prospects. *Contemp. Law Rev.* 36, 4.

Yang, Z. J. (2023). Study on the global marine ecological security situation and governance. *People Trib.* 20, 14–19.

Yang, H. (2024). The constitutional normative construction of China's maritime jurisdiction. *China Leg. Sci.* 1, 286–304.

Yao, Y. (2021). The contribution of the CPC's maritime strategy to the development of the international law of the sea. *Jilin Univ. J. Soc.Sci. Edi.* 61, 1.

Yao, Y. (2022). Foreign-related rule of law for oceans: Background, connotations and paths. *Wuhan Univ. Int. Law Rev.* 4, 22–43.

Yi, X. F. (2014). On constitutional protection of sea power—Study on incorporation of marine clause into Chinese Constitution and protection system of sea power law. *Pac. J.* 22, 6.

Yu, Z. R. (2006). Current status of China's marine legal system and its outlook. *Ocean Dev. Manage.* 4, 29–34.

Zhai, Y. (2015). National ocean strategy and its basis in the rule of law. *Soc Sci. Front.* 4, 192–206.

Zhang, W. M. (2014). *On China's Maritime Power* (Beijing: Ocean Press).

Zhang, H. B. (2015). On the conflict between the right in fisheries and the right to the use of sea areas and its coordination. *J. Hainan Univ. (Humanities Soc Sci.)* 33, 1.

Zhang, S. A. (2021). PRC's practice on international law policy: Maritime security and the "defensive interpretation" of the law of the sea. *Asia-Pac. Secur. Marit. Aff.* 6, 35–54.

Zhang, H. W. (2022). National maritime security and its rule of law response under the unprecedented changes of the century. *Theor. Explor.* 1, 5–11.

Zhang, Y. (2022). China's maritime security: Concept connotation and practical significance. *Asia-Pac. Secur. Marit. Aff.* 1, 19–34.

Zhang, X. L., and Ye, Q. (2013). The legal safeguard of building maritime power: The perfection of China's marine legal system. *Wuhan Univ. Int. Law Rev.* 16, 1.

Zhu, C. J. (2015). *Research on China's Maritime Security System* (Beijing: Ocean Press).

Zou, K. Y. (1999). Implementing marine environmental protection law in China: Progress, problems and prospects. *Mar. Policy* 23, 207–225. doi: 10.1016/S0308-597X(98)00043-8

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 15 July 2024
DOI 10.3389/fmars.2024.1418435

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
University of International Business and Economics, China

REVIEWED BY
Robin Kundis Craig,
University of Southern California, United States
Fabio Pranovi,
Ca' Foscari University of Venice, Italy

*CORRESPONDENCE
Bastiaan E. Klerk
bastiaan.e.klerk@uit.no

RECEIVED 16 April 2024
ACCEPTED 25 June 2024
PUBLISHED 15 July 2024

CITATION
Klerk BE, Heinrich K and Primicerio R (2024) Beyond equilibrium thinking: dynamic area-based management tools in a changing ocean. *Front. Mar. Sci.* 11:1418435. doi: 10.3389/fmars.2024.1418435

COPYRIGHT
© 2024 Klerk, Heinrich and Primicerio. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Beyond equilibrium thinking: dynamic area-based management tools in a changing ocean

Bastiaan E. Klerk[1]*, Katharina Heinrich[2,3] and Raul Primicerio[4]

[1]Faculty of Law, UiT The Arctic University of Norway, Tromsø, Norway, [2]Arctic Centre, University of Lapland, Rovaniemi, Finland, [3]Faculty of Biological and Environmental Sciences, University of Helsinki, Helsinki, Finland, [4]Faculty of Biosciences, Fisheries and Economics, UiT The Arctic University of Norway, Tromsø, Norway

Area-based management tools (ABMTs), including marine protected areas (MPAs) are often static and fail to reflect the dynamic realities of marine ecosystems. Marine ecosystems are characterized by their embodiment of constant change, which is further amplified by anthropogenic stressors, particularly climate change. ABMTs and MPAs are, however, premised on an implicit assumption of environmental equilibrium as their boundaries and management framework are often fixed and difficult to adjust. This article seeks to lay bare the tension between static conservation strategies and the deeply and inherently dynamic nature of marine ecosystems. It further seeks to advance the notion of dynamic ABMTs, proposing an integrated conceptualization of ABMT governance, one that is more apt to respond to the type of challenges that the dynamism of complex marine ecosystems presents. Dynamism, in this context, is broadly construed as encompassing three dimensions: spatial, with fluid and adjustable conservation measures; normative, denoting a volatile and adaptive management framework that utilizes ecological and management thresholds as an initiator for adaptive, timely, and prospective approaches to enhance management outcomes; and institutional, i.e., sufficiently flexible and dynamic institutional machinery overseeing ABMT implementation. Following a comprehensive conceptualization of dynamic ABMTs, the article addresses the question whether the legal frameworks governing the ocean can sustain such a dynamic mode of ocean governance.

KEYWORDS

area-based management tools (ABMTs), marine protected areas (MPAs), biodiversity conservation, dynamic management, adaptive management, climate change

1 Introduction

The contemporary environmental epoch is characterized by change and uncertainty (Ortuño Crespo et al., 2020). Ever-intensifying climate change and biodiversity loss are rapidly altering the environmental conditions, putting the resilience of marine ecosystems to the test and forcing them to adapt. These changes are often non-linear, adding to the already complex and dynamic nature of ecosystems. Marine ecosystems, in particular, are characterized by their embodiment of constant change, which is further amplified by anthropogenic pressures. Our endeavours to protect these ecosystems should account for this dynamism, however, these considerations are largely absent in the design of area-based management tools (ABMTs), specifically for existing marine protected areas (MPAs). Rather, they are premised on an implicit assumption of environmental equilibrium (Allee et al., 1974; Cuddington, 2001)[1]. These spatial management tools are in virtually all instances static in their design; their spatial delineation and conservation measures are often fixed and difficult to amend due to strenuous decision-making processes and rigid institutional arrangements.

The present paper puts forward an alternative conceptual framework for ABMTs in a way that better reflects the dynamic nature of the ocean. A dynamic ABMT (hereinafter: dABMT) design is proposed that encapsulates three spheres of dynamism: spatial, normative, and institutional. It further utilizes ecological and management thresholds as an initiator for adaptive, timely, and prospective approaches to enhance management outcomes. The result is a macro-level conceptualization of dABMTs, that, although elements thereof require further research and elaboration, holds the potential for application across diverse marine regions and ecosystems. It moreover accounts for temporal variation in ecosystem processes, as it builds upon the temporal model developed by Ortuño Crespo et al. (2020). This model encompasses four temporal scales at which the movement of species, habitats, and ecosystems occur. Their framework facilitates the development of management strategies that appropriately match the spatial and temporal scales of ocean changes (Simmons et al., 2021).

In light of existing literature on dynamic ocean governance (Craig, 2012; Hobday et al., 2014; Maxwell et al., 2015; Ortuño Crespo et al., 2020), particularly regarding ABMTs and MPAs (Cashion et al., 2020; Maxwell et al., 2020), this article distinguishes itself by offering a novel synthesis of spatial, normative, and institutional dynamism. In doing so, the paper builds upon existing research by drawing from existing theories and concepts such as adaptive management, the use of thresholds in ocean management, adaptive governance, and social-ecological resilience, utilizing and applying them in the context of dABMT governance. This integrated approach aims to bridge monodisciplinary theoretical concepts by merging various theoretical insights, thereby advancing the discourse on dABMTs.

At the outset, a few terminological remarks are in order. Firstly, the term 'dynamic' denotes "characterized by constant change, activity, or progress" when referring to a process or system (Oxford English Dictionary, 2021). This choice of nomenclature is adopted since the proposed ABMT design primarily aims to incorporate the ever-changing nature of marine ecosystems, and it corresponds with the established jargon in the MPA literature. Secondly, the terms AMBTs and MPA warrant further clarification. While there is no agreed-upon definition of either term, ABMTs are generally understood to be geographically defined areas within which human activities, such as shipping or fishing, are regulated for one or more purposes in order to minimize their (potential) adverse impacts on the ecosystem and its biodiversity (BBNJ, 2023, art. 1(1))[2]. ABMTs simply denote the management of processes and human activities in a given area, whether for conservation purposes or other objectives. There are a variety of ABMTs available ranging from single-sector tools (e.g., vulnerable marine ecosystems (VMEs); fisheries closures) to cross-sectoral tools (e.g., marine reserves), with the degree of protection varying from low to highly protected. They thus incorporate a high degree of flexibility due to their broad range of application, spanning a spectrum ranging from sectoral management restrictions on a single activity to more integrated approaches where restraints are imposed on all human interferences. As we will see later on, this flexibility leaves room for dynamism in their application, which is why the present article builds on the concept of ABMTs.

However, this does not preclude MPAs, which are part of the wider portfolio of tools encapsulated within the overarching concept of ABMTs. MPAs are distinct from most other ABMTs as they tend to be more holistic and cross-sectoral in nature. In addition, they put a stronger emphasis on conservation, which is aptly illustrated by the definition contained in the Agreement for the Conservation and Sustainable Use of Biological Diversity in Areas Beyond National Jurisdiction (BBNJ Agreement). Therein, MPAs are defined in article 1(9) as "a geographically defined marine area that is designated and managed to achieve specific long-term biological diversity conservation objectives and may allow, where appropriate, sustainable use provided it is consistent with the conservation objectives". This emphasis on conserving components of biodiversity necessitates a more integrated approach to mitigating human activities (Klerk, 2021)[3]. which has been shown to be a key element in successful conservation strategies (Sala and Giakoumi, 2017). Consequently, it comes as no surprise

1 In the present article, the term equilibrium is understood in an ecological sense, where it is generally construed to be akin to the notion of the "balance of nature", i.e., "stability, orderliness and predictability in natural systems".

2 For a comprehensive elaboration on the content and meaning of ABMTs, see: UN General Assembly, Addendum 2 to the Report of the Secretary General on Oceans and law of the sea (10 September 2007) A/62/66/Add.2 para 117-118.

3 Internationally, implementing such MPAs is complex due to the siloed, sectoral nature of UNCLOS. Hence, MPAs designated on the high seas, such as those under the OSPAR Convention, are not of a cross-sectoral character and may be more aptly be characterized as ABMTs.

that MPAs are widely regarded as indispensable instruments in our endeavors to mitigate ocean threats, conserve biodiversity, and enhance resilience to environmental impacts (UNEP-WCMC et al., 2021)[4].

The remainder of this article is structured as follows. The subsequent section presents an overview of the relevant literature depicting the intrinsic as well as human-induced complexity and dynamism of marine ecosystems. It moreover juxtaposes this dynamism to the static nature of ABMTs, thereby laying the foundation for section 3, which forms the core of this article as it comprehensively introduces the concept of dABMTs, discussing their spatial, normative and institutional elements, including the use of thresholds in ocean management. Section 4 addresses the question of whether the legal frameworks governing the ocean can sustain such a dynamic ABMT design, and finally, section 5 provides a summary of the key findings and offers concluding remarks.

2 The dynamic ocean

The approach to area-based management as outlined in this article seeks to better align governance of human activities with the fluid and dynamic nature of the marine environment. It thus emanates from scientific considerations, a brief discussion of which is in place before delving into the substantive issues relating to ABMT design.

The marine environment is, indeed, deeply and inherently dynamic—even more so than terrestrial ecosystems, from which our current static approach to protection is derived. Although the ocean and the atmosphere are both subject to the same laws of fluid dynamics, they have very different physical properties such as density, thermal expansion coefficient, and viscosity (Steele et al., 2019). These different properties manifest in various ways. For instance, plankton and most fish, unlike insects and birds, exhibit near-neutral buoyancy, minimizing the energy expended to remain suspended (Steele et al., 2019). This buoyancy and dissolved nutrients allow for primary production in the upper, illuminated sections of the water column, enabling suspended food webs without a solid foundation. Thus, whole ecosystem components can float and flow with the marine currents as seen in rivers. Take, for instance, the Sargasso Sea, a rich and diverse ecosystem providing essential habitat for many endangered species, hailed as the 'golden floating rainforest of the Atlantic Ocean' as it is based upon the floating *Sargassum* macroalgae (Laffoley et al., 2011).

The ocean's inhabitants are in constant motion due to the currents, tides, and waves, and marine animals dwelling in the water column must actively orient and swim to maintain their position or travel to distant foraging areas (Putman, 2018). In temperate coastal ecosystems, tidal currents serve as the primary drivers of ecosystem dynamics, influencing various levels of the food chain, from primary productivity to zooplankton, fish, and top predators (Embling et al., 2012). Currents play a pivotal role in pelagic ecosystem dynamics *inter alia* by facilitating the dispersal of marine species, transporting eggs and larvae over vast distances. Oceanic circulation further influences the success of spawning, dispersal, and settlement processes (Dubois et al., 2016).

Marine species are thus generally more mobile and subject to passive transport compared to those living on land[5]. This elevated mobility is particularly evident on a larger spatial scale, as marine mammals are capable of undertaking migrations spanning far greater distances than terrestrial species. For instance, Western North Pacific Gray Whales demonstrated the longest documented mammalian migration in a single year, with one female completing a round trip of 22,511 kilometers (Mate et al., 2015). It is not just marine mammals that migrate across the ocean. Fish, too, are known to engage in transoceanic migrations. The Atlantic bluefin tuna offers a well-documented example, as they migrate seasonally between the Gulf of Mexico and the eastern Atlantic and Mediterranean Sea (Luschi, 2013). Sharks and turtles are known to undertake similar journeys (Boyle et al., 2009). These migrations do not only occur horizontally but also vertically through different depths of the water column, known as diel vertical migration (DVM). It is said to be the largest synchronized movement of biomass, observed for a number of marine and freshwater species (Sims et al., 2005; Berge et al., 2009; Mehner and Kasprzak, 2011). Zooplankton, for instance, normally remains in deeper waters during the day and rises at dusk towards the surface to feed (Sims et al., 2005).

2.1 Human-induced dynamism

Human interference, and climate change in particular adds another layer of dynamism. The ocean has absorbed more than 93% of the excess heat from greenhouse gas emissions since the 1970s, causing their temperatures to rise (IPCC, 2021). Marine life responds to these changes in the environment by shifting their geographical range, generally towards the poles (Lenoir and

4 This follows implicitly from the proliferation of MPAs in recent years, with global coverage having more than doubled in the last decade (8.2% now compared to 3.4 in 2014, as well as by the prominent role accorded to MPAs in the Convention on Biological Diversity's (CBD) recently adopted 2030 Kunming Montreal Global Biodiversity Framework (GBF), which sets forth the target to 'ensure' that by 2030, "at least 30 per cent of terrestrial, inland water, and of coastal and marine areas ... are effectively conserved and managed through ecologically representative, well-connected and equitably governed systems of protected areas and other effective area-based conservation measures" (Convention on Biological Diversity, 'Post-2020 Global Biodiversity Framework' (5 December 2022) CBD/WG2020/5/L.2).

5 Long-distance migrant birds may be considered as an exception to this rule, although seabirds, who are known to undertake the longest bird migrations (e.g. the Arctic terns, who migrate over 80.000 km yearly in some cases, see: Egevang et al., 2010) are considered marine species as they form an integral part of marine ecosystems.

Svenning, 2014)[6]. Many marine species have already done so, moving at an average rate of up to ~70 km per decade (Poloczanska et al., 2016). Notably, these range shifts occur at different speeds and depths, impacting all layers of ocean space. Deep-sea species' velocities are already impacted by changes in ocean temperature, even more so than those living close to the surface (Brito-Morales et al., 2020).

These human-driven changes in spatial distribution also have an impact on how ecosystems function, as well as on their composition. In a warming ocean, warm-water species populations are expected to increase, and cold-water species populations to decline (Poloczanska et al., 2016). In the Arctic, for instance, marine food web structures and ecosystem functionality are projected to undergo substantial changes as large piscivorous species are rapidly replacing smaller bottom-dwelling species (Kortsch et al., 2020; Ingvaldsen et al., 2021). Species respond to changes in their environment in different ways, leading to disruptions in their interactions and ultimately to the emergence of new biotic communities and rapid shifts in ecosystem functioning. Ecosystem functioning is further altered by climate-induced changes in species abundance (Sutton-Grier and Sandifer, 2018).

Some ecosystems may even vanish completely, such as warm-water coral reefs, which are likely to be eliminated by 2040-2050, even in lower greenhouse gas emission scenarios (Hoegh-Guldberg et al., 2017). Such cases qualify as *regime shifts*, which are shifts between the states of different systems and are defined as large, persistent, and often unexpected changes that might occur on different temporal and spatial scales (Cooper et al., 2010; Sguotti and Cormon, 2018). Another example of a regime shift is the weakening of thermohaline circulation (THC) in the ocean, also described as an overturning of the world's ocean, such as the slowing down of the Gulf Stream as a result of the weaker circulation of warmer surface waters and colder water in deeper layers of the ocean (Rahmstorf, 2006; Rocha et al., 2014). While the latter example is hypothesized to be an effect of climate change, other regime shifts may be traced back to a failure in marine management.

For instance, a regime shift in a marine food web may occur with the overexploitation of a key species (e.g. Atlantic cod or Antarctic krill). The status of (over)exploitation of a species is determined on an ecological threshold, a concept akin to the notion of tipping points, that have been crossed. Such shifts may be difficult to foresee, as the underlying drivers and internal feedback of a system can be subject to gradual change with minor impacts on the overall system state (Rahmstorf, 2006). For the purpose of this paper, ecological thresholds are broadly understood as a point, level, or value, that when crossed initiates or triggers an abrupt change or considerable response of the ecosystem in regards to the ecosystem quality or characteristics, including regime shifts or a state after an impact has occurred which may lead to a profound change not necessarily defined as a regime shift (Groffman et al., 2006; Foley et al., 2015).

6 However, there has been a significant increase in the number of reports documenting different kinds of range shifts. These shifts include movements in an east-west direction across longitudes and, surprisingly, towards tropical latitudes and lower elevations.

3 Implications for ABMTs and MPAs

While the high degree of complexity and dynamism in marine ecosystems is by no means a scientific novelty and a large body of scientific literature is devoted in particular to the impacts of climate change on marine life, these considerations seem to be largely absent in the current *modus operandi* of marine environmental protection, which primarily centers around designating long-term ABMTs with static boundaries. However, the above discussion has a number of fundamental implications for ABMT governance. First of all, the apparent differences between marine and terrestrial ecosystems (with the former exhibiting a higher degree of dynamism) raises the question of whether our current approach to environmental protection, which is derived from nature preservation on land is appropriate (Peters, 2020)[7]. These concerns are even stronger in relation to migratory species engaging in transoceanic journeys, which need to be considered when developing protection mechanisms. They moreover require protection in their spawning and feeding grounds, the location of which may vary seasonally.

When considering the impacts of climate change and other human interference with marine ecosystems, the merit of static approaches diminishes even further, as ABMT boundaries become void when species shift their geographical range (Tittensor et al., 2019; Ortuño Crespo et al., 2020; Goodman et al., 2022). Moreover, significant changes in ecosystem functioning and composition are occurring, effectively transforming ecosystems. Over time, they may bear little resemblance to their past state, leading to a potential mismatch between the protective measures put in place and the protective *needs* [8] require a more dynamic mode of protection.

4 Dynamic area-based management tools

The present section seeks to answer the question of how ABMTs can be conceptualized to optimally reflect the ocean's dynamism. An integrated conceptualization of ABMT governance is put forward, one that is more apt to respond to the type of challenges that the dynamism of complex marine ecosystems presents. Dynamism, in this context, is broadly construed as encompassing three dimensions: spatial, normative, and

7 Peters (2020) observes that 'zonal demarcations' of ocean space work on the basis of 'territorialization', borrowed from land, "where lines, fences and borders have been, and continue to be, physically marked and built-upon for the purposes of governance", and further that "such modes of demarcating space do not 'belong' at sea but have been transported there from the land and landed logics of territory-making, governance and control".

8 Conventional, 'static' MPAs have been shown to be potentially highly effective and we unequivocally advocate for their continued utility in marine conservation efforts. However, given their limitations as pointed out here, we argue that dABMTs should be added to the arsenal of ocean governance tools as they can supplement and in some instances replace static MPAs.

institutional. It should be noted, however, that although conceptually separated, in practice these spheres are interactive and deeply intertwined.

4.1 Spatial dynamism

Geographical, or spatial dynamism, denotes ABMTs with fluid, non-static boundaries, allowing them to respond to ecological, oceanographic, and atmospheric variability (Ortuño Crespo et al., 2020). As described in the foregoing section, variability exists not only in horizontal movements of marine life, but also vertically through different depths of the water column. Depending on the scope and objectives of existing ABMTs, they typically distinguish between activities in the water column (e.g. fishing, pelagic sampling), on the surface (e.g. shipping, recreational boating), and on the seabed (e.g. seabed mining, laying submarine cables). This limited vertical differentiation suffices, given that vertical migrations typically only occur within the water column.

Thus, horizontal boundary adjustments are adequate to attain a sufficient degree of spatial dynamism to account for the highly mobile nature of marine life. These adjustments should be aligned with the *spatial* as well as the *temporal* scales at which the movement of species, habitats, and ecosystems occur (Ortuño Crespo et al., 2020). Both of these variables are contingent upon the dynamic characteristics of the ecosystem in question. That is, which dynamic processes does the ABMT seek to address, and over which spatial and temporal scales do they unfold?

The spatial delineation of a geographically dynamic ABMT is fundamentally contingent upon its scope. This scope may concentrate on specific species, ecosystems, or activities, with the corresponding boundaries established accordingly. For example, dABMTs targeting a particular species are demarcated based on the geographical distribution of that species. An illustrative instance is the implementation of seasonal fisheries closures, designed to safeguard designated species within their feeding and breeding habitats, the location of which may vary[9]. In some cases, dABMTs may even target individual (often critically endangered) species. Examples of these extremely targeted and technologically intensive dABMTs are discussed in more detail below. Conversely, when a dABMT focuses on *components of biodiversity*, its spatial configuration mirrors that of a static ABMT, aligning with the location of the ecosystem in question. Depending on the extent to which that ecosystem is spatially dynamic, boundary adjustments can be implemented. Take, for instance, Australia's Great Barrier Reef (GBR), which is subject to rapid coral bleaching as well as ongoing reef restoration projects (Ainsworth et al., 2016; Great Barrier Reef Foundation, 2024). The spatial location of its ABMT network could be adjusted to accommodate these changes.

As can be inferred from the above discussion, the temporal dimension of an ABMT is intricately linked to its spatial dimension, both being contingent upon accommodating dynamic processes. If changes are occurring rapidly, as is the case with the GBF, spatial adjustments must be implemented regularly[10]. Conversely, if a process unfolds over longer periods (e.g. changes in oceanic circulation), boundary adjustments can be implemented at longer intervals. While oceanic processes are deeply intertwined and nonlinear, Ortuño Crespo et al. (2020) identified four key temporal scales at which such changes occur: contemporary; intra-annual; multi-annual; and multi-decadal. Such a segmented conceptualization of temporality is useful, as it allows us to develop management strategies that appropriately match both the spatial and temporal scales of ocean changes. For example: to respond to the changes occurring on the contemporary scale (i.e., normal variability in species distributions, such as aggregations of prey and predators at productive ocean features), ABMT boundaries could be adjusted in near real-time. This requires continuous monitoring of the marine environment through satellite-based remote sensing and tracking technologies, as well as real-time integration of this information into rapid management responses (Hobday et al., 2014). On the other side of the temporal spectrum, the multi-decadal scale – which concerns redistributions of marine life in the face of climate change – requires adjustments at a far lower frequency, given that such movements occur at a relatively slow rate (Poloczanska et al., 2016).

4.1.1 Models and examples of spatially dynamic ABMTs

The idea of protected areas with adjustable boundaries has been around since the early 2000s (Agardy et al., 2003; Tompkins and Adger, 2004) and quickly gained traction in scientific spheres, leading to a number of studies being conducted to assess their potential viability. Nonetheless, practical examples thereof are limited, and available studies are primarily using environmental modeling techniques. For example, modeling techniques, such as complex dynamic species distribution models (SDMs), which are traditionally static, are increasingly investigated for their use and as a more apt approach to management. While these are still in their infancy and are only seen as a waypoint in the advancement of climate-adapted management (Barnes et al., 2022), these have shown that dynamic approaches to environmental protection and resource management could yield a number of potential benefits. For one, dynamic spatial management is more focused: instead of protecting entire migration routes or habitats of (endangered) species year-round, real-time or seasonal adjustments for relevant areas could be implemented, which require significantly less spatial coverage. This was aptly illustrated in a modeling study, using a habitat prediction model conditioned with temperature preference data, which would be adjusted and updated frequently to match the real time conditions of the ecosystem (*i.e.* occurrence of targeted species in a predicted time-period) to allocate fishing effort and reduce by-catch. As such, it simulated a single temperature-dependent species' habitat using a 12°C – 15°C temperature range (Maxwell et al., 2015). Across these temperature scenarios, the

9 As, for instance, adopted by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR Commission), see, e.g., CCAMLR Conservation Measure 32-01 (2001).

10 In 2016, 30% of the corals in the GBF died off, see Hughes et al., 2017.

annual restricted fisheries time-area was between 62.1 and 86.1% less in a dynamic management approach, compared to a static one. Compared to traditional seasonal closures, between 34.2 and 82.0% less space was required (Maxwell et al., 2015).

In a similar vein, fisheries closures could be 2 to 10 times smaller than existing static closures, while still providing adequate protection of endangered species (Hazen et al., 2018). This higher degree of spatial efficiency could result in significant economic benefits. For instance, it has been estimated that in New England cod fisheries alone, the economic benefits of a dynamic approach, in comparison to a static one could be up to a third of the value of all of the cod landed, that is, USD 52,750,000 (Hazen et al., 2018).

Spatially dynamic ABMTs are not just economically attractive, they also bear the potential to yield substantial ecological benefits. One ecosystem modeling study, focusing specifically on the effects of climate change-induced redistributions and the effects thereof on MPA effectiveness, compared six MPA designs in a hypothetical ecosystem with 4°C warming at the end of the 21st century (Cashion et al., 2020). As such, the study used a static mass-balanced model modified by a temporal scenario and spatialized to a certain habitat, meaning that changing nature of the chosen (theoretical) ecosystem, in a designated spatial scale, was incorporated by including sea surface temperature change for a designated timeframe of 100 years. The results suggest that there is a significant difference in biomass in only one MPA design scenario, the 'square shifting' (i.e., dynamic) MPA, compared to the no-MPA scenario. This MPA design outperforms network MPA designs, as well as the 'square static' MPA design on all aggregate measures. The study shows that there may be some, albeit modest, benefits to dynamic MPAs for some species and fishing fleets (Cashion et al., 2020). Even in ecosystems that consist of fixed structures and are thus not an obvious choice for dynamic management, dynamic MPAs can bring about considerable conservation benefits. A study looking at dynamic MPAs that rotate among an appropriate subset of the entire reef system (e.g., rotating 10 protected areas between only 20 reefs in a 100-reef system) found that dynamic closures always lead to increased mean herbivore biomass (Game et al., 2009).

Although few in number, there are some real-life examples of ABMTs that embody some form of spatial dynamism. A well-known example of real-time dynamic spatial management, also referred to as dynamic ocean management (DOM)[11], is the protection of the quota-managed southern bluefin tuna (*Thunnus maccoyii*) off the coast of south-eastern Australia. Southern bluefin tuna make annual winter migrations, during which they interact with a year-round tropical tuna longline fishery (Eastern Tuna and Billfish fishery) (Hobday and Hartmann, 2006). A temperature-based habitat model for southern bluefin tuna was developed to mitigate the bycatch of the non-target species. This model enables managers to estimate the distribution of tuna in real-time, providing a basis for decision-making regarding the placement of management boundaries. The projected location of the tuna is determined by matching temperature preferences to satellite-derived sea surface temperature data and vertical temperature data obtained from an oceanographic model. Based on this data, fishing access to areas where southern bluefin tuna are believed to be present is restricted. In a retrospective study on the efficacy of this approach, it was found that it is successfully mitigating the bycatch of southern bluefin tuna (Hobday and Hartmann, 2006).

A similar, albeit voluntary, program is the *TurtleWatch* project in Hawaii-based pelagic longline fishery. Based on data from satellite-tagged turtles, as well as ocean surface temperatures, maps were generated that indicate the area that fishers should avoid. The TurtleWatch program has successfully reduced the bycatch of the endangered loggerhead turtle from bycatch in the Hawaii-based longline fishery (Howell et al., 2008). However, significant bycatch continued to occur, which can primarily be attributed to the voluntary nature of the program. The majority of all loggerhead turtle bycatch occurred in the area where fishing was discouraged, which shows that the program was successful in indicating the area where bycatch is most likely to occur (Howell et al., 2008).

The above-outlined illustrates that the development of dynamic ecological modelling techniques is increasing and a number of ecological indicators, such as sea surface temperature, are used to identify and develop apt approaches to changing conditions. Yet, these models are highly complex and, in instances, still in their infancy, subject to high uncertainty and depend on oftentimes large, high-quality datasets. More research is certainly required, but these studies and examples indicate that there may be some considerable benefits to spatially dynamic ABMTs. Against the backdrop of the persistent acceleration of climate change, it can reasonably be expected that these benefits will increase even further, given the disruptive effects thereof on marine ecosystems. However, to account for the full extent of oceanic dynamism, mere adjustment of boundaries is insufficient.

4.2 Normative dynamism

Normative dynamism, i.e., the regular readjustment of ABMT measures can occur structurally through adaptive management (hereinafter: AM) of ABMTs, which is a thread that runs through and ties together all three spheres of dynamism. It can be described as "an approach to policy implementation in which ecological responses to management actions are monitored and compared to expected responses, then differences between observations and expectations are used to refine management in an iterative process" (Walters, 2010). AM provides a useful and comprehensive theoretical framework that, when applied in the context of area-based management, can result in a high degree of normative dynamism. Its first articulations date back to the mid-twentieth century, and AM has now matured to the extent that it can be considered a discipline of its own (Beverton and Holt, 1957).

Given the wealth of available literature, many different definitions and applications exist, however, three elements can be

11 DOM differs from dABMTs as conceptualized in this article in that it focuses solely on *near real-time* management, and thus only addresses changes occurring on the *contemporary* temporal scale. See, in this regard, Maxwell et al., 2015.

said to be universal: (i) planning, i.e., identifying and setting management objectives and identifying key uncertainties; (ii) designing and implementing actions to achieve the objectives; (iii) monitoring management effectiveness and reviewing the management program to improve outcomes (Fuentes et al., 2014). Importantly, AM differs from a trial-and-error approach due to its structural nature, with each step informing and guiding the others iteratively to improve the understanding of the socio-ecological system being managed.

AM is a conceptually robust approach to management. However, it is also under constant scrutiny in the scientific literature and has often been criticized (Lee, 2001; Allen and Gunderson, 2011; Månsson et al., 2023). It is well-established that its feasibility is heavily contingent on the socio-ecological context of a given region. More specifically, commentators found that AM is ill-suited for application to large, complex problems, as well as in contexts wherein very rapid or very slow changes in ecosystem states occur (Rist et al., 2012; Månsson et al., 2023). Indeed, in systems of intricate complexity, or where changes occur over an extended timespan, it becomes extremely difficult to distinguish the impacts of management interventions from the myriad other factors at play. Conversely, if changes occur very rapidly, the stepwise learning that is at the core of AM may be too slow to keep pace (Månsson et al., 2023). Within these parameters, however, AM has proven to be a potent framework to address uncertainty and predictability in complex systems (Westgate et al., 2013; Johnson et al., 2015).

Another often-hailed criticism of AM is the "inherent tension between its acknowledgment of complexity, uncertainty, and emergence and its presumption that goals and system metrics can be established to assess and adapt interventions" (Rist et al., 2012). Indeed, there is an implicit assumption inherent in AM that ecosystem responses can, at least to some degree, be predicted. Management is treated as an 'adaptive learning process' (Walters, 1986), and hence rests on an assumed predictability, i.e., "that the structural features of the resource system and the underlying environment are dynamically stable" (Williams, 2011). The predictability of marine ecosystems is a subject of considerable debate within ecological discourse. Gaüzère et al. (2018), for instance, posit that "ecological systems might intrinsically be unpredictable due to their complexity and the amount of chaotic, neutral, or stochastic processes impairing their dynamics". When, in addition, the environmental conditions and ecological processes influenced by them are themselves changing, for example, due to climate change, further complications arise in the application of AM (Petchey et al., 2015). The impacts of climate change on the dynamics of marine biodiversity, as described previously, impair our ability to predict these impacts and to forecast the responses of biodiversity to climate change (Gaüzère et al., 2018). Even under gradual climate change, ecological systems demonstrate non-linear responses. As a consequence of the nonlinearity in the external factors influencing ecosystems, their dynamics may increase in complexity and we are only beginning to understand these changes (Saros et al., 2019).

Thus, in an increasingly unpredictable and dynamic world, AM may not always be the appropriate means to achieve normative dynamism. Indeed, concerns have been raised around AM's excessive reliance on linear system models (McLain and Lee, 1996), and the "tendency among scientists to overstate their capability to measure complex functional relationships through experimentation." (Allen and Gunderson, 2011). The adequacy of AM should be carefully considered on a case-by-case basis, which depends on myriad factors[12]. AM appears ill-suited for application to changes occurring on the multi-annual to multi-decadal scales, as well as to processes unfolding on large spatial scales. In such cases, management changes should be informed by observed, rather than projected changes. Indeed, a reactive approach to management that relies on adaptive monitoring may be more appropriate in the uncertain times we find ourselves in and could be used to supplement AM programs, making them more robust to unexpected or rapid ecosystem changes (Lindenmayer and Likens, 2009). A potential component of a reactive management approach is the (designation and) application of ecological and management thresholds. Therein, thresholds serve as tools applicable on a case-by-case basis and may provide a basis for the designation and implementation of adequate management of changing ecosystems.

4.2.1 Thresholds in ocean management

In this context, two types of thresholds (see section 2), which are tools borrowed from existing management approaches that make use of thresholds, can be employed to address these challenges and foster a high degree of normative dynamism.

Ecological thresholds may serve as a tool to tackle environmental problems and as an initiator for adaptive, timely, and prospective approaches to enhance management outcomes (Foley et al., 2015). To this end, it is critical to understand the conditions leading to the crossing of thresholds, which is generally an undesirable outcome (Groffman et al., 2006). While it is true that ecological thresholds presuppose predictability of an ecosystem or ecosystem component and are context-specific, there may be ways to use thresholds as a tool to support an anticipatory and precautionary approach for the management and conservation of a dynamic ecosystem.

Thresholds are predictive when considering changes that occur on a multidecadal scale, as their establishment is based on historical data and modelling. Their interpretation relates to future scenarios. For more dynamic, rapid changes on shorter temporal scales, thresholds may be developed and based on real-time or near-real time data, which allow and support a reactive and more dynamic approach to ocean management. Therein, ecological thresholds can trigger management tools on a shorter time scale.

The (sudden) crossing of an ecological threshold initiates a reaction following an undesirable event, which ideally should have been avoided and may lead to a fundamental change that may not

12 These relate *inter alia* to socio-economic context of a specific region given the relatively high financial and institutional resources required to successfully implement AM, as well as stakeholder participation and sufficient leadership and direction. See, in this regard, comprehensively Allen and Gunderson, 2011.

be easily restored or returned to the initial state. To avoid such outcome and allow for the implementation of management measures, an additional and different type of threshold may be operationalized.

This refers to the concept of a regulatory limit, which may also be called decision or management threshold (Hitchin et al., 2023). It is established on a level indicating the limit of human disturbance after which undesirable ecological change would occur and through which a response before the crossing of the tipping point is initiated. This level, further referred to as management threshold, is determined by decision-makers based on existing scientific information provided through and determined with the guidance of the ecological thresholds (see Figure 1). By creating a buffer zone between the level of the management threshold and the crossing of the ecological threshold, the aspect of uncertainty, which is inherent within ecological systems, may be accounted for. With the crossing of the management threshold a level of the last acceptable state of a resource, ecosystem or habitat is set. Thus, a designated period of time is created, allowing for the implementation of management measures to avoid the crossing of the ecological threshold. While the concept of thresholds arguably is predictive, it still represents a tool, when used strategically, that may support normative dynamism by contributing to the understanding of the marine ecosystem, its species, and complex interrelations. Such understanding is key for decision-making.

The utilization of ecological and management thresholds to support decision-making processes concerning environmental problems is not new. For example, the use and integration of thresholds has been discussed previously in the context of deep-sea mining under the regulatory regime of the International Seabed Authority (ISA) (Hitchin et al., 2023). Therein, their value as part of an early warning system has been emphasized, especially referring to their ability to support the fulfilment of the legal obligations under the UN Convention on the Law of the Sea (UNCLOS), as well as to provide flexibility in the management of the activity in line with the present legal obligations.

Moreover, the use of thresholds is also highlighted in respect of the EU Marine Strategy Framework Directive (EU MSFD). Thresholds are established and used based on defined MSFD criteria, which reflect the predominant pressures and impacts on the environment. The criteria and their linked thresholds contribute to the achievement of a Good Environmental Status (GES). Accordingly, they serve as tools for the management of EU waters through cooperation on a Union, regional, or subregional scale (e.g. in the framework of Regional Seas Conventions) and ultimately lead to an "environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions" (GES) (MFSD, 2008, art. 3(5)).

The UN Fish Stocks Agreement (UNFSA, 1995) is another example for the use of thresholds, on both ecological as well as management scales. Article 6 provides for the establishment and utilization of so-called stock-specific and region-specific reference points to be established by Regional Fisheries Management Organizations (RFMOs), which are designated as the relevant institutional bodies. The article is given further substance through the guidelines for the application of precautionary reference points provided in Annex II, defining the precautionary reference point as an "estimated value derived through an agreed scientific procedure, which corresponds to the state of the resource and of the fishery, and which can be used as a guide for fisheries management." (UNFSA, 1995, art. 1). Moreover, two possible types of reference

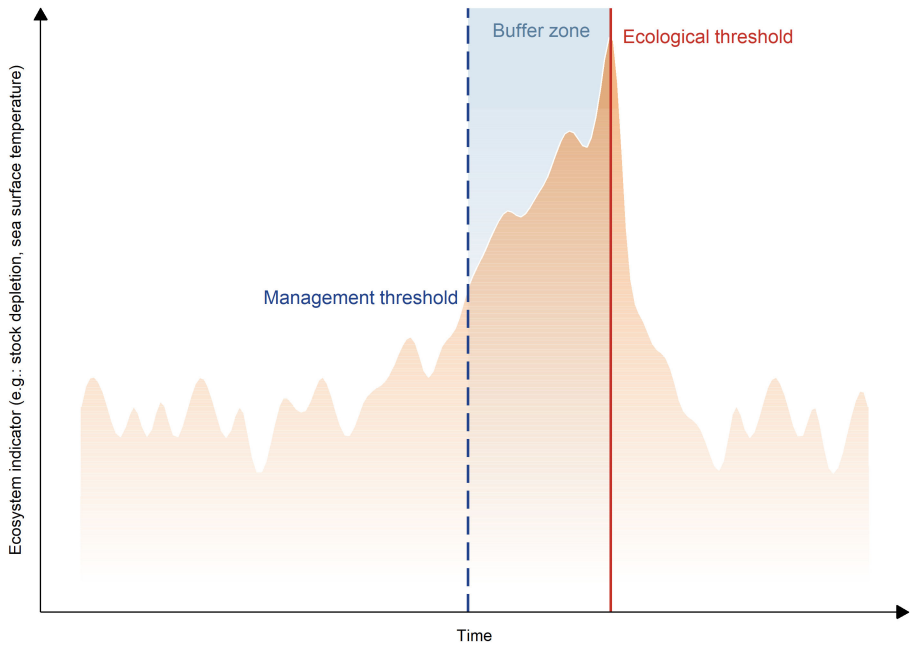


FIGURE 1
Simplified illustration of the proposed placement of management and ecological thresholds on a timescale in regard to ecological indicators indicating a potential regime shift.

points are set out. These are: (i) conservation, or limit, reference points and (ii) management, or target, reference points, which in both cases shall be stock specific and include sources of uncertainty (UNFSA, 1995, art. 2 and 3). The first type aims to set boundaries intended to constrain the harvesting within safe biological limits, referring to the maximum sustainable yield (MSY), which is at the same time determined to be the minimum standard of reference points to be set by the responsible organization/entity (UNFSA, 1995, art. 7). While the first type is akin to the concept of ecological thresholds which are purely scientific, the second type is intended to meet management objectives and falls under the concept of management thresholds. Notably, management reference points shall account for both, ecological and socio-economic aspects (i.e. the type of fisheries) of the stock. What is more, they serve as a trigger for pre-agreed conservation and management activities, such as "harvest control rules" meaning that the taking of fish stocks shall be kept within safe biological limits (UNFSA, 1995, art.2; Baez et al., 2016). This may be understood as a mechanism allowing for automatic protection of the targeted resource (UNFSA, 1995, Annex II, art.4). The Agreement further deals with uncertainty and the possibility of data gaps, in which case provisional reference points shall be set. However, these may be revised based on monitoring and improved data availability (UNFSA, 1995, art. 6).

While several uncertainties regarding the development of reference points under the UNFSA remain, an example of the application of thresholds, in practice, are real-time closures based on 'move-on rules', which is a form of DOM. Accordingly, a threshold triggers a move-on rule and determines the shift of a fishing activity and the implementation of a targeted closure of an area for a temporary period. Relevant thresholds are determined based on the fishing or bycatch quota, aiming to reduce bycatch of juveniles and non-target species (Dunn et al., 2013). The closure may be implemented on a broader scale, with closures lasting from days to weeks over various distances, thus embodying the consolidation of the temporal and spatial scale (Dunn et al., 2016). In the case of the Eastern Australian long-line fishery, which has been highlighted in section 4.1, another form of a DOM approach constitutes an oceanographic closure, which is defined by environmental conditions, and may be implemented daily or bi-weekly (Lewison et al., 2019).

4.3 Institutional dynamism

The management strategies outlined in the foregoing sections, that is, aligning the spatial and normative fabric of ABMTs with the inherent complexity and dynamism of the ecosystems they seek to protect, are contingent upon sufficiently flexible and indeed, dynamic, institutional machinery for their implementation. Institutional dynamism denotes a governance structure that is capable of sustaining the required degree of dynamism for the implementation of dABMTs.

There is, however, no one-size-fits-all institutional approach to achieve this. Ostrom and Cox argue that we should 'move beyond panaceas', that is, proposing oversimplified institutional prescriptions for complex environmental issues (Ostrom and Cox, 2010). Rather, institutional processes should be matched to the scale and characteristics of the particular social-ecological system, with a view to avoid mismatches between ecosystems and institutions (Young, 2002). Young refers to this as the problem of 'fit', that is, the "congruence or compatibility between ecosystems and institutional arrangements created to manage human activities affecting these systems". He proposes an approach of institutional diagnostics, which starts from the premise that one size does not fit all when it comes to designing institutions bestowed with a conservation mandate and stresses the need to identify critical features of a specific problem, subsequently undertaking an endeavor to determine institutional arrangements that are most adept at addressing those aspects effectively (Young, 2002). He further argues that the effectiveness of institutional frameworks protecting the environment is "determined in considerable measure by the degree to which they are compatible with the biogeophysical systems with which they interact". As such, it is key to acknowledge and internalize the human component of coupled human-natural systems when designing institutional models to govern them.

It is thus essential to be cognizant of the differences among ecosystems for which dABMTs are designated and carefully study their characteristics to align the institutional machinery overseeing their implementation accordingly. The aforementioned temporal scales are a useful framework to identify dynamic processes targeted by ABMTs, determining the frequency at which spatial and normative adaptations should occur, and subsequently calibrating the institutional structures accordingly (e.g., by structurally incorporating monitoring, review and decision-making processes at the required intervals).

This process of mirroring and alignment is key to fostering social-ecological resilience of intertwined natural-human systems, that is, the capacity of social-ecological systems to adapt or transform in the face of change without shifting to a new regime with a different set of processes and structures (Walker and Salt, 2006). Like ecosystems, social-ecological systems are complex systems with non-linear, dynamic processes that occur at various spatial and temporal scales. To govern them effectively and sustainably, their institutional components should, in parallel with ecological paradigms, embody a high degree of diversity and redundancy of institutions at multiple organizational levels, from individual actors to actor groups, organizations and governments (Jones et al., 2013).

The need of institutions to operate in sync with the dynamics of ecosystems finds resonance with adaptive governance scholarship, a theoretical framework for "addressing uncertainty and change with institutions and policy processes that reflect the social context" (Quimby, 2023). Adaptive governance theory stresses the importance of adaptability as a key component of resilience in social-ecological systems (Dietz et al., 2003; Folke et al., 2005). Folke et al. (2005) identify the need for multilevel governance systems to not only synchronize with ecosystem dynamics but also to anticipate changes and develop the capacity to endure external

perturbations. This requirement constitutes one of the four key factors necessary to foster adaptive governance. They further stress the importance of acquiring reliable ecological data to feed into adaptive management processes, and, in a similar vein, to "build knowledge and understanding of resource and ecosystem dynamics" (Folke et al., 2005). Lastly, institutional flexibility and multilevel governance systems are identified as an important aspect of adaptive governance. Young (2002) echoes the importance of institutional flexibility, which he finds is crucial to the success of efforts to alleviate or eliminate mismatches. This is particularly true, he argues, "when knowledge regarding dynamics of key ecosystems is limited at the time of regime creation and where the ecosystems are prone to nonlinear and even transformative changes" (Young, 2002), as is often the case with ecosystems befitting protection through dABMTs.

Adaptive governance is particularly applicable to marine contexts, effectively addressing the spatial scale and unpredictability inherent in these environments (Quimby, 2023), as discussed previously, and appears well-suited for overseeing dABMT implementation and management. However, specific challenges emerge when applying adaptive governance in marine settings. For instance, Quimby stresses the need to "recognize existing social and political dimensions, support social learning and equity", rather than conceptualizing the oceans as empty and ahistorical. These concerns are even stronger in relation to dABMTs due to their spatially dynamic nature and heavy reliance on scientific data. Therefore, it is crucial that decision-making processes consider the historical and cultural significance of the ocean areas designated for dABMTs. Similarly, stakeholder participation, which Quimby identifies as a vital component of adaptive governance, may be complicated by the varying presence and activities of individuals involved in marine fisheries. The spatially dynamic nature of dABMTs necessitates continuous stakeholder engagement rather than intermittent consultations solely prior to dABMT designation.

4.3.1 Institutional dynamism in an international context

Building and sustaining an institutional structure that fully reflects the complexity, diversity, and non-linearity occurring at various spatial and temporal scales within marine ecosystems poses a significant challenge, if not an insurmountable one. In an international context, achieving institutional dynamism as portrayed here is especially challenging. International legal institutions often have rigid and time-intensive decision-making processes[13], and in a transboundary context, fostering cooperation among States and international organizations is imperative but also entails considerable time investments.

There are, however, some international legal frameworks that leave ample scope for institutional flexibility and dynamism, such as the UNFSA, which seeks to foster greater cooperation between States in the conservation and management straddling and highly migratory fish stocks. To this end, RFMOs – the appropriate institutions to implement management measures – are required by virtue of 8 to "tak[e] into account the specific characteristics of the subregion or region", as well as to agree on "the area of application … and the characteristics of the subregion or region, including socio-economic, geographical and environmental factors" (article 9). These provisions resonate with the above discussion on aligning institutional machinery with the characteristics of socio-ecological systems.

Institutional flexibility can moreover be observed in that, while States are under an obligation to cooperate, they are free to shape their cooperation as they see fit; they can do so through an *organization* (RFMO) or *arrangements* (RFMA). It is not specified how such an organization or arrangement must be structured. Thus, while there are undoubtedly many pitfalls on the way to achieving institutional dynamism in an international context, it should not be dismissed as an unattainable goal from the outset. Ultimately, a lot will boil down to whether enough political will can be harnessed to restructure and align institutions with the dynamic nature of the ocean. As Holling and Anderson aptly put it, "until modern human institutions are built on ecological dynamism, and designed to flex with natural variability, their principal impact will be to impede nature, not to sustain it" (Holling and Anderson, 1996).

5 The legal framework

Having clarified the conceptual intricacies of dABMTs, the question arises whether there is scope for implementing such dynamic modes of ABMT governance under the existing legal constellation governing the ocean. This question can, broadly speaking, be answered affirmatively; the law of the sea, although not mentioning ABMTs or MPAs anywhere (notwithstanding the BBNJ Agreement, to which we turn shortly) leaves ample room for implementing such a tool. Given its framework nature, among the main functions of UNCLOS is to allocate jurisdiction and sovereign rights in coastal States' maritime zones, which are balanced against the rights and duties of foreign States[14]. Within the parameters of this jurisdictional framework, States are free to give substance to their duty to protect the marine environment (UNCLOS, 1994, art. 192 *et seq*)[15].

Thus, given that UNCLOS does not contain any specific obstacles to the implementation of dABMTs, States are free to include this tool in their marine environmental strategies. The

13 A good example is the ongoing process under the international seabed organization (ISA) to develop the 'Mining Code'. This process commenced in 2014 and is expected to be finalized in 2025 (Rosenberg, 2023).

14 E.g., UNCLOS art. 56, providing for the coastal State's sovereign rights and jurisdiction in its exclusive economic zone, in which other States enjoy various freedoms as set out in art. 87 "subject to the relevant provisions of this Convention" (art. 58).

15 Art. 194(5) is of particular relevance for present purposes, is it requires States to take special measures to protect and preserve rare or fragile ecosystems and the habitat of depleted, threatened or endangered species and other forms of marine life.

examples of spatially dynamic ABMTs discussed earlier demonstrate that some States have already done so. However, domestic legal and institutional contexts vary significantly and may often impede the successful implementation of dABMTs. Distinct legal frameworks may apply to different activities, and coordination can be complicated by a fragmented institutional landscape where, in addition to the State, various regional and local agencies and bodies hold competencies.

An illustrative example of these complexities is the case of the California Current System (CCS) offshore California, in the United States, where seasonal upwelling events take place. The timing, evolution, intensity, and duration of coastal upwellings in the CCS exhibit significant seasonal variation (Bograd et al., 2009), making this area well-suited for dynamic conservation strategies. However, the legal and institutional landscape of the CCS is highly fragmented with at least 20 federal agencies tasked with implementing over 140 federal ocean-related legal instruments. In addition, the States of California, Oregon and Washington have jurisdiction within 3 nautical miles off the coast, each with their own legislative frameworks, further adding to the legal complexity of the region, leading to transboundary issues and spatial mismatches between scales of ecosystems and governance systems (Crowder et al., 2006).

Similar issues may arise in other countries and regions, although the CCS presents an extreme example. Notwithstanding these challenges, a dynamic management program was developed within the CCS to mitigate whale-ship collisions[16]. While this program remains voluntary, the collaborative effort involving NGOs, universities, and the National Oceanic and Atmospheric Administration (NOAA) demonstrates that even in particularly challenging normative and institutional contexts like the CCS, opportunities for dABMT implementation exist.

In an international context, similar transboundary issues arise, albeit on a larger scale. While UNCLOS indeed does not prohibit the designation of dABMTs, one significant limitation lies in the jurisdictional architecture of the ocean, i.e., the fragmentation thereof in different maritime zones, subsuming each fragment into a different legal regime[17]. This is problematic for many reasons, which have been extensively discussed elsewhere (Tanaka, 2004), and can impede implementing dABMTs since the ecosystems and species they seek to protect are not bound by these artificial boundaries. The zonal and sectoral fragmentation of ocean space and the activities taking place therein make establishing dABMTs complex – especially if they straddle between two or more maritime zones – but not impossible. It would, however, require substantial political commitment and a high degree of international cooperation among States and international organizations.

Whereas UNCLOS does not mention ABMTs or MPAs, the 1992 Convention on Biological Diversity (CBD) in article 8 provides for the establishment of MPAs. This must be read in conjunction with the Kunming-Montreal Global Biodiversity Framework, adopted in December 2022, which replaces the Strategic Plan for Biodiversity 2011-2020 including the Aichi Targets and provides for AMBTs, including MPAs, as a key tool to protect at least 30% of the marine and coastal areas[18]v The CBD explicitly acknowledges the dynamic nature of ecosystems[19], and defines protected areas broadly enough to encompass dABMTs and can hence be said to provide ample scope for their implementation.

In areas beyond national jurisdiction (ABNJ), i.e., the high seas and the Area, a distinct legal regime applies by virtue of Parts V and XI. The high seas are governed by Part V of UNCLOS, of which article 87, setting forth the 'high seas freedoms', forms the centre of gravity. Recently, however, this regime was supplemented by the new BBNJ Agreement, which seeks to "ensure the conservation and sustainable use of marine biological diversity of [ABNJ]" through, *inter alia*, the "establishment of a comprehensive system of [ABMTs], with ecologically representative and well-connected networks of [MPAs]" (BBNJ, 2023, art. 14(a)). Although the BBNJ Agreement does not explicitly allow for the designation of dABMTs, there appears to be some scope for their implementation. MPAs, in article 1(12), are described as "a geographically defined marine area that is designated and managed to achieve specific long-term biodiversity conservation objectives and may allow, where appropriate, sustainable use provided it is consistent with the conservation objective". The definition is broad enough to encompass ABMTs with fluid boundaries, as long as the boundaries are geographically defined at any given point in time. Furthermore, *normative dynamism*, i.e., volatile conservation measures subject to regular review, also falls within the ambit of this definition, as it merely requires the area to be 'managed'. Nothing in the Agreement explicitly precludes the possibility of designating dABMTs, and there are even some dynamic elements that could facilitate their implementation, such as the creation of a Scientific and Technical Body (BBNJ, 2023, art. 49) and the periodic monitoring and review of ABMTs (BBNJ, 2023, art. 26(3)).

Thus, it can be concluded that the principal legal frameworks governing the ocean do not contain any specific impediments for designating dABMTs, nor do they explicitly foster their implementation. Within these frameworks, however, there is ample space for flexibility and, indeed, dynamism, to designate these tools. The complexities in implementing these tools intensify when one ventures further offshore, where sovereignty erodes and is replaced by extensive rights and

16 See https://ecosystemsentinels.org/whalesafe/. The tool can be accessed here: https://whalesafe.com/.

17 See, e.g., UNCLOS (1994) articles 3, 55 *et seq*, and 76.

18 CBD Decision 15/4 (19 December 2022) CBD/COP/DEC/15/4. MPAs are not mentioned specifically, however the document refers to 'protected areas', which, in a marine context are thus ABMTs, such as MPAs. In addition to protected areas, 'other effective conservation measures' (OECMs) are also included in this target. For a detailed discussion on OECMs and their role in the GBF, see: Alves-Pinto et al. (2021).

19 CBD, art. 2 defines an 'ecosystem' a *dynamic* complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.

freedoms of third States, making international cooperation a prerequisite for their implementation. The newly adopted BBNJ Agreement provides a potential platform through which such cooperation can take place (Westholm and Argüello, 2024).

6 Concluding remarks

Equilibrium thinking is deeply ingrained in the way we conceptualize, manage, and design ocean space. This mode of thinking is pervasively present in all levels of ocean governance, from the jurisdictional architecture of the ocean to marine spatial management and conservation strategies. The present article commenced by unpacking ocean space, highlighting its inherently and deeply dynamic nature. Rather than a static equilibrium, the ocean is a movescape[20], and hence our efforts to conserve the ocean and sustainably manage its resources should reflect these fundamental properties. Against this background, an integrated conceptualization of dABMTs was outlined in the main body of this article. In addition to spatial, normative and institutional dynamism, a set of ecological and management thresholds may be incorporated to trigger (pre-agreed) conservation measures, which prevent ecologically undesirable outcomes such as regime shifts.

It is worth noting, however, that the implementation of dABMTs, as proposed herein, is contingent upon specific contexts and should ideally complement rather than replace static MPAs. Indeed, dAMBTs present certain limitations that make them ill-suited for application in certain contexts. For instance, their successful implementation is heavily contingent upon the availability of reliable scientific data, thus necessitating the establishment of robust and comprehensive monitoring programs —a costly endeavor fraught with concerns regarding the politicization of scientific findings[21]. Similarly, setting up the required institutional and technological machinery requires substantial investments.

Conversely, spatially and normatively static MPAs, in addition to being less costly to implement, undeniably possess a higher degree of legal certainty, clarity and stability—qualities generally considered desirable in ocean governance. The present paper sought to highlight the (potential) ecological and economic benefits of dABMTs, that will ultimately need to be weighed against any potential downsides to their utilization, taking into account specific social-ecological context of a given region or ecosystem.

On the other hand, one must not forget the dire and ever-worsening state of our climate and biodiversity, in the midst of which we need to rethink and reshape the way in which we relate to and govern the natural world. We may need to venture into unknown and uncomfortable territory. After all, to safeguard our ocean and address the pressing challenges it faces, more than mere tinkering at the margins is required. We must embrace innovation, adaptability, and cooperation in the governance of our planet's most vital and vulnerable ecosystems. Governance of marine activities should embody change, rather than resist it.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

BK: Writing – original draft. KH: Writing – original draft. RP: Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

We would like to thank Professor Joanna Mossop for her insightful comments on an earlier version of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

20 That is, a functional landscape of movement, see Bastille-Rousseau and Wittemyer, 2020.

21 The recent tensions in the Antarctic Treaty System around the establishment of MPAs in the Southern Ocean aptly illustrate how science is increasingly used as a political means (Dervovic and Heinrich, 2023; Goldsworthy et al., 2023).

References

Agardy, T., Bridgewater, P., Crosby, M. P., Day, J., Dayton, P. K., Kenchington, R., et al. (2003). Dangerous targets? Unresolved issues and ideological clashes around marine protected areas. *Aquat. Conservation: Mar. Freshw. Ecosystems.* 13, 353–367. doi: 10.1002/aqc.583

Ainsworth, T. D., Heron, S. F., Ortiz, J. C., Mumby, P. J., Grech, A., Ogawa, D., et al. (2016). Climate change disables coral bleaching protection on the Great Barrier Reef. *Science.* 352, 338–342. doi: 10.1126/science.aac7125

Allee, W. C., Emerson, A. E., Park, O., and Al, E. (1974). *Principles of animal ecology* (Philadelphia Etc: Saunders).

Allen, C. R., and Gunderson, L. H. (2011). Pathology and failure in the design and implementation of adaptive management. *J. Environ. Manage.* 92, 1379–1384. doi: 10.1111/ele.12443

Alves-Pinto, H., Geldmann, J., Jonas, H., Maioli, V., Balmford, A., Ewa Latawiec, A., et al. (2021). Opportunities and challenges of other effective area-based conservation measures (OECMs) for biodiversity conservation. *Perspect. Ecol. Conserv.* 19, 115–120. doi: 10.1016/j.pecon.2021.01.004

Baez, S., Fabra, A., Friedman, A., Galland, G., Nickson, A., and Warwick, L. (2016). *Global progress toward implementing the united nations fish stocks agreement* (PEW Charitable Trust). Available online at: https://www.pewtrusts.org/-/media/assets/2016/05/un-review-conf-brief-mar2016-final.pdf (Accessed 28 January 2023).

Barnes, C. L., Essington, T. E., Pirtle, J. L., Rooper, C. N., Laman, E. A., Holsman, K. K., et al. (2022). Climate-informed models benefit hindcasting but present challenges when forecasting species–habitat associations. *Ecography* 10, e06189. doi: 10.1111/ecog.06189

Bastille-Rousseau, G., and Wittemyer, G. (2020). Characterizing the landscape of movement to identify critical wildlife habitat and corridors. *Conserv. Biol.* 35:1, 346–359. doi: 10.1111/cobi.13519

BBNJ. (2023). *Agreement under the United Nations convention on the law of the sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, New York, 19 June 2023 (adopted 19 June 2023).*

Berge, J., Cottier, F., Last, K. S., Varpe, Ø, Leu, E., Søreide, J., et al. (2009). Diel vertical migration of Arctic zooplankton during the polar night. *Biol. Letters.* 5, 69–72. doi: 10.1098/rsbl.2008.0484

Beverton, R. J. H., and Holt, S. J. (1957). *On the dynamics of exploited fish populations* (Her Majesty's Stationery Office: London). doi: 10.2307/1440619

Bograd, S. J., Schroeder, I., Sarkar, N., Qiu, X., Sydeman, W. J., and Schwing, F. B. (2009). Phenology of coastal upwelling in the California Current. *Geophysical Res. Lett.* 36, 2. doi: 10.1029/2008GL035933

Boyle, M. C., FitzSimmons, N. N., Limpus, C. J., Kelez, S., Velez-Zuazo, X., and Waycott, M. (2009). Evidence for transoceanic migrations by loggerhead sea turtles in the southern Pacific Ocean. *Proc. R. Soc. B: Biol. Sci.* 276, 1993–1999. doi: 10.1098/rspb.2008.1931

Brito-Morales, I., Schoeman, D. S., Molinos, J. G., Burrows, M. T., Klein, C. J., Arafeh-Dalmau, N., et al. (2020). Climate velocity reveals increasing exposure of deep-ocean biodiversity to future warming. *Nat. Climate Change.* 10, 576–581. doi: 10.1038/s41558-020-0773-5

Cashion, T., Nguyen, T., ten Brink, T., Mook, A., Palacios-Abrantes, J., and Roberts, S. M. (2020). Shifting seas, shifting boundaries: Dynamic marine protected area designs for a changing climate. *PloS One* 15, e0241771. doi: 10.1371/journal.pone.0241771

Cooper, G. S., Willcock, S., and Dearing, J. A. (2010). Regime shifts occur disproportionately faster in larger ecosystems. *Nat. Commun.* 11, 1–10. doi: 10.1038/s41467-020-15029-x

Craig, R. K. (2012). Ocean governance for the 21st century: making ocean zoning climate change adaptable. *Harvard Environ. Law Rev.* 36, 305.

Crowder, L. B., Osherenko, G., Young, O. R., Airamé, S., Norse, E. A., Baron, N., et al. (2006). Science policy forum 313, 617–618. doi: 10.1126/science.1129706

Cuddington, K. (2001). The "Balance of nature" Metaphor and equilibrium in population ecology. *Biol. Philosophy.* 16, 463–479. doi: 10.1023/A:1011910014900

Dervovic, M., and Heinrich, K. (2023). Law-science nexus in international law-making: perspectives from arctic fisheries governance. *Nordic J. Int. Law* 92, 599–622. doi: 10.1163/15718107-bja10073

Dietz, T., Ostrom, S., and Stern, P. C. (2003). The struggle to govern the commons. *Science* 302, 1907–1912. doi: 10.1126/science.1091015

Dubois, M., Rossi, V., Ser-Giacomi, E., Arnaud-Haond, S., López, C., and Hernández-García, E. (2016). Linking basin-scale connectivity, oceanography and population dynamics for the conservation and management of marine ecosystems. *Global Ecol. Biogeography.* 25, 503–515. doi: 10.1111/geb.12431

Dunn, D. C., Boustany, A. M., Roberts, J. A., Brazer, E. O., Sanderson, M., Gardner, B., et al. (2013). Empirical move-on rules to inform fishing strategies: a New England case study. *FISH and FISHERIES* 15 (3), 359–375. doi: 10.1111/faf.12019

Dunn, D. C., Maxwell, S. M., Boustany, A. M., and Halpin, P. N. (2016). Dynamic ocean management increases the efficiency and efficacy of fisheries management. *Proc. Natl. Acad. Sci.* 113, 668–673. doi: 10.1073/pnas.1513626113

Egevang, C., Stenhouse, I. J., Phillips, R. A., Petersen, A., Fox, J. W., and Silk, J. R. (2010). Tracking of Arctic terns Sterna paradisaea reveals longest animal migration. *Proc. Natl. Acad. Sci.* 107, 2078–2081. doi: 10.1073/pnas.0909493107

Embling, C. B., Illian, J., Armstrong, E., van der Kooij, J., Sharples, J., Camphuysen, K. C. J., et al. (2012). Investigating fine-scale spatio-temporal predator-prey patterns in dynamic marine ecosystems: a functional data analysis approach. *J. Appl. Ecology.* 49, 481–492. doi: 10.1111/j.1365-2664.2012.02114.x

Foley, M. M., Martone, R. G., Fox, M. D., Kappel, C. V., Mease, L. A., Erickson, A. L., et al. (2015). Using ecological thresholds to inform resource management: current options and future possibilities. *Front. Mar. Sci.* 2. doi: 10.1007/s10021-003-0142-z

Folke, C., Hahn, T., and Olsson P and Norberg, J. (2005). Adaptive governance of social ecological systems. *Annu. Rev. Environ. Resour.* 30, 441–473. doi: 10.1146/annurev.energy.30.050504.144511

Fuentes, M. M. P. B., Chambers, L., Chin, A., Dann, P., Dobbs, K., Marsh, H., et al. (2014). Adaptive management of marine mega-fauna in a changing climate. *Mitigation Adaptation Strategies Global Change.* 21, 209–224. doi: 10.1007/s11027-014-9590-3

Game, E. T., Bode, M., McDonald-Madden, E., Grantham, H. S., and Possingham, H. P. (2009). Dynamic marine protected areas can improve the resilience of coral reef systems. *Ecol. Letters.* 12, 1336–1346. doi: 10.1111/j.1461-0248.2009.01384.x

Gaüzère, P., Iversen, L. L., Barnagaud, J. Y., Svenning, J. C., and Blonder, B. (2018). Empirical predictability of community responses to climate change. *Front. Ecol. Evolution.* 23. doi: 10.3389/fevo.2018.00186

Goldsworthy, L., Press, T., and Haward, M. (2023). China and Russia are blocking the creation of a third Antarctic marine protected area. *Polar J.* Available online at: https://polarjournal.ch/en/2023/06/19/china-and-russia-are-blocking-creation-of-a-third-antarctic-marine-protected-area/. (Accessed 2 July 2024).

Goodman, C., Davis, R., Azmi, K., Bell, J. D., Galland, G. R., Gilman, E., et al. (2022). Enhancing cooperative responses by regional fisheries management organisations to climate-driven redistribution of tropical Pacific tuna stocks. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.1046018

Great Barrier Reef Foundation. (2024). *Reef restoration*. Available online at: https://www.barrierreef.org/what-we-do/projects/reef-restoration (Accessed 28 January 2024).

Groffman, P. M., Baron, J. S., Blett, T., Gold, A. J., Goodman, I., Gunderson, L. H., et al. (2006). Ecological thresholds: the key to successful environmental management or an important concept with no practical application? *Ecosystems.* 9, 1–13. doi: 10.1007/s10021-003-0142-z

Hazen, E. L., Scales, K. L., Maxwell, S. M., Briscoe, D. K., Welch, H., Bograd, S. J., et al. (2018). A dynamic ocean management tool to reduce bycatch and support sustainable fisheries. *Sci. Adv.* 4, eaar3001. doi: 10.1126/sciadv.aar3001

Hitchin, B., Smith, S., Kröger, K., Jones, D., Jaeckel, A., Mestre, N., et al. (2023). Thresholds in deep-seabed mining: A primer for their development. *Marine Policy*. 149, 105505–105505. doi: 10.1016/j.marpol.2023.105505

Hobday, A. J., and Hartmann, K. (2006). Near real-time spatial management based on habitat predictions for a longline bycatch species. *Fisheries Manage. Ecology.* 13, 365–380. doi: 10.1111/j.1365-2400.2006.00515.x

Hobday, A. J., Maxwell, S. M., Forgie, J., McDonald, J., Darby, M., Seto, K., et al. (2014). Dynamic ocean management: integrating scientific and technological capacity with law, policy, and management. *Stanford Environ. Law J.* 33:2, 125–165.

Hoegh-Guldberg, O., Poloczanska, E. S., Skirving, W., and Dove, S. (2017). Coral reef ecosystems under climate change and ocean acidification. *Front. Mar. Sci.* 4. doi: 10.3389/fmars.2017.00158

Holling, C. S., and Anderson, S. (1996). ""Dynamics of (dis)harmony in ecological systems"," in *Rights to nature*. Eds. S. S. Hanna, K. Folke and K. G. Mäler (Washington D.C.: Island Press).

Howell, E., Kobayashi, D., Parker, D., Balazs, G., and Polovina, J. J. (2008). TurtleWatch: a tool to aid in the bycatch reduction of loggerhead turtles Caretta caretta in the Hawaii-based pelagic longline fishery. *Endangered Species Res.* 5, 267–278. doi: 10.3354/esr00096

Hughes, T. P., Kerry, J. T., Álvarez-Noriega, M., Álvarez-Romero, J. G., Anderson, K. D., Baird, A. H., et al. (2017). Global warming and recurrent mass bleaching of corals. *Nature* 543, 373–377. doi: 10.1038/s41586-018-0041-2

Ingvaldsen, R. B., Assmann, K. M., Primicerio, R., Fossheim, M., Polyakov, I. V., and Dolgov, A. V. (2021). Physical manifestations and ecological implications of Arctic Atlantification. *Nat. Rev. Earth Environ.* 2, 874–889. doi: 10.1038/s43017-021-00228-x

IPCC (2021). *Climate change 2021 working group I contribution to the sixth assessment report of the intergovernmental panel on climate change*. Available online at: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf (Accessed 15 April 2024).

Johnson, F. A., Boomer, G. S., Williams, B. K., Nichols, J. D., and Case, D. J. (2015). Multilevel learning in the adaptive management of waterfowl harvests: 20 years and counting. *Wildlife Soc. Bull.* 39, 9–19. doi: 10.1002/wsb.518

Jones, P. J. S., Qiu, W., and De Santo, E. M. (2013). Governing marine protected areas: Social–ecological resilience through institutional diversity. *Marine Policy*. 41, 5–13. doi: 10.1016/j.marpol.2012.12.026

Klerk, B. E. (2021). From undermining to strengthening. *Int. J. Mar. Coast. Law* 38, 107–139. doi: 10.1163/15718085-bja10112

Kortsch, S., Primicerio, R., Fossheim, M., Dolgov, A. V., and Aschan, M. (2020). Climate change alters the structure of arctic marine food webs due to poleward shifts of boreal generalists. *Proc. R. Soc. B: Biol. Sci.* 282, 20151546. doi: 10.1098/rspb.2015.1546

Laffoley, D.d'A, Roe, H. S. J., Angel, M. V., Ardron, J., Bates, N. R., and Boyd, I. L. (2011). *The protection and management of the sargasso sea. Summary science and supporting evidence case*. Available online at: http://www.sargassoseacommission.org/storage/documents/Sargasso.Report.9.12.pdf. (Accessed 2 July 2024).

Lee, K. N. (2001). "Appraising adaptive management," in *Biological diversity*. Ed. L. E. Buck (Boca Raton: CRC Press).

Lenoir, J., and Svenning, J. C. (2014). Climate-related range shifts - a global multidimensional synthesis and new research directions. *Ecography* 38, 15–28. doi: 10.1111/ecog.00967

Lewison, R., Hobday, A. J., Maxwell, S., Hazen, E., Hartog, J. R., Dunn, D. C., et al. (2019). Dynamic ocean management: identifying the critical ingredients of dynamic approaches to ocean resource management. *BioScience* 65, 486–498. doi: 10.1093/biosci/biv018

Lindenmayer, D. B., and Likens, G. E. (2009). Adaptive monitoring: a new paradigm for long-term research and monitoring. *Trends Ecol. Evol.* 24, 482–486. doi: 10.1016/j.tree.2009.03.005

Luschi, P. (2013). Long-distance animal migrations in the oceanic environment: orientation and navigation correlates. *ISRN Zoology* 2013, 1–23. doi: 10.1155/2013/631839

Månsson, J., Eriksson, L., Hodgson, I., Elmberg, J., Bunnefeld, N., Hessel, R., et al. (2023). Understanding and overcoming obstacles in adaptive management. *Trends Ecol. Evol.* 38, 55–71. doi: 10.1016/j.tree.2022.08.009

Mate, B. R., Ilyashenko, V. Y., Bradford, A. L., Vertyankin, V. V., Tsidulko, G. A., Rozhnov, V. V., et al. (2015). Critically endangered western gray whales migrate to the eastern North Pacific. *Biol. Lett.* 11, 20150071. doi: 10.1155/2013/631839

Maxwell, S. M., Gjerde, K. M., Conners, M. G., and Crowder, L. B. (2020). Mobile protected areas for biodiversity on the high seas. *Science Policy Forum*. 367 (6475), 252–254. doi: 10.1126/science.aaz9327

Maxwell, S. M., Hazen, E. L., Lewison, R. L., Dunn, D. C., Bailey, H., Bograd, S. J., et al. (2015). Dynamic ocean management: Defining and conceptualizing real-time management of the ocean. *Mar. Policy* 58, 42–50. doi: 10.1016/j.marpol.2015.03.014

McLain, R. J., and Lee, R. G. (1996). Adaptive management: Promises and pitfalls. *Environ. Manage.* 20, 437–448. doi: 10.1007/BF01474647

Mehner, T., and Kasprzak, P. (2011). Partial diel vertical migrations in pelagic fish. *J. Anim. Ecol.* 80, 761–770. doi: 10.1111/j.1365-2656.2011.01823.x

MFSD. (2008). *Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy* . OJ L 164, 25.6 (Marine Strategy Framework Directive).

Ortuño Crespo, G., Mossop, J., Dunn, D., Gjerde, K., Hazen, E., Reygondeau, G., et al. (2020). Beyond static spatial management: Scientific and legal considerations for dynamic management in the high seas. *Mar. Policy* 122, 104102. doi: 10.1016/j.tree.2011.04.007

Ostrom, E., and Cox, M. (2010). Moving beyond panaceas: a multi-tiered diagnostic approach for social-ecological analysis. *Environ. Conserv.* 37, 451–463. doi: 10.1017/S0376892910000834

Oxford English Dictionary (2021) (Oxford University Press).

Petchey, O. L., Pontarp, M., Massie, T. M., Kéfi, S., Ozgul, A., Weilenmann, M., et al. (2015). The ecological forecast horizon, and examples of its uses and determinants. *Ecol. Letters.* 18, 597–611. doi: 10.1111/ele.12443

Peters, K. (2020). The territories of governance: unpacking the ontologies and geophilosophies of fixed to flexible ocean management, and beyond. *Philos. Trans. R. Soc. B: Biol. Sci.* 375, 20190458. doi: 10.1098/rstb.2019.0458

Poloczanska, E. S., Burrows, M. T., Brown, C. J., García Molinos, J., Halpern, B. S., Hoegh-Guldberg, O., et al. (2016). Responses of marine organisms to climate change across oceans. *Front. Mar. Sci.* 3. doi: 10.3389/fmars.2016.00062

Putman, N. (2018). Marine migrations. *Curr. Biol.* 28, R972–R976. doi: 10.1016/j.cub.2018.07.036

Quimby, B. (2023). ""Adaptive governance for marine environments: methods, challenges, and lessons for ocean fisheries"," in *Handbook on adaptive governance*. Ed. S. Juhola (Cheltenham: Edgar Elgar Publishing).

Rahmstorf, S. (2006). ""Thermohaline ocean circulation"," in *Encyclopedia of quaternary science*. Ed. S. A. Elias (Amsterdam: Elsevier).

Rist, L., Campbell, B. M., and Frost, P. (2012). Adaptive management: where are we now? *Environ. Conserv.* 40, 5–18. doi: 10.1017/S0376892912000240

Rocha, J., Biggs, R., and Peterson, G. (2014). *Regime Shifts: What are they and why do they matter*. Available online at: https://zahachtah.github.io/ItSS/assets/images/Regime_Shifts_Intro1.pdf (Accessed 15 April 2024).

Rosenberg, D. (2023). *The legal fight over deep-sea resources enters a new and uncertain phase* (EJIL: Talk!). Available online at: https://www.ejiltalk.org/the-legal-fight-over-deep-sea-resources-enters-a-new-and-uncertain-phase/ (Accessed 15 April 2024).

Sala, E., and Giakoumi, S. (2017). No-take marine reserves are the most effective protected areas in the ocean. *ICES J. Mar. Sci.* 75, 1166–1168. doi: 10.1093/icesjms/fsx059

Saros, J. E., Anderson, N. J., Juggins, S., McGowan, S., Yde, J. C., Telling, J., et al. (2019). Arctic climate shifts drive rapid ecosystem responses across the West Greenland landscape. *Environ. Res. Letters.* 14, 074027. doi: 10.1088/1748-9326/ab2928

Sguotti, C., and Cormon, X. (2018). "Regime shifts – A global challenge for the sustainable use of our marine resources," in S. Jungblut, V. Liebich and M. Bode eds. *YOUMARES 8 – Oceans Across Boundaries: Learning from each other*, 155–166. doi: 10.1007/978-3-319-93284-2_11

Simmons, B. I., Blyth, P. S. A., Blanchard, J. L., Clegg, T., Delmas, E., Garnier, A., et al. (2021). Refocusing multiple stressor research around the targets and scales of ecological impacts. *Nat. Ecol. Evol.* 5, 1478–1489. doi: 10.1038/s41559-021-01547-4

Sims, D. W., Southall, E. J., Tarling, G. A., and Metcalfe, J. D. (2005). Habitat-specific normal and reverse diel vertical migration in the plankton-feeding basking shark. *J. Anim. Ecology.* 74, 755–761. doi: 10.1111/j.1365-2656.2005.00971.x

Steele, J. H., Brink, K. H., and Scott, B. E. (2019). Comparison of marine and terrestrial ecosystems: suggestions of an evolutionary perspective influenced by environmental variation. *ICES J. Mar. Sci.* 76, 50–59. doi: 10.1093/icesjms/fsy149

Sutton-Grier, A. E., and Sandifer, P. A. (2018). Conservation of wetlands and other coastal ecosystems: a commentary on their value to protect biodiversity, reduce disaster impacts, and promote human health and well-being. *Wetlands* 39, 1297. doi: 10.1126/science.aai9214

Tanaka, Y. (2004). Zonal and integrated management approaches to ocean governance: reflections on a dual approach in international law of the sea. *Int. J. Mar. Coast. Law.* 19, 483–514. doi: 10.4324/9781315564678

Tittensor, D. P., Beger, M., Boerder, K., Boyce, D. G., Cavanagh, R. D., Cosandey-Godin, A., et al. (2019). Integrating climate adaptation and biodiversity conservation in the global ocean. *Sci. Adv.* 5, eaay9969. doi: 10.1126/sciadv.aay9969

Tompkins, E. L., and Adger, W. N. (2004). Does adaptive management of natural resources enhance resilience to climate change? *Ecol. Soc.* 9, 1–14. doi: 10.5751/ES-00667-090210

UNCLOS. (1994). (Montego Bay: United Nations Convention on the Law of the Sea). 1833 UNTS 3. Available at: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf.

UNEP-WCMC, IUCN and NGAS (2021). *Protected planet report 2020*. Available online at: https://livereport.protectedplanet.net/ (Accessed 9 November 2023).

UNFSA. (1995). *Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, New York, 4 August 1995 (adopted 4 August 1995, in force 21 December 2001) 2167 UNTS 3*.

Walker, B. H., and Salt, D. (2006). *Resilience thinking: sustaining people and ecosystems in a changing world* (Washington, DC: Island Press).

Walters, C. (1986). *AM of renewable resources* Vol. 7 (London: Collier Macmilian Publishers).

Walters, C. J. (2010). *Adaptive management of renewable resources* (Caldwell, N.J: Blackburn Press).

Westgate, M. J., Likens, G. E., and Lindenmayer, D. B. (2013). Adaptive management of biological systems: A review. *Biol. Conserv.* 158, 128–139. doi: 10.1016/j.biocon.2012.08.016

Westholm, A., and Argüello, G. (2024). Dynamic ocean management in areas beyond national jurisdiction. *Ocean Dev. Int. Law* 4, 1–21. doi: 10.1080/00908320.2023.2296392

Williams, B. K. (2011). Adaptive management of natural resources—framework and issues. *J. Environ. Management.* 92, 1346–1353. doi: 10.1016/j.jenvman.2010.10.041

Young, O. R. (2002). *The institutional dimensions of environmental change* Vol. 19 (Cambridge: The MIT Press).

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 29 July 2024
DOI 10.3389/fmars.2024.1405157

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
University of International Business and Economics, China

REVIEWED BY
Zafar Ullah,
Lasbela University of Agriculture, Water and Marine Sciences, Pakistan
Chao Fan,
Zhejiang Ocean University, China

*CORRESPONDENCE
Dahai Liu
liudahai@fio.org.cn

RECEIVED 22 March 2024
ACCEPTED 15 July 2024
PUBLISHED 29 July 2024

CITATION
Li Y, Wang Y, Liu D and Hou Y (2024) Connotation analysis and path discussion of China's land-sea coordination policy: based on the interregional externality theory. *Front. Mar. Sci.* 11:1405157. doi: 10.3389/fmars.2024.1405157

COPYRIGHT
© 2024 Li, Wang, Liu and Hou. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Connotation analysis and path discussion of China's land-sea coordination policy: based on the interregional externality theory

Yanping Li[1,2], Yuping Wang[3], Dahai Liu[1]* and Yuting Hou[1]

[1]First Institute of Oceanography, Ministry of Natural Resources, Qingdao, Shandong, China, [2]College of Environmental Science and Engineering, Ocean University of China, Qingdao, Shandong, China, [3]School of Economics and Resource Management, Beijing Normal University, Beijing, China

As two spatial geographic units that are both independent of each other and closely linked, the land and sea have complex spatial interactions. Therefore, China implements the land-sea coordination policy (LSC) needs to be approached from a more macroscopic, systematic and comprehensive perspective. Based on the interregional externality theory, this study takes the land-sea coordination policy of China as an example, and focuses on the interaction process and manifestation between land and sea, and then explores the connotation and realization path of LSC. Firstly, we delineated the spatial unit and analyzed the land-sea interactions (LSI) using Vensim software. Secondly, the characteristics and manifestations of LSI are summarized from the perspective of interregional externalities. Finally, this study elucidates the foundational concept of implementing LSC and further propose actionable pathways for promoting land and sea development in a coordinated way, aimed at offering supportive decision-making insights for achieving LSC within the broader framework of China's territorial spatial planning. Initiating LSC implementation involves strategies such as source control, process management, and interaction interface optimization. Deepening LSC effectiveness entails strengthening positive interregional externalities while mitigating negative interregional externalities.

KEYWORDS

interregional externality, China's land-sea coordination (LSC), land-sea interactions (LSI), connotation analysis, path discussion

1 Introduction

The coastal zone is the important spatial intersection of the land and the sea, and has gradually developed into an area with the greatest potential for economic and social development, due to its unique conditions in terms of resources, climate, transportation and the human environment (Li et al., 2021). However, along with the rapid economic and social development of coastal areas, the development and utilization of coastal zones in recent decades have gradually shown the characteristics of high intensity, complexity and diversification, which has triggered a series of problems such as damage to ecosystems, coastal erosion, reduction of biodiversity, pollution of the marine environment and insufficient supply of resources. Although China's central and local governments have been exploring optimal integrated coastal zone management models for a long time, the dichotomous governance of land and sea has become a key constraint to the improvement of spatial governance capacity in the region. In 2018, the Chinese government established the Ministry of Natural Resources (MNR) to unify the exercise of spatial management responsibilities for both land and sea, and carried out reforms of the territorial spatial planning, realizing the unified compilation and implementation of spatial planning for both land and sea. Against this background, the concept of the land-sea coordination policy (LSC) has received widespread attention from government administrations and planning academies, expecting that territorial spatial planning based the concept of LSC will help improve the comprehensive management capacity of the coastal zone and the high-quality development of the coastal regions.

With the rapid development of the marine economy, the concept of marine spatial governance and the land-sea coordination extended therefrom have begun to receive the attention of Chinese academics and management departments. In 2010, the Chinese Government introduced the concept of "land-sea coordination (LSC)" for the first time. In a narrower sense, LSC pertains to the integrated planning and allocation of resources, production factors, and other elements across both terrestrial and maritime domains. This aims to achieve effective alignment between land policies and ocean policies. In a broader sense, LSC encompasses comprehensive coordination across dimensions such as economic development, social and cultural progress, environmental sustainability, resource management, transportation infrastructure, urban governance, and other related areas (Han and Li, 2015). The connotation of LSC implies the distinctive features and inherent requirements of unity, wholeness, coordination and three-dimensionality, which is an all-round and high-level strategic thinking (Li et al., 2022). Over the past decade, "land-sea coordination (LSC)" has ascended to the status of a national strategy in China, garnering increasing attention from scholars. There has been a growing recognition of LSC' s constructive impact in safeguarding territorial spatial security, optimizing the pattern of territorial spatial development and protection, and fostering high-quality development of the national economy. Consequently, there has been a profound exploration into the essence of LSC, the economic interplay between land and sea, the preservation of land and sea ecosystems, and the integrated management of coastal areas (Makino et al., 2013; Zaucha et al., 2016; Caviedes et al., 2020). However, at this stage, the fragmented governance of land and sea management sectors still restricts the realization of LSC. Until 2018, the formation of the Ministry of Natural Resources laid the organizational foundation for the further deepening of LSC. In 2019, Chinese Government initiated the compilation of land spatial planning and marine spatial planning within a unified framework, wherein LSC has become the fundamental principle guiding the compilation of China's national territorial spatial planning in coastal regions. Scholars began to pay attention to the theoretical basis, methodological innovation and practical application of LSC in the field of territorial spatial planning (Zaucha and Jay, 2022; Baker et al., 2023; Qu et al., 2023; Yao et al., 2023).

At the international level, integrated coastal zone management (ICZM), which originated in the 1970s, embodies the idea of unified management of land and marine resources and the realization of synergistic development of land and sea. ICZM focuses on the formulation of management strategies, the evaluation of management effects, the management model, and public participation in the management process, etc., and its objectives, contents, and means of implementation are richer and the system is more complete than that of the LSC (Halpern et al., 2009; Ngoran and Xue, 2015; Khelil et al., 2019; Brooks et al., 2022). During the same period, research on LSI was initiated in various countries around the world. LSC was first proposed by the field of natural sciences to reveal the effects of changes in various parts of the Earth system on the coastal zone in order to scientifically evaluate changes in the coastal zone due to human impacts (Wilkinson et al., 1997; Poulos et al., 2000; Matear and Wang, 2010). At the beginning of the 21st century, the research on LSI was extended to the field of marine spatial planning, which began to emphasize the interaction between coastal zones and human activities as well as the integrated management of the land and the sea (Vanclay, 2012; Pinillos et al., 2023; Hua et al., 2024). The relevant theories and technical methods have been widely practiced in many countries, which has improved the scientific nature of coastal zone management and marine spatial planning (Reis et al., 2014). For example, the California state in the United States has implemented classified management of spatial units with different functions in coastal areas, and the United Kingdom has integrated unified management of land-sea interfaces by defining the boundaries between land spatial planning and marine spatial planning (Smith et al., 2011; Turner and Essex, 2016). There exists a notable alignment between LSI and LSC in their mutual concern for the dynamic interconnection between land and sea. Stemming from the realm of natural sciences, LSI underscores the scientific rigour of planning methodologies, the procedural soundness, and the utilization of findings from natural sciences research in planning endeavors.

In addition to spatial planning, scholars have also explored the implementation path of LSC from the aspects of total pollutant control, coastal industrial layout, and land-sea transportation system (Guan et al., 2016; Li et al., 2018; Ren et al., 2024; Jung and Thill, 2022). In terms of research on total pollutant control, rapid socio-economic development has led to a continuous increase in the total amount of land-based pollutants discharged from the land space to the sea space. Since the 1970s, scholars both domestically and internationally have made notable advancements in various aspects concerning coastal areas. These include the assessment of overall

land-based pollutant quantities, the development of methodologies and technologies for allocating pollutant discharge quotas, the advancement of pollutant emission reduction technologies, and the remediation of marine environmental pollution (Huang et al., 2013; Pantusa et al., 2023; Guggisberg, 2024). In terms of coastal industrial layout, in-depth studies have been conducted on the measurement of the level of land-sea economic integration, the layout of coastal industries, and the assessment of the ecological impact of coastal industrial development (Hsieh and Li, 2009; Mejjad et al., 2022; Ni et al., 2024). In addition, the land and sea transportation system is an important node connecting land space and sea space. Scholars have focused on the measurement of the effectiveness of port transportation development in the coastal zone, the evaluation of spatial suitability and optimization of its regional pattern, the planning of shipping routes, and the control of flow in coastal ports from the perspective of multidisciplinary and multifactorial research (Saeidpour et al., 2019; Zhang et al., 2023; Chen et al., 2024).

In conclusion, China's exploration of LCS centers on conceptual frameworks, underlying meanings, and tailored planning initiatives. Internationally, while there lacks a precise definition or terminology for land-sea integration, concepts like ICZM and LSI posited by foreign scholars similarly advocate for the amalgamation of land and marine resource management, aiming at synergistic development of both domains. Nevertheless, existing research outcomes in these domains predominantly concentrate on legal frameworks, policies, procedural methodologies, among other aspects. The complexity of various types of spatial activities in the coastal zone area and the intertwining, integration and mutual influence of various connections make it difficult for researchers to research the LSC from the perspective of a single scale, a single process or a single dimension. There is an imperative to develop a robust and pragmatic theoretical analytical framework for the examination of LSC, aiming to comprehensively address inquiries concerning its theoretical underpinnings, scope, technical methodologies, and other pertinent aspects. This study introduces the interregional externality theory, analyzes the whole process and manifestation of the interaction between the two major spaces of the land and the sea at the macro level, focuses on the effects and characteristics of the interaction between different functional spatial units at the meso level, and researches the dynamic relationship between the spatial utilization activities and the natural environment in each region at the micro level. Building upon this foundation, the study delves into a comprehensive examination of the connotation and the implementation path of LSC, aiming to offer guidance for integrating economic development and ecological preservation in coastal zones. The overall research framework of the article is shown in Figure 1.

2 Theoretical foundation: the interregional externality theory

2.1 Interregional externality theory: concept and formation conditions

The externality is the important economic concepts, introduced by the British welfare economist Pegu. It refers to an economic activity of an individual or group that imposes unreimbursed benefits or unrecoverable costs on other individuals or groups. The unreimbursed benefits are called positive externalities, while the unrecoverable costs are called negative externalities. As an open system, regional development is bound to have a positive or negative impact on other regions in accordance with the law of geographical diffusion (Duan et al., 2010; Lu, 2011; Lu et al., 2018). Therefore, the externalities theory is one of the important analytical tools in research in the fields of economic geography and regional economics, where the region is the object of study (Han and Ke, 2013; Ren et al., 2021). Due to the hierarchical and spatially differentiated nature of economic activities and their environmental impacts, externalities exhibit distinct ecological, economic, social, and other characteristics across varying spatial scales. Externalities can be categorized into intra-regional externalities and inter-regional externalities according to the spatial scope of influence. Intra-regional externalities are the effects of economic activity within a region on itself, while inter-regional externalities are the effects of economic activities within a region on other regions. If the effect of interregional externalities are positively contributing, it is called positive interregional externalities(PIE), and vice versa, it is called negative interregional externalities(NIE) (The criteria for determining "positive impact" and "negative impact" are shown in the Appendix 1). Interregional externalities primarily occur at the micro-spatial scale, reflecting the impact of specific spatial utilization activities on the local natural environment. When this impact extends to broader geographical areas, it manifests as interregional externalities. At the mesoscale, interregional externalities are chiefly shaped by spatial interactions among adjacent regions. At the macroscale, these externalities involve interactions among geospaces comprising multiple regions sharing similar attributes, highlighting broader and more integrated spatial dynamics. Internationally, interregional externalities are often referred to as regional externalities or spatial externalities, which are used to study the interactions between geographic elements with distinct spatial characteristics and to explain phenomena such as industrial clusters, industrial networks, globalization and open environmental economic systems (Bagella et al., 2004; Heijman, 2007; Sunley, 2008). Most of Chinese scholars have mainly applied the interregional externality theory to the study of ecological compensation in subjective function zoning and the coordination of urban cluster development, while few scholars have paid attention to the process and characteristics of the LSI from the perspective of externalities. The interregional externatilities theory synthesizes the disciplinary strengths of geography and economics, grounded in the geographical realities of development and utilization activities in land space and sea space. By meticulously analyzing the dynamics of geographic elements, this theory explores the processes, characteristics, patterns, and extents of their interactions. Furthermore, it recommends remedial strategies and methodologies based on economic property rights theory and public regulation theory to tackle externalities. This approach seeks to thoroughly elucidate the economic linkages and environmental ramifications between land space and sea space, thus offering a stronger theoretical basis for the effective implementation of China's LSC policy.

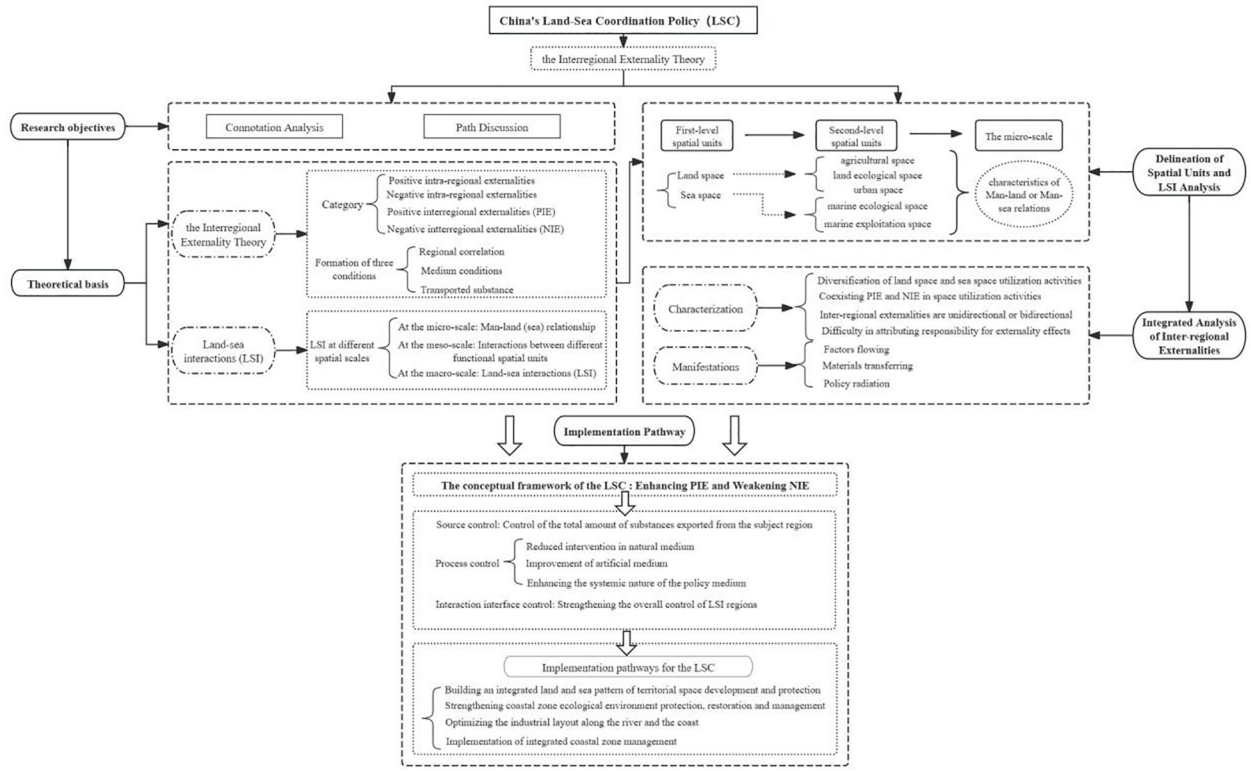


FIGURE 1
Research Framework.

It can be seen that interregional externalities are based on regional spatial interactions. A region is a synthesis of various elements (including natural and human elements), geographical processes and human activities within a specific spatial scope, and its spatial characteristics and functions show significant differences depending on the scale. In the process of economic and social development, spatial activities between different regions are not isolated, but uninterrupted exchanges and interactions of energy, information, people and other elements. Therefore, the externalities of regional spatial activities not only affect the direction of spatial development in this region, but also profoundly influence the natural environment and economic and social patterns of different regions within a larger spatial scale. From the perspective of spatial interactions, the formation of interregional externalities requires the fulfillment of three necessary conditions, including regional correlation, medium conditions and transported substance (Stouffer, 1940).

2.1.1 Regional correlation

Regional correlation is the basis on which spatial interactions between regions arise. Different regions may be interconnected in terms of industrial development, resource utilization, ecological processes, environmental impacts and so on. In the process of spatial interaction, it can be assumed that the exertor of the "external effect" is the subject region and the recipient of the "external effect" is the receptor region. Moreover, according to the spatial interaction theory, the closer the spatial distance, the easier it is for matter, energy and information to flow and spread in a shorter period of time, and the closer the regional ties.

2.1.2 Medium conditions

Medium conditions are the vehicle that connects two or more different regions. It is difficult to make connections between regions that lack medium connections. From the perspective of regional development, medium conditions can be categorized into natural medium (e.g., rivers, atmosphere, seawater, raining, etc.), artificial medium (e.g., pipelines, roads, channel, sea-crossing bridge, railway, artificial river channel, etc.) and policy medium (e.g., laws, regulations, policy documents, plannings, etc.) (Shown as Figure 2). The medium moves in different directions, which determines the direction of evolution of interregional externalities.

2.1.3 Transported substance

The transported substance is the specific elements of matter, energy, and information taken by different medium. Under normal conditions, the type and quantity of transported substance are in a relatively stable state. When there is a sudden change in the amount or type of transported substance, it can easily lead to the movement of the transported substance across the region, thus creating the phenomenon of interregional externalities. This sudden change is usually caused by the subject region and is also a trigger for changes in the receptor region.

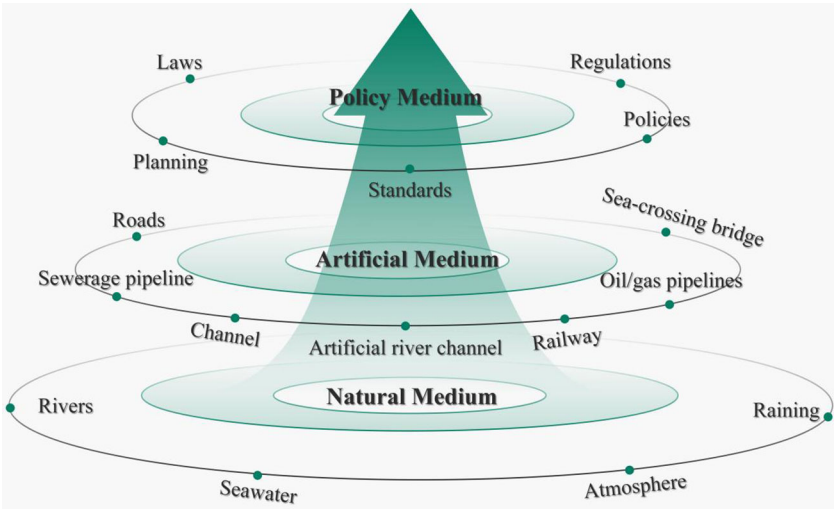


FIGURE 2
Types of mediating conditions for interregional externalities.

2.2 The fit between the interregional externality theory and LSC

The land and the sea are both independent of each other and closely linked, with very different functional positioning, development needs and resource and environmental carrying capacities. Land and marine ecosystems have established a dynamic equilibrium system over long-term evolutionary processes, facilitated by the circulation of materials and energy flows. Within the ecological carrying capacity, land and sea spaces can foster a synergistic relationship. Marine environments, rich in untapped resources, complement the resource diversity of land space, thereby mitigating land resource scarcity. Conversely, advanced technologies, systems, and human capital from terrestrial domains can contribute to the sustainable development and utilization of marine environments. When land space and sea space are viewed as distinct domains of interest, a competitive relationship between land space and sea space becomes apparent. This competition manifests across multiple dimensions including spatial development trajectories, resource utilization, ecological conservation, environmental governance, and other facets. In practice, LSI includes both interactions based on natural processes (e.g., sediment transport in rivers, storm surges, saltwater intrusion, etc.) and interactions dominated by human activities (e.g., pollutant discharges to the sea, construction of coastal projects, ecological protection and restoration of coastal zones, etc.). More complexly, the above interactions processes between land and sea are intertwined, integrated and mutually influential, together shaping the natural environment and economic and social patterns of the coastal zone area (Shown as Figure 3). LSI are not only vertical linkages between land space and sea space, but also imply horizontal linkages between different types of space within land or sea space (Li et al., 2021). Furthermore, the interaction between land space and sea space is marked by the simultaneous presence of both positive and negative externalities, which requires systematic consideration of the natural processes and the economic development between the land and the sea, as well as harmonized management on that basis. Therefore, the study of LSC should not be limited to the interaction of the two spatial geographic units of land and sea, but should also take into account the interaction of different types of space within the independent space of land or sea.

Intra-regional externalities and inter-regional externalities characterize LSI at different spatial scales, respectively. Intra-regional externalities are mainly concerned with the dynamic relationship between various types of spatial utilization activities and the natural environment at the micro scale, which is the cause of spatial interactions. Inter-regional externalities are concerned with the effects of different functional spatial units at the meso-scale on the one hand, and between land and sea at the macro-scale on the other hand (Shown as Figure 4). This coincides with the need for research on different spatial scales and different types of spatial activities for China's territorial spatial planning.

Therefore, the interregional externality theory can provide an effective research paradigm for land and sea integrated territorial spatial planning, so as to avoid planning research being limited to a single process and a single scale. Under the framework of the interregional externality theory, analyzing the issue from the perspectives of spatial linkages, medium conditions and transported substance between the subject and receptor regions will help to clarify the process of LSI and their manifestations. This contributes to a holistic understanding of the causes and processes of the phenomenon of interregional externalities between land and sea, and leading to a deeper understanding of the key demands and tasks of China's LSC policy.

3 Delineation of spatial units and analysis of spatial interactions

Combined with the previous analysis, to explore LSC based on the interregional externality theory, it is necessary not only to

10.3389/fmars.2024.1405157



Note:

①Discharge of industrial wastewater and domestic sewage from the urban space to rivers through sewerage pipelines;

②Pollution of groundwater by overuse of pesticides and fertilizers in the agricultural space;

③Emissions of polluting waste gases into the atmosphere from the urban space;

④Dispersion of air pollutants;

⑤Absorption of atmospheric pollutants by plants in the ecological space;

⑥Dispersal of air pollutants causing air pollution in other spaces;

⑦Atmospheric pollutant deposition (rainfall, etc.);

⑧Over-exploitation of groundwater in the urban space;

⑨Sewage from coastal urban spaces is discharged directly into the sea;

⑩Saltwater intrusion; Seawater intrusion into adjacent land spaces;

⑪Port construction;

⑫Aquaculture;

⑬Maritime transportation;

⑭Marine ecosystems;

⑮Sea reclamation;

⑯Construction of sea bathing beaches and coastal scenic areas, etc.;

⑰Upward movement of air currents such as evaporation;

⑱Offshore engineering operational activities;

⑲Radiation of policy effects

FIGURE 3
Typical manifestations of LSI.

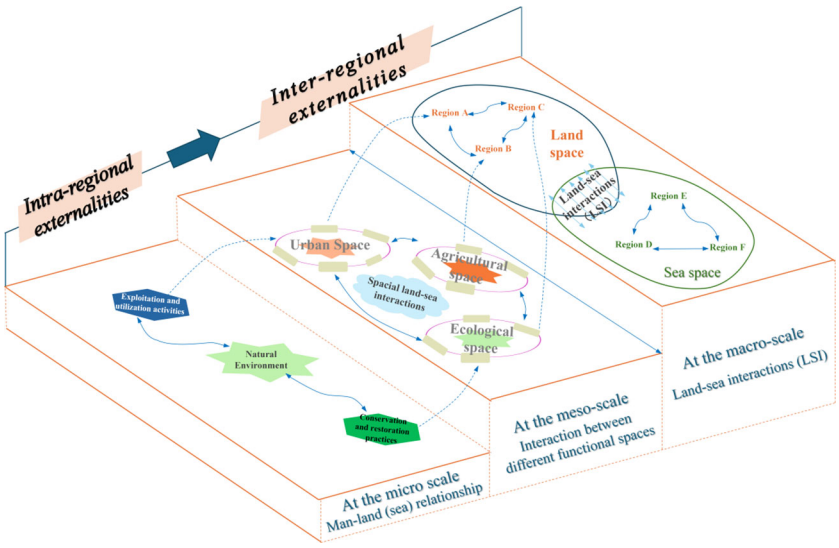


FIGURE 4
LSI at different spatial scales.

consider the effects of spatial utilization activities within the region on the natural environment at the micro-scale, but also to fully explore the process of interactions and their characteristics between different spatial types at the meso-scale, and to analyze the pattern and form of LSI at the macro-scale on this basis. Therefore, the rational division of spatial units is the basic premise for analyzing LSI. Combined with the practice of territorial spatial planning, this study firstly delineates the two first-level spatial units of land space and sea space at the macro scale. At the meso-scale, land space is divided into three types of second-level spatial units, namely, agricultural space, land ecological space and urban space, and sea space is divided into two types of second-level spatial units, namely, marine ecological space and marine exploitation space (consisting of fishery space, industrial, mining and communications space, transportation space, recreational space, special sea-use space, etc.). At the micro-scale, this study focuses on the characteristics of man-land or man-sea relations in the implementation of various types of spatial activities.

China's LSC policy is mainly applied to cross-regional resource and environmental issues (especially the interregional externalities of land-sea junction zones), and since the forms, intensity, elements, subjects and impacts of utilization activities vary, it is difficult to fully clarify the LSI by the enumeration method alone. China's LSC policy is characterized by its global and comprehensive characteristics. Starting from a systemic thinking will help to better clarify the manifestation of intra-regional externalities and the formation process of interregional externalities in each spatial unit. Reconceptualizing the complex spatial utilization activities occurring within land space and sea space as interactions among various spatial units enhances the precision of interpreting the essence of the LSC policy. This study applies the concept of system dynamics and uses Vensim software to create a flow diagram that illustrates the dynamics of LSI. By integrating the components of the Vensim flow diagram with the characteristics, of each spatial unit, including functions, intra-regional externaltities or interregional externaltities, we aim to uncover the key factors influencing the man-land (sea) relationship, and to simplify the complex interactions between these spatial units. (Shown as Table 1). The analysis reveals that intra- and inter-regional externalities are intertwined, interdependent and mutually constraining, forming an intricate spatial interaction between land space and sea space (Shown as Figure 5).

3.1 Land spatial units

3.1.1 Agricultural space

Agricultural space includes subdivided unit types such as rural development space and farmland protection space. Agricultural space has multi-dimensional functions such as arable land protection, agricultural development, farmers' life and modern rural construction. Through agricultural production activities such as cultivation of arable land, animal husbandry, freshwater aquaculture, and development of economic forests, the development of primary industries such as agriculture, forestry, animal husbandry, and fisheries can contribute to the sustained supply of agricultural products needed for the daily lives of human beings and other organisms from agricultural space to other spatial units, thus creating PIE. At the same time, the excessive use of pesticides, fertilizers and chemicals will cause land pollution and a decline in soil fertility in the agricultural space, thus creating negative intra-regional externalities. This part of agricultural

TABLE 1 Analysis of LSI in China based on Vensim system flow diagrams.

Spatial units	The core functions of spatial units (Horizontal variables)	China's intra-regional exploitation activities (Input variables)	China's interregional externalities (Output variables)
Agricultural space	Agricultural production and rural livelihoods	Expansion of urban construction area; emission of pollutants from the development of agriculture, forestry, animal husbandry and fisheries; rural livelihoods, etc.	Decrease in the area of arable land resulting in insufficient supply of agricultural products for the livelihood of urban space dwellers; land contamination and decline in soil fertility due to pollutant emissions, etc.
Land ecological space	Ecological goods production and ecological services	Delineation of the red line of ecological protection and strict limitation of development and utilization; ecological protection and restoration, etc.	Purify air; conserve water; reduce soil erosion, etc.
Urban space	Promoting economic and social development	Industrial production; urban construction; mining; transportation; urban living, etc.	Atmospheric pollution caused by industrial and transportation emissions; pollution of rivers or offshore waters caused by domestic and industrial wastewater discharges; destruction of soil structure by groundwater mining, etc.
Marine exploitation space	Development of the sea-based economy (within the carrying capacity of the marine environment)	Mariculture; marine transportation; port construction; land reclamation; coastal tourism; marine sand mining, etc.	Seawater inundation, saltwater intrusion into adjacent land spaces; seawater pollution; damage to marine biodiversity, etc.
Marine ecological space	Marine ecological environment protection, marine biodiversity conservation and marine ecological services, etc.	Delineation of the red line for the protection of marine ecology and strict restrictions on utilization; protection and restoration of marine ecology, etc.	Maintaining climate stability; protecting biodiversity; rehabilitating marine ecosystems, etc.

The spatial units shown in Table 1 are delineated according to China's land spatial planning practice, and the intra-regional and interregional externalities shown are mainly for China, which is conducive to a more accurate understanding of China's LSC policy.

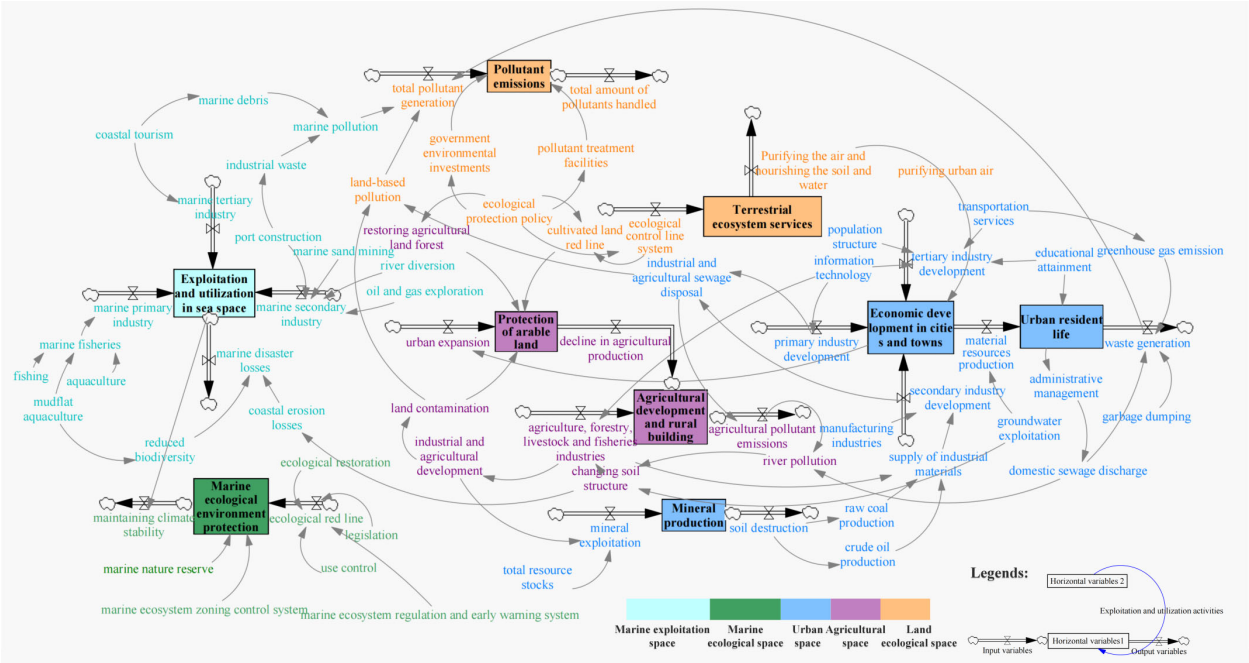


FIGURE 5
System dynamics flow diagrams for land space and sea space utilization activities.

pollutants will be discharged into the neighboring rivers and aquifers, and eventually pollutants will be transported to the sea space, forming NIE.

3.1.2 Land ecological space

Land ecological space includes subdivided unit types such as ecological protection space and ecological control space. Land ecological space is used to protect terrestrial space with special important ecological functions or ecological sensitivity and fragility, as well as the need to preserve the original form and strengthen ecological conservation. Within the land ecological space, through afforestation, pollutant emission control, ecological restoration and the construction of nature reserves, it is possible to restore and protect land natural areas with special important ecological functions or ecologically sensitive and fragile areas in this space. These measures can keep terrestrial ecosystems in a relatively stable state, further exerting their functions of water and soil conservation and air purification, and creating positive intra-regional externalities. Moreover, land ecological space can continuously deliver ecological products and services to other spatial units through surface runoff and atmospheric movement, promoting the improvement of ecological environment quality in other spatial units and forming PIE.

3.1.3 Urban space

The urban space has economic and social development as its core function, and is a centralized area for industrial agglomeration, energy development and population movement. Within the urban space, various types of human development and utilization activities to promote the economic development of towns and cities can be categorized as the development of primary, secondary and tertiary industries. The development of these three major industries creates a steady flow of material resources for urban residents to support the normal functioning of human society and the upgrading of urban development. However, this process also generates a large amount of waste such as domestic garbage, industrial solid waste, greenhouse gases, industrial sewage, etc., which damages the ecological environment of the city and the livable space for the residents, thus creating negative intra-regional externalities. When the total amount of waste exceeds the maximum capacity of the urban pollutant treatment system, the pollutants will be transported to the sea space along with atmospheric deposition and river movement, causing pollution of the near-shore environment and destruction of coastal landscapes, thus forming NIE.

3.2 Sea spatial units

3.2.1 Marine exploitation space

Marine exploitation space is an important area for the development of the marine-based economy, carrying multiple uses such as seawater aquaculture, marine transportation, industrial and mining exploitation, and leisure and recreation. Within the maximum carrying capacity of the marine environment, the utilization of marine resources can provide a supply of resources and space for the development of land space when land-based resources are close to being scarce. At the same time, space utilization activities for ocean development and exploitation can be carried out more efficiently owing to the advantages of land space, such as advanced technology, mature planning policies and strong financial resources. As a result, the

land and sea economies interact positively, creating positive intra-regional externalities. However, if the scale and intensity of the use of the sea area continue to expand, it will cause serious damage to the marine ecological environment, thus forming negative interregional externalities. Marine pollutants will cause varying degrees of disturbance to coastal land space through natural processes such as seawater movement and atmospheric deposition, creating NIE.

3.2.2 Marine ecological space

Marine ecological space consists of marine ecological protection space and marine ecological control space. It is used to protect marine spaces that have ecological functions of special importance or are ecologically sensitive and vulnerable, and that require preservation and enhanced ecological conservation. Within the marine ecological space, to prevent irreversible deterioration of the marine ecological environment as a result of the increased intensity of human utilization activities and the excessive discharge of pollutants through the delineation of a red line for the protection of marine ecology, and to further protect marine biodiversity. Damaged marine ecosystems can be restored through the establishment of marine nature reserves, the implementation of ecological restoration, and the strengthening of marine ecosystem regulation and early warning capabilities, thereby preventing and mitigating marine environmental disasters and environmental accidents, harmonizing the relationship between marine utilization activities and marine environmental protection, then creating positive externalities within marine ecological space areas. Further, actively exploiting the effective role of marine ecosystems in stabilizing the climate and sequestering and reducing carbon can improve the climate environment in both land and sea space at a macro-scale level, forming PIE.

4 Integrated analysis of interregional externalities in coastal zones

4.1 Characterization of interregional externalities in coastal zone

Combined with the results of the analysis of the system dynamics flow diagram, it can be seen that different spatial units interact with each other through various types of medium to form PIE or NIE, which are characterized as follows:

4.1.1 Diversification of land space and sea space utilization activities

There are significant differences between land space and sea space in terms of natural environment, material composition, spatial structure, etc. Combined with Figure 4, it can be found that the interregional externalities of land space and sea space have different manifestations in terms of resources, ecology, environment, industry, etc., which directly leads to the diversified characteristics of the utilization activities of land space and sea space. The forms of space utilization activities have diversified characteristics. Since the coastal zones are the main area of frequent material exchange and energy flow between land space and sea space, and utilization activities with different intensities, natures and types are carried out there. The object of spatial planning includes both the various types of space utilization activities and the spatial carriers of these activities and natural elements. This means that exploring LSI from the perspective of territorial spatial planning requires comprehensive consideration of the spatial linkages between land-sea natural processes and human activities.

4.1.2 Coexisting positive and negative externalities in space utilization activities

Land space and sea space have different functional positions and interest orientations. For different space units, the same space utilization activity may have both positive and negative externalities. When the functional orientation of a space unit is compatible with the purpose of a space utilization activity, the space utilization activity creates a positive externality for the space unit, and vice versa, a negative externality. For example, land reclamation can have PIE for urban space by allowing them to expand their land area without incurring additional costs. However, land reclamation imposes unrecoverable costs on marine ecological space, thus creating NIE in marine ecological space.

4.1.3 Interregional externalities are directional

Depending on the direction of factor movement, interregional externalities take the form of unidirectional or bidirectional. An interregional externalities is bidirectional if the subject region affects the receptor region while at the same time responding to changes in the receptor region. Conversely, if the subject region will not be disturbed by the receptor region, the interregional externalities is expressed as unidirectional. For example, the formation process of land-based sources of pollution is a unidirectional process, where the subject region is the urban space and agricultural space, and the receptor area is the ocean space. In contrast, the interaction between land-based industries and marine-based industries is a two-way process, with marine-based industries being both subject and receptor regions, as is the case with land-based industries.

4.1.4 Difficulty in attributing responsibility for externality effects

In general, administrative boundaries, functional area boundaries and geographical boundaries do not overlap. Physical geographic processes often span multiple administrative units or functional area types. This leads to an inability to accurately define the attribution of responsibility for externality effects when interregional externalities occur. For example, when pollution from socio-economic activities in land space spreads to sea space, it is often not the land space alone that bears the responsibility for pollution management, but the sea space also has to bear the huge cost of environmental management.

4.2 Manifestations of interregional externalities in coastal zone

Interregional externalities are essentially the existence of uninterrupted exchanges of various elements between spatial units, such as matter, energy, information, etc., which are transmitted through different types of medium. Therefore, this study classifies interregional externalities into three forms of factors flowing, materials transferring and policy radiation based on medium characteristics (Shown as Figure 6 and Table 2).

4.2.1 Factors flowing

Factors flowing is the interactions between land space and sea space through natural medium. Common forms of factor flows in land and sea space include the atmospheric cycle, the water cycle, etc. The above processes are mediated by natural processes such as rivers, atmosphere, precipitation, etc., which cause spillovers of intra-region externalities generated in the land (sea) space to the sea (land) space. For example, the excessive use of fertilizers in agricultural space will cause some nitrogen and phosphorus compounds to be discharged into the sea with rivers or rainwater, resulting in eutrophication of sea water and red tides, and ultimately creating NIE. Planting trees in the ecological space enables a large number of tree species to produce a large amount of oxygen through photosynthesis, and the surplus oxygen in the ecological space spills over to the surrounding urban space, thus greatly improving the air quality of the urban space and forming PIE.

4.2.2 Materials transferring

Materials transferring is the interactions between land space and sea space through artificial medium. Common forms of materials transferring include the transportation of goods through transportation infrastructure such as railroads, roads, ports, etc., or the discharge of sewage and the transport of oil and gas resources through pipelines, etc. Land and marine transportation infrastructure together constitute a comprehensive three-dimensional transportation network, which greatly promotes the extension of the marine-based industry chain to the land, forming a clear trend of land and marine industry linkage. This allows regions that are not directly adjacent to each other in terms of geographic location to transfer spatial effects across regions without the need for the natural medium. It not only accelerates the transformation of intraregional externalities into interregional externalities, but also makes the form of interactions between spatial units more complex. The construction of various sewage pipes also enables pollutants in urban space to be easily transferred to the sea space, resulting in marine ecological pollution and the formation of NIE.

4.2.3 Policy radiation

Policy radiation is the interactions between land space and sea space through the policy medium of laws, regulations, policies, plans, etc. Policy changes within a region may alter the goals, direction and mode of spatial development of this region, which in turn may have spatial effects on other regions through natural or artificial medium. For example, with the increasing scarcity of land resources, the Chinese government has imposed strict controls on arable land resources, strictly controlling the area of arable land that has been converted to construction land. In this context, in order to expand development space, coastal areas acquire land resources through reclamation and other means, thus causing serious harm to the marine resources and environment, which is reflected in NIE. Another example is that the Chinese government has implemented

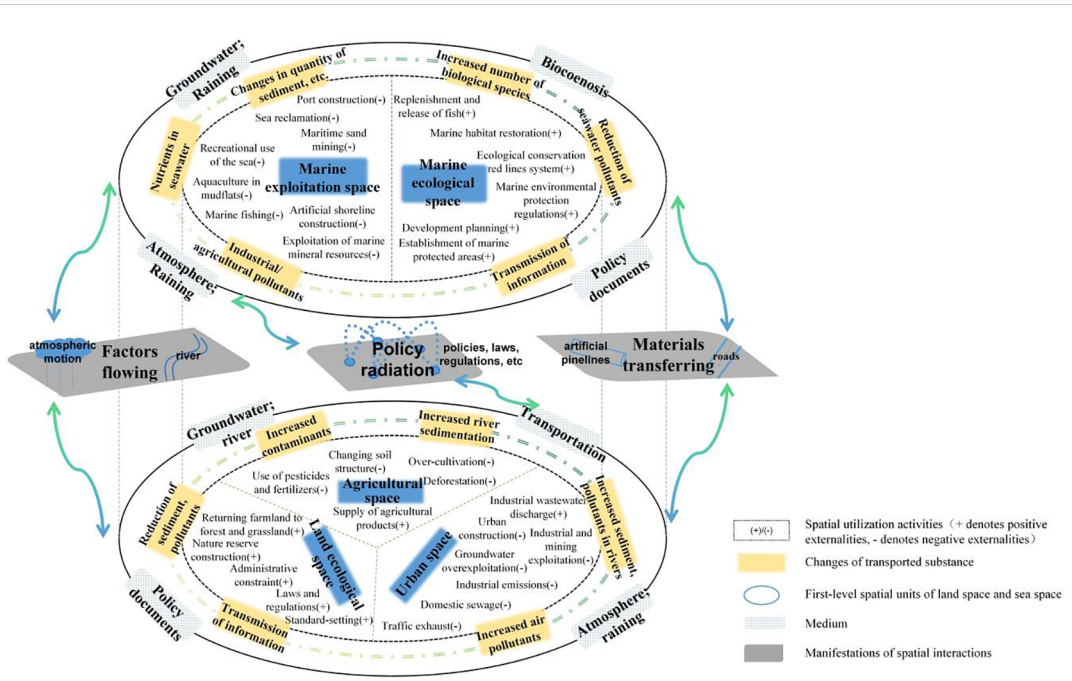


FIGURE 6
Typical manifestations of LSI.

TABLE 2 Main processes of LSI.

Manifestations of interregional externalities	Main activities	Transported substance	Medium	Type of interregional externalties	The practical implications of interregional externalties	The subject region	The receptor region
Factors flowing	Vegetation destruction	Dirt and sand	Rivers, rainfall, etc.	Negative externalties	Soil erosion, increased sand content in rivers; Silt accumulation at river mouths	Agriculture space, Urban space	Sea space
	Excessive use of pesticides, fertilizers, etc.	Nitrogen, phosphorus, heavy metals, etc.	Rivers, rainfall, etc.	Negative externalties	Pollution of groundwater, eutrophication of seawater; Reduction of biodiversity; Destruction of coastal landscapes	Agriculture space	Sea space
	Restoring agricultural land forest	Gas molecules, etc.	Atmosphere, river, etc.	Positive externalties	Conservation of soil and water; Regulation of climate between land and sea; Purification of river water quality; Reduction of the amount of pollutants discharged into the sea by rivers	Agriculture space	Urban space, Land ecological space, Sea space
	Over-exploitation of groundwater	Freshwater, seawater, salt, etc.	Seawater, river, etc.	Negative externalties	Groundwater becomes salty and the land salinized	Urban space, Agriculture space	Agriculture space, Urban space
	Exploitation of marine resources	Pollutant	Seawater	Negative externalties	Pollution of the marine environment, destruction of coastal landscapes, etc.	Marine exploitation space	Urban space
	River diversion	Dirt, sand, pollutant, etc.	Man-made waterway	Negative externalties	Damage to watershed ecosystems, which in turn affects the marine environment	Urban space	Sea space
	Enclosure of reclaimed land (e.g. paddy fields)	Dirt, sand, pollutant, etc.	Seawater	Negative externalties	Pollution of the marine environment, destruction of ecosystems, destruction of coastal landscapes, etc.	Urban space	Sea space
Materials transferring	Industrial effluents discharged into the sea	Pollutant	Sewerage pipeline	Negative externalties	Pollution of the marine environment	Urban space	Sea space
	Marine oil and gas resources and mineral exploitation	Oil and gas resources, mineral resources, etc.	Pipelines, channel, etc.	Positive externalties	Securing resources for economic and social development	Marine exploitation space	Agriculture space, Urban space
	Aquaculture	Seafood	Road, Railway, etc.	Positive externalties	Providing food for human survival	Marine exploitation space	Agriculture space, Urban space
	Land-based resource extraction, industrial and agricultural production, etc.	Various resources and industrial and agricultural products	Road, Railway, Channel, etc.	Positive externalties	Provision of raw materials or resources for the exploitation of the sea	Urban space, Agriculture space	Marine exploitation space
Policy radiation	Laws, regulations and policy planning related to land space management[1]	Information	Laws, regulations, polices, planning, etc.	Positive externalties	Reducing impacts on marine ecosystems and supporting marine economic development	Urban space, Agriculture space	Sea space

(Continued)

10.3389/fmars.2024.1405157

10.3389/fmars.2024.1405157

TABLE 2 Continued

Manifestations of interregional externalities	Main activities	Transported substance	Medium	Type of interregional externalties	The practical implications of interregional externalties	The subject region	The receptor region
	Laws, regulations and policy planning related to land space management[2]	Information	Laws, regulations, polices, planning, etc.	Negative externalties	Damage to marine ecosystems	Urban space, Agriculture space	Sea space
	Laws, regulations and policy planning related to sea space management[3]	Information	Laws, regulations, polices, planning, etc.	Positive externalties	Protecting coastal ecosystems and enhancing coastal landscapes	Sea space	Land space

[1]For example, laws and regulations and policy plans for the protection of vegetation, the control of soil erosion, and the control of industrial and agricultural pollution.
[2]Relevant laws, regulations and policy plans, such as those on the protection of arable land and the control of the scale of construction land, have led to the intensification of reclamation.
[3]For example, the implementation of a coastal building setback line system to protect the coastal terrestrial ecosystem and landscape.

a policy of great protection for the Yangtze River, strictly controlling the discharge of sewage from industries along the river. This initiative has resulted in a significant reduction in the total amount of pollutants entering the sea, which has effectively protected the marine environment and is reflected in PIE.

5 Land-sea coordination policy: conceptual framework and implementation pathway

5.1 The conceptual framework of the LSC

There are differences between land space and sea space due to differences in interest needs and goal orientation. Individuals with relevant interests located in the coastal zone diverge in their choices of economic development and ecological protection, leading to the formation of various forms of interregional externalities in terms of resources, ecology, environment and industry. Under the framework of the interregional externatilities theory, this study argues that LSC is about harmonizing the functions and development objectives of different spatial units. Treating land and sea as a unified regional system makes it possible to regard issues of land-sea conflict as an internal problem of the complex system of coastal zones. While weakening the heterogeneity between land space and sea space in terms of natural geographic features, management systems, development and utilization modes, etc., it fully coordinates the demands of the two different types of subjects, the land space and the ocean space, in terms of ecological protection and economic development. Only in this way will it be conducive to the realization of the integrated coordination of land and marine space utilization activities and protection. Within the theoretical framework of economics, internalization emerges as a pivotal approach to address the challenges posed by externalities. Two broad categories of methods are usually included: The first is the government-driven “Pegu method” through the imposition of sewage and environmental taxes. The second is the “Coase method”, which is dominated by market forces through the definition of property rights and the differentiation of interests. Ecological protection focuses on government control, while economic development emphasizes market mechanisms. Therefore, to promote the LSC, it is necessary to make comprehensive use of the “Pegu method” and the “Coase method”. It requires to integrate the comparative advantages of land and sea resources and to take into account the specific interests and needs of land and sea when they are different subjects from a more macro and systematic perspective.

The essence of interregional externalities is that the subject region relies on the medium to transmit the transported substance, which enters the receptor region and thus affects the receptor region positively or negatively. Based on this premise, the implementation of LSC can start from source control, process control and interaction interface control. Increase the depth of LSC by enhancing the PIE and weakening the NIE.

5.1.1 Source control: control of the total amount of substances exported from the subject region

The transported substance is direct factors that can cause externality effects. Therefore, strengthening source control can restrict the total amount of substances exported from the subject region. For inter-district positive externality effects, the material output of the subject region can be further strengthened. For PIE effects, the total amount of transported substance exported by the subject region should be further increased. For example, the development of the land-based economy requires various products generated by the marine economy, and the supply of marine products can be increased moderately within the carrying capacity of the marine environment to better support the high-quality development of the land-based economy. For NIE effects, consideration should be given to reducing the total amount of substance exported by the subject region. For example, a variety of pollutants generated by industrial production and the lives of urban residents in land space units enter the sea space through rivers, pipelines, etc., which are an important source of marine pollution. Therefore, the generation of pollutants from land-based sources and their transport processes should be controlled at source in order to further reduce the level of pollution of the marine environment by pollutants.

5.1.2 Process control: optimizing the medium's transportation of substances

The medium is the vehicle through which different spatial units interact. The direction, intensity and manifestation of LSI can be effectively regulated through scientific adjustment of medium conditions. Specifically including:

1. Reduced intervention in natural medium. In the process of LSI, natural medium such as rivers, atmosphere and rainfall play a key role in shaping the topography, geomorphology and ecosystems of the coastal zone, profoundly affecting the near-shore marine environment and ultimately influencing the economic and social development of coastal zones.
2. Improvement of artificial medium. Improving the construction of artificial medium, such as roads, railroads and oil and gas pipelines, can further strengthen the links between different spatial units and thus improve the efficiency of resource transportation. The construction of sewage pipelines has also accelerated the pollution of rivers and oceans, making near-shore waters a catchment area for pollutants in a short period of time. Therefore, in territorial spatial planning, on the one hand, the spatial layout of artificial medium such as transportation infrastructure should be optimized to give full play to its articulation and enhance its positive externality effects. On the other hand, it is also necessary to reasonably control the construction of artificial medium such as sewage pipelines and reduce its negative externality effects.
3. Enhancing the systemic nature of the policy medium. Land and sea management policies are often characterized by contradictory and conflicting regimes, as different laws apply to land and sea space. Therefore, policy regimes for coastal zones should be systematic. It is important to consider the coastal zone space as a whole and to avoid "losing sight of the big picture". This means that one spatial element cannot be protected at the expense of others.

5.1.3 Interaction interface control: strengthening the overall control of LSI regions

The coastal zone is the area with the strongest land-sea interaction, where various types of positive and negative externalities are formed, which profoundly affect the ecological environment and economic and social development of the region. Therefore, effective coordination of various types of spatial conflicts and the promotion of benign interaction between land and sea are the basic starting points for spatial governance in the region. LSI are characterized by complexity and diversity, which requires the formulation of relevant planning policies to take into account comprehensively such spatial activities as resource utilization, disaster prevention, industrial development, ecological protection, environmental governance and the enhancement of the human habitat. On the one hand, the internal coordination of the different functional units should be strengthened in a unidirectional dimension in conjunction with land and sea spatial units. For example, in addition to considering the utilization of resources in the fishery space, it is necessary to strengthen environmental management and landscape control. In addition to considering the needs of port shipping development, port space should also strengthen environmental management, conflicts with other sea utilization activities, and connection with urban transportation. On the other hand, there is also a need to plan the coastal zone as a whole from a comprehensive dimension, to strengthen disaster defense and the protection of sea-friendly space.

5.2 Implementation pathways for the LSC

The formation and development of inter-regional externalities necessarily passes through three stages: the formation of intra-regional externalities in the subject region, spillovers through the medium, and effects on the receptor region. Therefore, according to the different stages of the formation of inter-regional externalities, the implementation pathways of LSC can focus on three links: source control, process control and interaction interface control. In conjunction with the relevant requirements and means of territorial spatial planning, the LSC can be implemented in the following ways.

5.2.1 Building an integrated land and sea pattern of territorial space development and protection

The spatial pattern of the subject region, medium and the receptor region determines the form and intensity of interactions between the different regions and profoundly influences the effects of interregional externalities on land and sea. Hence, within the framework of territorial space planning, it is imperative to establish an integrated national spatial development and protection pattern

that encompasses both land and sea, aiming to enhance coordination between these two domains and mitigate adverse consequences.

At the macro scale, spatial linkages between land and sea should be systematically considered. Emphasis should be placed on the close relationship between land and sea in terms of economic interaction, resource complementarity, ecological integration, land-based sources of pollution, and the mediums such as rivers and transportation infrastructure that link land and sea. Building upon this foundation, the spatial configuration of land and sea integration can be optimized. This can be achieved through the enhancement of transportation infrastructure, including ports, inland waterways, railroads, and highways. By bolstering these transportation networks, the economic connectivity between land and sea can be strengthened, facilitating the synergistic utilization of terrestrial and marine resources. Furthermore, this will reinforce the economic influence and impetus of coastal regions on inland areas, fostering greater economic radiation and spillover effects.

At the meso scale, the development objectives of each type of space and its effect on other spaces are considered in an integrated manner. On the basis of scientific evaluation, agricultural space, land ecological space, urban space, marine ecological space, and marine exploitation space should be rationally delineated. Conflicts between the three types of agricultural space, land ecological space and urban spaces should be reduced, thus promoting the harmonization of land-based economic and social development with ecological protection and arable land conservation. The spillover of intra-regional externalities such as agricultural pollution and soil erosion into ocean space should be further curbed, thereby reducing the problem of negative interregional externalities such as seawater pollution and damage to marine biodiversity.

At the micro scale, unified control of spatially adjacent and closely linked land and marine spatial units in the coastal zone. Firstly, it is recommended to designate natural ecosystems such as mangrove forests, salt marshes, and estuaries, which span both land and sea, as cohesive ecological protection units. This approach facilitates the integrated implementation of land-sea ecological preservation, control, and restoration measures. Secondly, spatially contiguous regions that involve closely linked land-based and marine activities, such as port waters, shorelines, and their corresponding terrestrial areas, can be identified as comprehensive development and utilization units. This designation enables the harmonization of spatial arrangements for land-based and marine development activities, optimizing spatial functions and providing essential support for the growth of the marine-based industry.

5.2.2 To settle land by sea: strengthening coastal zone ecological environment protection, restoration and management

The degradation of coastal zone ecosystems and the decline in the quality of the marine environment are long-term challenges to the economic and social development of the coastal zone. The vulnerability of coastal zone ecosystems, subjected to multifaceted pressures from both terrestrial and marine domains, is undeniably apparent. Simultaneously, these ecosystems play a crucial role in providing ecological services to both land and sea space, thereby enhancing overall spatial quality. Consequently, prioritizing the protection of coastal zone ecosystems and implementing comprehensive marine environmental management emerge as imperative tasks within the context of the LSC.

Firstly, typical ecosystems such as mangrove forests and seagrass beds will be assigned to the red line of ecological protection for strict protection, so as to ensure that the ecological function, area and nature of the coastal zone will not be reduced or altered. Strengthening the resilience of coastal zone ecosystems in the face of climate change, marine disasters, and human spatial utilization activities is of paramount importance.

Secondly, systematic protection of intertidal ecosystems with strong land-sea interactions is needed. Elevating the spatial access threshold is crucial to prevent intrusive development and construction activities from encroaching upon vital coastal zones, including bedrock intertidal zones, sandy intertidal zones, silty intertidal zones, and biological intertidal zones. By safeguarding these intertidal habitats, particularly those crucial for migratory bird species, the protection of intertidal biodiversity can be effectively upheld.

Thirdly, strengthening the control and management of all types of land-based pollutants. Stringent regulation of sewage discharge into rivers and coastal waters via sewage pipes, while ensuring compliance with established standards, is imperative. In cases where the quality of seawater in bays falls below the prescribed standards, emission reduction measures are implemented within river catchment areas and coastal zones to progressively restore the seawater quality.

Fourthly, enhancing the overall restoration of coastal zone ecosystems. Regarding compromised natural shorelines, the restoration of ecological functions can be achieved through the removal of sea-enclosure farming facilities and the ecological transformation of seawalls. In the case of damaged coastal wetlands, a combination of natural and artificial restoration approaches will be employed. For severely fragmented and functionally degraded natural wetlands, a comprehensive restoration strategy will be implemented, encompassing silt removal, dredging, topographical and geomorphological restoration, shoreline maintenance, aquatic vegetation restoration, habitat construction, and other appropriate measures to gradually reinstate the ecological functions of the wetlands.

5.2.3 Optimizing the industrial layout along the river and the coast

Relying on the advantages in transportation, resources and opening up to the outside world, riverine and coastal areas are often areas of industrial concentration. While this promotes the development of industrial clusters, it also puts heavy pressure on the marine environment. Therefore, the relationship between the development of land-based and marine-based industry and environmental protection should be harmonized in territorial spatial planning. Firstly, a stringent control mechanism should be implemented to prevent non-water-dependent industries from

occupying valuable shoreline resources. This measure aims to safeguard the natural shoreline and establish high-quality sea-friendly areas accessible to the public. Secondly, the establishment of highly polluting and energy-consuming industries along rivers and coastlines must be strictly prohibited. Additionally, direct discharge of sewage into rivers and the sea should be strictly forbidden, accompanied by intensified environmental monitoring of river outlets and near-shore waters. These measures are crucial for enhancing the near-shore marine environment's quality. Thirdly, there is a need for effective coordination of sea use requirements across different industries. This entails promoting the offshore and deep-water development of traditional aquaculture and offshore energy sectors, while also reducing the development intensity of offshore waters. Fourthly, the integration of tourism with mariculture and offshore wind power should be encouraged, allowing tourism activities to extend seaward. Furthermore, implementing robust land space governance policies is essential to safeguard the construction of land-based supporting facilities required by marine industries, ultimately raising the standard of marine economic development.

5.2.4 Implementation of integrated coastal zone management

Coastal zones are the areas where the LSI is the strongest, so the realization of the LSC requires the implementation of integrated land-sea management for coastal zones. First, the scope of the coastal zone should be rationally delineated. At present, there are various forms of delineation of the scope of the coastal zone, including specific distances, geographic indications, administrative units, etc. This study argues that the scope of the coastal zone should not be too large, and suggests that the scope of the coastal zone be delineated from the perspective of spatial control in order to implement strict use control measures. In practice, key objectives such as marine disaster defense, environmental pollution control, ecological environmental protection, and protection of sea-friendly space can be considered comprehensively. The scope of the coastal zone should be comprehensively delineated in conjunction with the first coastal highway, the typical ecosystem boundary of the coastal zone, the land area of the port and other geographic landmarks or the current status of spatial development, and the scope should not be too large.

On the basis of the delineation of the extent of the coastal zone, it is appropriate to implement a strict use control system, taking into account the key challenges facing the integration of land and sea. For example, in response to the disappearance of natural shorelines, damage to typical ecosystems and encroachment on seafaring space, coastal building retreat lines can be delineated, and the control of the use of land space in the coastal zone can be strengthened to reduce the disturbance of land space in the coastal zone caused by human activities. In response to the problem of serious pollution of near-shore waters, seawater farming and livestock farming in coastal areas should be strictly controlled, the construction of outfalls should be scientifically justified, and marine environmental governance should be strengthened.

Moreover, when formulating coastal zone planning and implementing corresponding measures, it is essential to adhere to a systemic and holistic approach. This necessitates avoiding the narrow focus on singular spatial elements or specific activities while disregarding the comprehensive impacts of various development and utilization endeavors. Consequently, throughout the planning and implementation stages, active engagement and guidance should be provided to involve relevant departments responsible for natural resources, marine affairs, transportation, ecological environment, agriculture and rural areas, as well as tourism-related sea management. This concerted effort aims to enhance policy coordination among these diverse departments, fostering a cohesive and integrated approach.

6 Conclusion and research prospectives

Based on the interregional externality theory, this study discusses the manifestation and formation mechanism of the LSI, and further explores the basic concept and specific paths for implementing the LSC. Firstly, this study introduces the interregional externality theory from the traditional economic concept of externality, and clarifies the necessary conditions for the formation of inter-regional externalities and their fit with the LSC based on the perspective of regional spatial interaction. Secondly, to elucidate the impacts of spatial utilization activities on the natural environment within the region at the micro-scale and investigate the progression of intra-regional externalities into interregional externalities at the meso-scale, this study delineates the fundamental units of land and sea space. In accordance with the principles of territorial spatial planning, the paper meticulously examines the spatial activities occurring within distinct types of spatial units and explores the intricate process of spatial interaction between land and sea. Thirdly, from the interregional externality theory, this study summarizes and condenses the characteristics of interregional externalities in the coastal zone and the manifestations of land-sea unit interactions. Finally, the planning pathways of the LSC is proposed from the perspective of internalization of interregional externalities. Through the above research process, this paper obtains the following conclusions:

1. The spatial utilization activities in coastal zones have both intra-regional and interregional externalities. These two types of externalities are intertwined, interdependent and mutually constraining, forming an intricate spatial interaction between land space and sea space. Among them, intra-regional externalities are mainly concerned with the dynamic relationship between various types of spatial activities and the natural environment at the micro scale. Interregional externalities pertain to the consequences arising from the intricate interplay among diverse functional units at the meso scale. Simultaneously,

these externalities encompass the dynamic interactions occurring between land and sea at the macro scale. This fits precisely with the research needs of territorial spatial planning for different spatial scales and different types of spatial activities.

2. The formation of interregional externalities in coastal zones requires the fulfillment of three conditions: regional correlation, medium conditions and transported substance. The interregional externalities can be classified into three forms of factors flowing, materials transferring and policy radiation based on medium characteristics.
3. The basic ideas of realizing the LSC is to focus on source control, process control and interaction interface control, so as to enhance the positive interregional externality effect and weakening the negative interregional externality effect. This specifically includes: Source control is implemented to regulate the overall quantity of material exported from the subject region; Process control is employed to optimize the transport functions of the media involved. Interaction interface control is undertaken to enhance comprehensive management over land-sea interaction zones.
4. In conjunction with the relevant requirements and means of territorial spatial planning, the LSC can be implemented in the following ways: Building an integrated land and sea pattern of territorial space development and protection; Strengthening coastal zone ecological environment protection, restoration and management; Optimizing the industrial layout along the river and the coast; Implementation of integrated coastal zone management.

Developing a well-developed interregional externality theory could significantly enhance both the theoretical framework and practical applications of LSC and LSI research in China. This paper theoretically aligns the concept of interregional externalities with LSC studies and initially establishes an analytical framework to apply this theory to LSC-related issues. However, there remain gaps in the quantitative analysis of interregional externalities and in practical case studies, which suggest avenues for further refinement and expansion of this theory in the future.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

YL: Conceptualization, Formal analysis, Funding acquisition, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing. YW: Conceptualization, Formal analysis, Methodology, Software, Visualization, Writing – original draft. DL: Conceptualization, Methodology, Resources, Writing – review & editing. YH: Conceptualization, Formal analysis, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by National Key Research and Development Plan (Grant No. 2022YFC3800801) and the National Natural Science Fund of China (NO. 42306247).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Bagella, M., Becchetti, L., and Cicero, M. (2004). Regional externalities and direct effect of legislation against money laundering: A test on excess money balance in the five Andean countries. *J. Money Laund. Contro.* 7, 347–366. doi: 10.1108/13685200410810056

Baker, S., Constant, N., and Nicol, P. (2023). Oceans justice: trade-offs between sustainable development goals in the Seychelles. *Mar. Pol.* 147, 105357. doi: 10.1016/j.marpol.2022.105357

Brooks, K., Barclay, K., Grafton, R. Q., and Gollan, N. (2022). Transforming coastal and marine management: Deliberative democracy and integrated management in New South Wales, Australia. *Mar. Pol.* 139, 104053. doi: 10.1016/j.marpol.2020.104053

Caviedes, V., Arenas-Granados, P., and Barragán-Munoz, J. (2020). Regional public policy for Integrated Coastal Zone Management in Central America. *Ocean Coast. Manage.* 186, 105114. doi: 10.1016/j.ocecoaman.2020.105114

Chen, J., Kang, S., Wu, A., and Chen, L. (2024). Projected emissions and climateimpacts of Arctic shipping along the Northern Sea Route. *Environ. Pollut.* 341, 122848. doi: 10.1016/j.envpol.2023.122848

Duan, X., Yu, X., Lu, D., and Nipper, J. (2010). The study of new economic geography of Krugman and its significance. *Acta Geogr. Sin.* 65, 131–138. doi: 10.11821/xb201002001

Guan, X., Liu, W., and Chen, M. (2016). Study on the ecological compensation standard for river basin water environment based on total pollutants control. *Ecol. Indic.* 69, 446–452. doi: 10.1016/j.ecolind.2016.05.011

Guggisberg, S. (2024). Finding equitable solutions to the land-based sources of marine plastic pollution: Sovereignty as a double-edged sword. *Mar. Pol.* 159, 105960. doi: 10.1016/j.marpol.2023.105960

Halpern, B., Ebert, C., Kappel, C., Madin, E., Micheli, F., Perry, M., et al. (2009). Global priority areas for incorporating land-sea connections in marine conservation. *Conserv. Lett.* 2, (4). doi: 10.1111/j.1755-263X.2009.00060.x

Han, F., and Ke, S. (2013). Spatial externalities, comparative advantage and manufacturing agglomeration. *J. Quant. Technol. Econ.* 30, 22–38+116. doi: 10.13653/j.cnki.jqte.2013.01.012

Han, L., and Li, D. (2015). Blue food system: cuarantee of China's food security. *Agric. Econ.* 36, 24–29+110. doi: 10.13246/j.cnki.iae.2015.01.005

Heijman, W. (2007). *Regional Externalitie* (Berlin: Springer), 1–10. doi: 10.1007/978-3-540-35484-0

Hsieh, P., and Li, Y. (2009). A cluster perspective of the development of the deep ocean water industry. *Ocean Coast. Manage.* 52, 287–293. doi: 10.1016/j.ocecoaman.2009.03.006

Hua, T., He, L., Jiang, Q., Chou, L., Xu, Z., Yao, Y., et al. (2024). Spatio-temporal coupling analysis and tipping points detection of China's coastal integrated land-human activity-ocean system. *Sci. Total Environ.* 914, 169981. doi: 10.1016/j.scitotenv.2024.169981

Huang, J., Li, Q., Tu, Z., Pan, C., Zhang, L., Ndokoye, P., et al. (2013). Quantifying land-based pollutant loads in coastal area with sparse data: Methodology and application in China. *Ocean Coast. Manage.* 81, 14–28. doi: 10.1016/j.ocecoaman.2012.07.011

Jung, P., and Thill, J. (2022). Sea-land interdependence and delimitation of port hinterland foreland structures in the international transportation system. *J. Trans. Geogr.* 99, 103297. doi: 10.1016/j.jtrangeo.2022.103297

Khelil, N., Larid, M., Grimes, S., Berre, I., and Peuziat, I. (2019). Challenges and opportunities in promoting integrated coastal zone management in Algeria: Demonstration from the Algiers coast. *Ocean Coast. Manage.* 168, 185–196. doi: 10.1016/j.ocecoaman.2018.11.001

Li, J., Tian, P., Li, C., and Gong, H. (2022). Land-sea economic relations and land space utilization based on land-sea coordination: Research status, problems and future priorities. *J. Nat. Resour.* 37, 924–941. doi: 10.11821/dlyj020200397

Li, K., He, J., Li, J., Guo, Q., Liang, S., Li, Y., et al. (2018). Linking water quality with the total pollutant load control management for nitrogen in Jiaozhou Bay, China. *China. Ecol. Indic.* 85, 57–66. doi: 10.1016/j.ecolind.2017.10.019

Li, Y., Liu, D., and Luo, T. (2021). The internal logic and developing direction of land-sea coordination in land space planning: from the perspective of complex system theory. *Geogr. Res.* 40, 1902–1916. doi: 10.11821/dlyj020200397

Lu, D. (2011). The methodology of human economic geography and its characteristics. *Geogr. Res.* 30, 387–396. doi: 10.11821/yj2011030001

Lu, M., Chen, Y., and Lu, Y. (2018). The competition and cooperation spatial pattern between railway transport and shipping in China under the Belt and Road Initiative. *Geogr. Res.* 37, 404–418. doi: 10.11821/dlyj201802013

Makino, A., Beger, M., Klein, C., Jupiter, S., and Possingham, H. (2013). Integrated planning for land-sea ecosystem connectivity to protect coral reefs. *Biol. Conserv.* 165, 35–42. doi: 10.1016/j.biocon.2013.05.027

Matear, R., and Wang, Y. (2010). Andrew Lenton. Land and ocean nutrient and carbon cycle interactions. *Curr. Opin. Environ. Sustain.* 2, 258–263. doi: 10.1016/j.cosust.2010.05.009

Mejjad, N., Rossi, A., and Pavel, A. (2022). The coastal tourism industry in the Mediterranean:A critical review of the socio-economic and environmental pressures & impacts. *Tour. Manage. Perspect.* 44, 101007. doi: 10.1016/j.tmp.2022.101007

Ngoran, S., and Xue, X. (2015). Addressing urban sprawl in Douala, Cameroon: Lessons from Xiamen integrated coastal management. *J. Urb. Manage.* 4, 53–72. doi: 10.1016/j.jum.2015.05.001

Ni, Y., Du, P., and Chen, H. (2024). Enhancing blue: The resilience of blue economy and the efficiency of China's sea-land industrial synergy. *Technol. Forecast. Soc Change.* 198, 123007. doi: 10.1016/j.techfore.2023.123007

Pantusa, D., Saponieri, A., and Tomasicchio, G. (2023). Assessment of coastal vulnerability to land-based sources of pollution and its application in Apulia, Italy. *Sci. Total Environ.* 886, 163754. doi: 10.1016/j.scitotenv.2023.163754

Pinillos, F., Muoz, J., and Ríos, F. (2023). Delimiting coastal zones for integrated management: The case of the island and the sea of Chiloé(Chile). *Mar. Pol.* 150, 105535. doi: 10.1016/j.marpol.2023.105535

Poulos, S., Chronis, G., Collins, M., and Lykousis, V. (2000). Thermaikos Gulf Coastal System, NW Aegean Sea: an overview of water/sediment fluxes in relation to air–land–ocean interactions and human activities. *J. Mar. Syst.* 25, 47–76. doi: 10.1016/S0924-7963(00)00008-7

Qu, Y., Wang, S., Tian, Y., Jiang, G., Zhou, T., and Meng, L. (2023). Territorial spatial planning for regional high-quality development-An analytical framework for the identification, mediation and transmission of potential land utilization conflicts in the Yellow River Delta. *L. U. Pol.* 125, 106462. doi: 10.1016/j.landusepol.2022.106462

Reis, J., Stojanovic, T., and Smith, T. (2014). Relevance of systems approaches forimplementing Integrated CoastalZone Management principles in Europe. *Mar. Pol.* 43, 3–12. doi: 10.1016/j.marpol.2013.03.013

Ren, Z., He, C., and Wang, W. (2021). Progress of research on economic complexity and regional economic development in the perspective of evolutionary economic geography. *Prog. Geog.* 40, 2101–2115. doi: 10.18306/dlkxjz.2021.12.010

Ren, W., Xu, Y., and Ni, J. (2024). Evolution of marine ecology-industry symbiosis patterns and ecological security assessment: New evidence from coastal areas of China. *Ocean Coast. Manage.* 247, 106939. doi: 10.1016/j.ocecoaman.2023.106939

Saeidpour, A., Chorzepa, M. G., Christian, J., and Durham, S. (2019). Probabilistic hurricane risk analysis of coastal bridges incorporating extreme wave statistics. *Eng. Struct.* 182, 379–390. doi: 10.1016/j.engstruct.2018.11.069

Smith, H., Maes, F., Stojanovic, T., and Ballinger, R. (2011). The integration of land and marine spatial planning. *J. Coast. Conserv.* 15, 291–303. doi: 10.1007/s11852-010-0098-z

Stouffer, S. (1940). Intervening opportunities: A theory relating mobility to distance. *Am. Sociol. Rev.* 5, 845–867. doi: 10.2307/2084520

Sunley, P. (2008). Relational economic geography: A partial understanding or a new paradigm. *Econ. Geogr.* 84, 1–26. doi: 10.1111/j.1944-8287.2008.tb00389.x

Turner, J., and Essex, S. (2016). Integrated terrestrial and marine planning in England's coastal inter-tidal zone: assessing the operational effectiveness of the Coastal Concordat. *Mar. Pol.* 72, 166–175. doi: 10.1016/j.marpol.2016.07.014

Vanclay, F. (2012). The potential application of social impact assessment in integrated coastal zone management. *Ocean Coast. Manage.* 68, 149–156. doi: 10.1016/j.ocecoaman.2012.05.016

Wilkinson, W., Leeks, G., Morris, A., and Walling, D. (1997). Rivers and coastal research in the Land Ocean Interaction Study. *Sci. Total Environ.* 194-195, 0–14. doi: 10.1016/S0048-9697(96)05350-8

Yao, L., Yue, B., Pan, W., and Zhu, Z. (2023). A framework for identifying multiscenario priorities based on SCP theory to promote the implementation of municipal territorial ecological conservation planning policy in China. *Ecol. Indic.* 155, 111057. doi: 10.1016/j.ecolind.2023.111057

Zaucha, J., Conides, A., Klaoudatos, D., and Noren, K. (2016). Can the ecosystem services concept help in enhancing the resilience of land-sea social-ecological systems? *Ocean Coast. Manage.* 124, 33–41. doi: 10.1016/j.ocecoaman.2016.01.015

Zaucha, J., and Jay, S. (2022). The extension of marine spatial planning to the management of the world ocean, especially areas beyond national jurisdiction. *Mar. Pol.* 144, 105218. doi: 10.1016/j.marpol.2022.105218

Zhang, R., Dai, J., Bai, Y., Barone, D., and Hill-Beaton, L. (2023). Risk-based transportation infrastructure management: An integrated framework and case study in USVI against coastal flood and sea level rise. *Ocean Coast. Manage.* 242, 106723. doi: 10.1016/j.ocecoaman.2023.106723

10.3389/fmars.2024.1405157

Appendix 1 Criteria for determining "positive impact effects" and "negative impact effects"

TABLE A.1 Criteria for determining "positive impact effects" and "negative impact effects".

Dimension	Positive impact effects	Negative impact effects
Economic	If the externality of a given utilization activity results in additional economic benefits for other economic agents without the beneficiaries having to pay the associated costs, the impact is usually considered positive.	If the externality of a particular utilization activity causes other economic agents to incur additional costs that are not borne by the individual causing the negative externality, the effect is usually considered to be negative.
Ecology and Environment	An externality is considered positive if it contributes to sustainable development (i.e., meeting current needs without compromising the ability of future generations to meet their needs, e.g., cleaning the air, building ecological reserves, reducing pollutant emissions, utilizing clean energy, etc.).	An externality is considered negative if it causes long-term damage to the environment, resources, or social structure, and thus is not conducive to sustainable development (e.g., wastewater discharges, over-exploitation of groundwater, pollution from household waste, indiscriminate logging, overfishing, etc.).
Social welfare	An externality is considered positive if it increases the level of social welfare (e.g., by improving environmental quality, improving health, increasing employment opportunities, etc.).	If an externality reduces the level of social welfare (e.g., through environmental pollution, health hazards, economic losses, etc.), then it is considered negative.
Laws & Regulations	If the externalities generated by an activity comply with laws and regulations, they can usually be considered positive.	An activity can be considered negative if it generates externalities that violate laws and regulations.
Public attitude	An externality is considered positive if it is widely recognized and supported by society.	An externality is considered negative if it provokes strong public opposition and protest.
Landscaping	If an activity or decision contributes to the protection, restoration or enhancement of the integrity and health of ecosystems (e.g., increase in biodiversity, protection of water sources, stabilization of soils, etc.) or enhances the services and functions provided by the environment, then the impact of the externality can be considered positive.	Externalities are considered negative if the activity or decision leads to the destruction, degradation or loss of functioning of ecosystems (e.g., species extinction, water contamination, soil erosion, etc.) or cuts back on the services and functions provided by the environment.

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 29 August 2024
DOI 10.3389/fmars.2024.1453760

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
University of International Business and Economics, China

REVIEWED BY
Periyadan K. Krishnakumar,
King Fahd University of Petroleum and Minerals, Saudi Arabia
Arzu Karahan,
Middle East Technical University, Türkiye

*CORRESPONDENCE
Xuewei Qi
15762264956@163.com

RECEIVED 24 June 2024
ACCEPTED 30 July 2024
PUBLISHED 29 August 2024

CITATION
Zhou W, Li T and Qi X (2024) New perspective on the recent challenges of regional environmental management plans under the background of deep-sea mining: from Northwest Pacific to global.
Front. Mar. Sci. 11:1453760.
doi: 10.3389/fmars.2024.1453760

COPYRIGHT
© 2024 Zhou, Li and Qi. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

New perspective on the recent challenges of regional environmental management plans under the background of deep-sea mining: from Northwest Pacific to global

Wencui Zhou[1], Tianzhao Li[2] and Xuewei Qi[1]*

[1]School of Law, Ocean University of China, Qingdao, China, [2]School of Physics, Beihang University, Beijing, China

With the utilization of the mineral resources of the international seabed area entering a new phase of exploitation, the international community's concern for the protection of the marine environment in the international seabed area has also reached an unprecedented level. Regional Environmental Management Plans (REMPs), formulated by the International Seabed Authority (ISA), are considered as an important component of marine environmental protection in the deep seabed. However, REMPs are faced with challenges in practice under the background of deep-sea mining. In this work, we review the historical evolution of REMP, sort out the challenges faced by REMP from NWP to global and provide our suggestions to solve these issues. Specifically, the difficulties in the Northwest Pacific (NWP) REMP are mainly located in the lack of environmental scientific data. Meanwhile, from a global perspective, besides difficulties in local region, such as NWP, REMPs are facing more challenges, such as the arguments about the legal force of REMPs, conflicts between REMPs and the BBNJ Agreement, as well as absence of regulations for balancing exploitation and conservation. Focus on these challenges, suggestions are proposed including using the ISA to coordinate the application between REMPs and BBNJ Agreement and using the principle of scientific evidence to improve the regulations of REMPs. This work not only introduces a new insight for improving the framework system for the protection of the marine environment in the international seabed area, but also provides a reference for the solution to new challenges in the field of marine environmental protection.

KEYWORDS

deep-sea mining, REMP, Northwest Pacific, global, challenges

1 Introduction

Deep-sea mineral resources have emerged as significant substitutes or supplements for land-based metallic resources in the 21 century (Du et al., 2024).The island nation of Nauru, who sponsors the Canadian mining corporation The Metals Company (TMC) to conduct research into deep-sea mining, triggered the so-called "two-year rule" of the International Seabed Authority (ISA) in 2021 (Singh, 2021). Per the agreement relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea (the Implementing Agreement), this rule obligated the ISA to allow consideration of mining permits on July 9, 2023, with or without completed regulations in place. TMC hopes to begin mining in coming years and is closely watching the developments at the ISA; the latest media statement from TMC, dated July 24, 2023, expressed disappointment that regulations were not finalized by July 9 and conveyed hope they would be completed in November, 2023 (Murdock R., 2024). However, Among the primary concerns driving opposition to deep-sea mining is the potential for environmental harm created by disturbing the seafloor as nodules are extracted (Blanchard and Gollner, 2022). In light of these potential risks and their uncertain nature, organized opposition to beginning industrial deep-sea mining now exists (Murdock, R.,2024). If clean energy transitions and electrification are pursued for decarbonizing economies, the need for deep seabed's minerals cannot be escaped.

In short, deep-sea mining, as an international issue concerning the development of all human beings, is subject to many controversies covering technical, environmental, financial, legal, and other fields (IISD, 2019). The United Nations (UN) now observance of 2021–2030 as the Decade of Ocean Science for Sustainable Development, alongside the existing Sustainable Development Goal 14 (which aims to conserve and sustainably use ocean resources), presents an opportunity to accelerate efforts to develop strong, well-informed frameworks for deep-sea mining as a comprehensive strategy (Howell et al., 2020). In addition, according to the United Nations Convention on the Law of the Sea (UNCLOS) (UN, 1982) and the Implementing Agreement, many countries have formulated laws and regulations on deep-sea mining. For example, New Zealand established the Continental Shelf Act 1964 for the exploration and exploitation of continental shelf (New Zealand, 1964), and formulated the United Nations Convention on the Law of the Sea Act 1996 (New Zealand, 1996) to give effect in the law of the New Zealand to provisions of Part XI of the Convention. African countries have relatively limited deep-sea activities, and only a few countries submitted relevant texts of deep-sea legislation to ISA. They advocated that the benefits of deep-sea mining should be shared by all humanity, meanwhile these mining activities should also consider environmental protection (Wang and Zhong, 2022) due to the impact on the living environment of benthic communities of invertebrates (Cuvelier et al., 2018).

Under the circumstance, in March 2024, the first part of the 29th session of ISA made significant progress in the ongoing negotiations of the draft exploitation regulations (the Mining Code) for mineral resources in the international seabed area(the "Area") (ISA, 2024). Against the backdrop of argument regarding deep-sea mining and environmental protection, an increasing number of States, social organizations and enterprises are publicly expressing their concerns about the opening of deep-sea mining (Greenpeace, 2024). After all, there are still significant gaps in the environmental, ecological and social impacts of deep-sea mining and its regulation, which is the most important issue to be solved.

The Implementing Agreement adopted in 1994, stipulates that the international seabed area beyond the limits of national jurisdiction and its mineral resources are the common heritage of mankind. The Implementing Agreement established the ISA to organize and control activities in the "Area", manage the mineral resources of the "Area", and formulate policies and measures for the protection and preservation of the marine environment. The ISA consists of the Assembly, the Council, the Finance Committee, the Legal and Technical Commission (LTC), and the Secretariat (UN, 1994).

The Regional Environmental Management Plans (REMPs) are environmental protection pdeep sealans formulated by the International Seabed Authority (ISA) (ISA, 2018) in accordance with Article 145 of the UNCLOS (UN, 1982), aiming to solving the prominent environmental protection issues in deep-sea mining. The establishment of the first REMP was formally proposed by the ISA in 2011 based on the Kaplan Project (2002–2007), which is a management tool for balancing the development of the mineral resources of the "Area" with the protection of the environment (ISA, 2011). In 2012, the ISA Council, on the recommendation of the LTC, approved a REMP for the CCZ in the eastern Pacific Ocean (ISA, 2012). The CCZ REMP used to consist of nine areas of particular environmental interest (APEIs) designed to protect biodiversity and ecosystem structure and functioning within the delineated area and to prohibit, in advance, the exploitation of mineral resources within the delineated area. At present, there are 13 APEIs in the CCZ (ISA, 2021).

In 2018, the ISA Council, in conjunction with the ISA Secretariat's proposal for a "preliminary strategy for the development of a regional environmental management plan for the 'Area'" (ISA, 2018b), agreed to the initial identification of the Mid-Atlantic Ridge, the Triple Junction Ridge and Nodule Belt of the Indian Ocean, the seamounts in the NWP, and the South Atlantic Ocean as the priority areas for the development of REMPs. Focusing on progress on the development of the REMP for the NWP, in May 2018, the Authority, in cooperation with the China Ocean Mineral Resources Research and Development Association (COMRA), organized the first workshop on the development of the REMP for the cobalt-rich ferromanganese crust region of the NWP in Qingdao, China (Permanent Mission of PRC to International Seabed Authority, 2018). A second workshop was convened online in 2020 (ISA, 2020b). Recently, the latest workshop was held in February 2024 in Tokyo (ISA, 2024), which validated and refined the design of the potential area-based management tools (ABMTs) and other issues related to the REMP for the NWP.

As for the development of the standardized approach for the whole REMP, in 2022, the LTC presented the Council with a draft proposal for a standardized approach for REMPs (ISA, 2022). The draft proposal (ISBA/27/C/37) is currently under further review by the LTC based on the Council's deliberations, and eight

stakeholders have submitted written comments on the draft. In the first part of the 29th Session of the ISA in March 2024, The ISA Commission decided at the technical level to support the practical implementation of the standardized approach by developing a guidance document for REMPs (ISA, 2024). The guidance document will be aligned with the standardized procedure and will contain practical and technical details, including the recommended scientific data and information, methodologies and approaches that should underpin the development, establishment and review of REMPs. All the relative documents will be reviewed during the second part of the twenty-ninth Session in July 2024.

In 2012, the ISA Council issued and implemented the Decision Relating to an Environmental Management Plan for the Clarion-Clipperton Zone (CCZ) (ISA, 2012). Since then, ISA has accelerated the construction process of REMPs in mineral resource-rich areas, such as the North Atlantic mid-ridge region and the Northwest Pacific (NWP) region (ISA Council, 2018a). However, the REMPs are hampered by multiple obstacles, thus few significant results have been achieved (Yan, 2021). For example. the REMP of CCZ encounters challenges, including insufficient legal binding and challenges in gathering and submitting environmental data (Zhang and Zhu, 2020). Moreover, due to insufficient data, the Indian Ocean region has not defined the scope for establishing REMPs currently (ISA, 2023). As for Northwest Pacific region, because of the complex ecological environment, the REMP for this region developed slowly. This study focuses on the development and implementation of REMPs. We summarize the difficulties of the construction of the REMP in the NWP region via considering impacts of deep-sea mining on environmental protection at the scientific and institutional levels. In addition, our discussions are extended to global on the ongoing challenges to the whole development of REMPs, in particular the one of where REMPs should go in the light of the impact of the Agreement under the UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (the BBNJ Agreement) on the ISA regime system.

2 Difficulties faced by the REMPs for the NWP

2.1 Overview of NWP

The broad area of the REMP for the NWP region is form 1°N to 40°N and from 132°E to 179°E. In terms of geomorphological and topographical features, the NWP region contains three major seamount groups, i.e., the Marcus-Wake Seamount Group, the Magellanic Seamount Group, and the Marshall Seamount Group, in which the contract areas of Japan, China, Russia, and the Republic of Korea are situated (ISA, 2020b). And the deep-sea pelagic basins of the Nadezhda, Kartagraf, Pigafetta, East Mariana, and Nauru basins are also located in the NWP region. Due to the Mesozoic tectonics and magmatism, the geography and morphology of this region are complex, and the distribution of the seamount chains and intermountain basins that have formed in different periods is irregular. The densest distribution of seamounts makes the region with the richest cobalt crust resources in the world (ISA, 2020c). The main mineral resources, e.g., cobalt-rich crusts, polymetallic nodules, and polymetallic sulfides, have broad mining prospects and are currently explored in the area. The back-arc region of the western Pacific Ocean has more polymetallic sulfides with mining value, while more polymetallic nodules are located in the abyssal plain region of the NWP (ISA, 2020).

In terms of habitats and species composition, the deep sea of the NWP has a complex ecology, with a wide variety of ecosystems, habitats, and species found in the deep waters of the region. Among these, benthic habitats are represented by two unique habitats, i.e., seamounts and abyssal plains. According to scientists' observations of plankton, pelagic fish, and benthic organisms, the surface of the ocean in the NWP region is rich in Prochlorococcus and Proteobacteria, while the benthic habitats are abundant with benthic invertebrates, sponges, corals, and other megafaunas (ISA, 2020c). Many benthic megafaunas are attached to or associated with cold-water corals and sponges, and some of them constitute vulnerable marine ecosystems, which are slow-growing, long-lived, and slow to recover. There is also a wide range of seabirds in the NWP. The area of the NWP, where ISA has awarded contracts for exploitation, overlaps with areas for sharks, marine mammals, and commercial fisheries (ISA, 2020c).

2.2 Impacts of deep-sea mining activities on the ecosystems of the NWP

Currently, some progress has been made in deep-sea mining activities in the NWP region (ISA Maps). For example, ISA has signed exploration contracts for the exploration of cobalt-rich ferromanganese crusts with the Japan Oil, Gas, and Metals National Corporation, COMRA, the Ministry of Natural Resources and Environment of the Russian Federation, and the Government of the Republic of Korea (ISA, 2024). Before actual mining activities, it is necessary to have a comprehensive understanding of the potential impact of deep-sea mining activities on seabed ecosystem, which is what scientists have been analyzing and researching all along. According to Tables 1, 2 (ISA, 2020b), by analyzing the potential impacts on the ecosystems of the NWP from natural and anthropogenic activities in the deep-sea mining process, negative impacts play more important role than positive impacts in the process. Vehicle compaction of soils, alteration of sediment chemistry, mining plumes, return plumes, noise and light from mining vehicles and surface vessels and other activities all have more negative impacts on benthic ecosystems. In particular, the noise and light generated by mining vehicles in the mining area can change the living environment of benthic organisms, thus harming the communication, foraging and reproduction behaviors of many species (ISA, 2020b).

Habitats of seamounts and abyssal plains are unique in the deep sea of NWP. Seamounts have abundant cobalt rich ferromanganese crusts, which are important potential sources of metals and rare earth elements (Hein et al., 2013). However, many seamounts grow very slowly, especially those forming biogenic structures such as

10.3389/fmars.2024.1453760

TABLE 1 Potential effects from mineral resource exploitation activities on the pelagic and abyssal plains of NWP.

No.	Pressure	Direct effect on	Description	Supporting Reference
1	Removal of hard substrate at the seafloor and of the top 10–30 cm of sediment	Microbial communities, Infauna, Epifauna Coral	All nodules will be removed over very broad areas (200 km2 per contractor per year), and nodules will not regrow to appreciable size for millions of years. Mining will destroy the top ~10–20 cm of the sediment column plus the organisms in it over the areas mentioned above. So ecosystems and biogeochemical functions do not regenerate well even over several decades. Removing of hard substances at the seafloor can lead to the rise, fall, and accumulation of sediments. Under the circumstances, the growth rate, reproductive yield, and mortality rate of deep-sea corals decrease.	Weaver and Billett, 2019: Vanreusel et al., 2016: Jones et al. (2017); Gollner et al., 2017. Carreiro-Silva et al., 2013
2	Compaction of the soil by vehicles and alteration of the chemical property of sediment	Microbial communities, Infauna	Sediment compaction under the tracks of the seabed mining tool will reduce porosity and permeability and thereby restrict porewater diffusive exchange and potentially hinder recolonization by benthic fauna. Additionally, the pore water content would be released in the bottom layer, altering the water chemistry of the bottom water, therefore influencing the microbial communities. Finally, the removal of sediment might bring to the surface the oxic–anoxic transition layer (deep oxic–transition layer in the CCZ, but this should be verified for the NW Pacific region).	De Stigter (2020)
3	Mining plume (seabed)	Infauna, Epifauna, Demersal fishes, Invertebrates	The ejected sediment mentioned above will also create a plume of suspended sediment with a high particle load near the mining vehicle where it will smother all seabed animals. At greater distance, filter feeders will be impacted or killed. This plume will also affect animals in the benthic boundary layer, with the plume extending hundreds of meters above the seafloor.	Weaver and Billett (2019): Gillard et al. (2019); Drazen et al. (2019)
4	Return plume (A)	Deep nekton, Deep predators	The water returned from nodule processing on the support ship could be discharged in mid-water where its particulate load will affect suspension feeding animals in the mesopelagic and bathypelagic zones.	Drazen et al. (2019)
5	Return plume (B)	Infauna, Epifauna, Demersal fishes, Invertebrates	If return plume contains toxic contaminants, mortality or severely reduced fitness with potential for sublethal impacts that can persist for years, causing continued degradation.	Drazen et al. (2019)
6	Noise from mining vehicle at the mine site	Demersal fishes and Invertebrates, Deep Nekton, Deep Predators	There is potential for noise from the nodule mining vehicle to impact animals on the seabed and in the benthic boundary layer. Additionally, the proximity of seamounts in the NW Pacific region would induce echo and deflections of the noise generated in the abyssal plains.	

(Continued)

TABLE 1 Continued

No.	Pressure	Direct effect on	Description	Supporting Reference
			Physical trauma to internal organs, reduced fitness, and reduced survivorship for vertebrates and invertebrates have been documented hundreds to thousands of meters from a sound source.	
7	Noise from surface vessel	Birds, Turtles, Whales	Diving sea birds exposed to underwater noise pollution are expected to suffer implications for survival and fitness. Detrimental injury, tissue damage, physical change, and masking of biologically significant sounds may change behavior and compromise fitness, communication, foraging and feeding, bonding, breeding, predator avoidance, habitat avoidance, etc. with long-term impacts and unknown recovery.	Røstad et al. (2006), Solé et al. (2013); Erbe et al. (2018)
8	Noise from pumps on riser pipes in SOFAR (sound-fixing-and-ranging) layer	Whales, deep nekton and deep predators	Sound is transmitted very long distances in the SOFAR layer and it may impact communication between cetaceans that use this layer for their long-distance communication.	Drazen et al. (2019)
9	Light from mine vehicles	Epifauna, Demersal fishes and Invertebrates	Amplifying effects of 3 Mining plume (seabed).	
10	Light from surface vessels	Birds, Fishes	Attracts birds at night, preventing foraging. Light collisions can be fatal or harmful. Lighting may also draw migratory birds to red wavebands. And vast majority of the pelagic community exhibits a strong light-escape response in the presence of artificial light.	Burke et al, 2012; Marquenie et al., 2014; Montevecchi, 2006; Poot et al., 2008; Ludvigsen et al. (2018)
11	Light from surface vessel may affect plankton	Predatory Fishes	Lights can attract and concentrate small fish and squid. These concentrations of fish and squid can, in turn, attract larger predators, such as dolphins, which leads to their higher predation.	Ludvigsen et al. (2018); (Valérie ALLAIN, 2005)
12	Toxicants	Demersal fishes and invertebrates	Metals can affect metabolism. At present, it is not known whether nodule mining will involve the release of metals. If released, toxins can progressively increase in chemical concentration with increasing trophic status (biomagnification), with lethal results.	
13	Marine debris	Phytoplankton, zooplankton, birds, turtles, whales, fishes, predatory fishes, nekton	Marine debris, especially plastics, is one of the rising pressures in the marine environment. The proximity of the western garbage patch to the NW Pacific Region renders this pressure important.	

cold-water corals and sponges (Clark et al., 2010, 2012; Carreiro-Silva et al., 2013). Abyssal plains have plentiful polymetallic nodules. If the nodules are removed during exploitation, all creatures (including demersal scavengers) relying on this hard substrate will be particularly susceptible to mining activities (Vanreusel et al., 2016; Leitner et al., 2017). To evaluate the impact of deep-sea mining activities on the seabed ecosystems, each individual potential mining site should be considered unique and will feature local characteristics that should be assessed accordingly (Cuvelier et al., 2018).

TABLE 2 Potential effects from mineral resource exploitation activities on benthic seamount ecosystem of the NWP.

No.	Types of activities	Direct effect on	Description	Supporting Reference
1	Removal of crust	Population recruitment	Loss of all community components and of habitat. Also removes ability for self-recruitment in the recovery process, and delays recovery by altering larval dispersal, mortality of larvae, and decreased settlement success.	Gollner et al., 2017
2	Plume removal (plume generated by direct removal of crusts), sedimentation	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids, invertebrate detritivores, microbial community, population recruitment	The sedimentation (i.e., particles falling out of suspension) would affect communities negatively by burying everything in the mining site.	
3	Plume removal, suspended sediment	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids	Suspended sediment would affect the filter and suspension feeders (corals, sponges) negatively by clogging feeding system/smothering.	
4	Return plume sedimentation	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges non-stalked crinoids, stalked crinoids, invertebrate detritivores, microbial community, population recruitment	Smothering; increased sediment covers available hard substratum; clogs filter feeding apparatus, loss of suspension feeders. If plume contains toxic pollutants: mortality or severely reduced fitness with potential for sublethal impacts to persist for years causing continued degradation.	Topçu et al., 2019.
5	Return plume–suspended sediment	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids	Increased handling time to sort the "chaff" from suspended matter; diminished fitness.	Anthony and Fabricius, 2000
6	Return plume–temperature	Benthopelagic fishes, local fishes and cephalopods, microbial community	Elevated temperature–effect probably short-lived and long-term impact unlikely. Individuals of some deep-sea species could suffer impeded growth, metabolism, reproductive success, and survival.	Impacts summarised by
7	Return plume sedimentation	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids, invertebrate detritivores, microbial community, population recruitment	Smothering; increased sediment drapes over desirable hard substratum; clogs filter feeding apparatus, loss of suspension feeders.	Topçu et al., 2019
8	Return plume–suspended sediment	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals, soft corals, colonial hard corals, embedded invertebrates, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids	Increased handling time to sort the "chaff" from suspended matter; diminished fitness.	Anthony and Fabricius, 2000

(Continued)

TABLE 2 Continued

No.	Types of activities	Direct effect on	Description	Supporting Reference
9	Noise	Benthopelagic fishes, local fishes and cephalopods, population recruitment	Fish are soundscape sensitive; changes in behavior and physiology documented.	Cox et al., 2018
10	Electromagnetism	Benthopelagic fishes, local fishes and cephalopods	Vibration and pulse would affect the mobile ecological component. The scale is not known.	
11	Light	Benthopelagic fishes, local fishes and cephalopods, invertebrate detritivores, invertebrate predators, invertebrate scavengers	Fish with visual systems affected; rods overwhelmed.	Widder et al., 2005
12	Toxicants	Benthopelagic fishes, local fishes and cephalopods	The toxicity associated with leaching crusts depends on the metal content of the crusts. However, how the elevated level of metal (e.g., As, Cu) would influence the organisms is uncertain. It might concentrate along the food chain, and as such influence mainly BPF and LFC. There is a risk of bioaccumulation at higher trophic levels.	
13	Abandoned equipment	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals and soft corals, plus colonial hard corals, encrusting sponges, glass sponges, non-stalked crinoids, stalked crinoids	Assuming there are no toxic chemicals or paints associated with the structures: anthropogenic structures provide elevation off bottom to access currents—promote settlement; eventually structure loss (erosion or cleanup) will destroy the recruits.	Schlining et al., 2013
14	Abandoned equipment	Carnivorous sponges, filter feeding sea stars, solitary hard corals, tunicates, rock pens, other corals and soft corals, plus colonial hard corals, encrusting sponges, glass sponge, non-stalked crinoids, stalked crinoids	Addition of hard substrate can create new habitat, assuming there are no toxic chemicals or paints associated with the structures.	

2.3 Difficulties faced by the REMP for the NWP

The hot-discussed REMP area in previous workshops is from 10°N to 27°N and from 146°E to 164°E (ISA, 2020b). In 2018, the ISA Council preliminarily agreed that the NWP should also be prioritized to establish REMP, and in May of the same year in Qingdao, China, the ISA organized a workshop on the development of REMP for the cobalt-rich ferromanganese crusts in the NWP (ISA, 2018b). The workshop aimed to understand national, regional, and international policies and laws, reach a common understanding of the design of REMP for the NWP region, form an initial framework for the development of REMP, and develop a two- to three-year cooperative plan to collect and share the data needed to design the REMP (ISA, 2018b). In November 2020, in collaboration with the Korean Ministry of Oceans and Fisheries and the Korea Institute of Ocean Science and Technology, the ISA hosted the second online workshop to develop REMP for the NWP. Based on the first workshop, this workshop comprehensively reviewed and analyzed relevant scientific data for the NWP (ISA, 2020a). During the workshop period, current exploration activities and resource distribution in the contract areas within the region are reviewed, and 14 potential areas in need of precaution (AINPs) were defined because these AINPs may be affected by future mineral resource exploitation and require enhanced management and preventive measures (ISA, 2020b). Moerover, this workshop also discussed a framework for addressing the cumulative impacts of future exploitation in order to achieve effective protection of the marine environment. So far, the two workshops have made some progress in the REMP for the NWP, however, there are more specific difficulties that need to be solved. In 2024, ISA accompanied with Japan Organization for Metals and Energy Security (JOGMEC) and Deep Ocean Resources Development etc., held a workshop on the development of the REMP for the NWP region (JOGMEC, 2024). Discussions and proposals from this workshop will contribute to the creation of rules for the development of mineral resources on the deep-sea floor of the NWP (ISA, 2024). By summarizing the content of the three workshops, we demonstrate some difficulties currently faced in construction of REMP in the NWP region in the following.

2.3.1 Difficulty in data acquisition on regional environmental assessment for the NWP

The regional environmental assessment (REA) report is one of the most important scientific bases for the development of the REMP for the NWP region. The report focuses on the scientific research that have been and are being conducted in the NWP region. The content of the REA report is organized according to the recommendations of the ISA in ISBA/25/LTC/6/Rev.1 (ISA Legal and Technical Commission, 2019) and centers on the need to carry out environmental baseline studies (ISA, 2020c). It collects and analyzes existing scientific data in the NWP region mainly from geology, oceanography, and biology. The REA report contains both environmental scientific data for the NWP region as a whole and site-specific scientific data, such as seamounts and abyssal plains. In addition, other environmental scientific data that may be lacking in the NWP region is also identified in the REA report (ISA, 2020c). However, there are still gaps in the content of the REA report. For example, the "depth band analysis" approach used at the workshop to analyze the selection of potential AINP locations is limited by the low resolution of the bathymetric data used. It would make mistakes that these data identify hilltops rather than individual seamounts, which would be an overstatement of the actual situation if interpreted as representative of individual seamounts. Just modeling with the data alone will lead to deviations from the reality of the ecosystems, constituting a challenge for the completion of the REA report (ISA, 2020c). Therefore, bathymetric data still need to be perfect through further scientific research on the NWP region.

2.3.2 Difficulties in data acquisition for the draft data report for the NWP

The data report for the NWP was prepared for the 2020 online workshop and is another important scientific basis for the development of the REMP for the NWP region. The data report covers several aspects, including environmental, biological, and biogeographic, human activities, and areas defined for management or conservation purposes. Most of the scientific data is unique to the NWP region and comes from open-access data sources such as contractors, relevant international organizations and scientific institutions such as Duke University (ISA, 2020a). However, expert Patrick Halpin, who participated in the 2020 workshop, pointed out that the existing data is not sufficient to establish REMP for the NWP region (ISA, 2020a). There is also a large amount of scientific data and papers on the NWP region that are not currently available in open resources. The difficulties in scientific data acquisition further hinder the advancement of the REMP for NWP.

2.3.3 Difficulties in predicting the impacts of deep-sea mining on benthic ecosystem in the NWP

Abundant seamounts and abyssal plains are lying in the deep sea of NWP region. At present, the NWP region contains five contract areas [Table 3 (ISA, 2020b)], which is surrounded by the Marcus-Wake Seamounts Chain, the Magellan Seamounts Chain, and the Marshall Seamounts Chain, sometimes referred to as the Triangle Area (TA) (ISA, 2020b). The ecosystems in the TA are also unique in the NWP region. On the one hand, the underlying geology of seamounts consists of a variety of morphologies, including rubble, nodules, and rocks, while complex topography of seamounts implies the complex ecosystems. For instance, some ecosystems are slow-recovering, less resilient, fragile, and more vulnerable to be damaged (ISA, 2020a). On the other hand, the biodiversity of seamounts is affected by many environmental factors, such as hydrodynamics, chemical condition changes, and the topography and geology of the seamounts (ISA, 2020a). However, due to the lack of current scientific data in the NWP region, the resilience of the ecosystems in the area is still confusing, leading to the extreme challenge to conservation of marine biodiversity in the area (ISA, 2020a).

Meanwhile, deep-sea areas have been already adversely affected by warming, acidification, pollution, and overfishing, and may be negatively impacted by future deep-sea mining activities, including changes in seawater temperature and material, light and noise pollution from human mining activities, and potentially toxic contaminants. These disturbances may alter the survival mode of deep-sea biological communities, impair physiological functions, and decrease reproductive rates (ISA, 2020a).In addition, there is still lack of scientific data on the multi-scale distribution, trophic relationships, ecosystem functioning, connectivity, and resilience of biological communities in the deep-sea environment. Therefore, the prediction of the damage to deep-sea ecosystems caused by deep-sea mining activities is facing great difficulties.

TABLE 3 ISA exploration contracts in the NWP.

Contractor	Mineral resources	Date of entry into force	Date of expiry	Sponsoring state
Japan Oil, Gas and Metals National Corporation (JOGMEC)	Cobalt-rich ferromanganese crusts	27 Jan 2014	26 Jan 2029	Japan
China Ocean Mineral Resources Research and Development Association (COMRA)	Cobalt-rich ferromanganese crusts	29 Apr 2014	28 Apr 2029	China
Ministry of Natural Resources and Environment of the Russian Federation (MNRE)	Cobalt-rich ferromanganese crusts	10 Mar 2015	09 Mar 2030	Russia
The Republic of Korea (RoK)	Cobalt-rich ferromanganese crusts	27 Mar 2018	26 Mar 2033	Republic of Korea
Beijing Pioneer High-tech Development Corporation (BPHDC)	Polymetallic nodules	18 October 2019	17 October 2034	China

3 Challenges faced by REMPs in global

Under the background of coping with climate change, reducing greenhouse gas emissions and vigorously advocating new clean energy, such as secondary batteries and solar energy, have become hot spots and achieved great commercial success. Materials such as lithium, cobalt and graphite are essential components of electric car batteries, wind turbines, solar panels and other low-carbon technologies that can power the world's clean energy systems. According to Table 4, with the dramatic increase of demand for mineral resources, the deep-sea mining activities have attracted great attention in global (Ashford et al., 2024). Due to the progress made in deep-sea scientific research, scientific community and governments gradually realize the negative impacts of deep-sea mining activities on the marine environment and biodiversity of habitats in deep sea. At the same time, the conservation of marine biodiversity of areas beyond national jurisdiction has received increasing international attention with the adoption of the BBNJ Agreement in 2023 (Table 5).

REMPs, as one of the most important tools for environmental protection in deep-sea mining, play more and more significant roles for ISA and other stakeholders. Eleven years have passed since the approval of the first REMP for the CCZ, although all relevant countries are actively promoting the establishment of REMPs in the Mid-Atlantic Ridge, the NWP and other regions, the ISA has not approved a second REMP yet. Obviously, in a reshaping period of global ocean governance rule, the development of the REMP, as an important institutional practice for deep seabed environmental governance, is faced with a few challenges.

TABLE 4 Deep-sea mining activities in other seas and oceans except NWP.

Other seas and oceans	Related mining activities
the Clarion-Clipperton Zone in Pacific Ocean (under ISA)	This mineral-rich region already hosts exploration contracts for 17 deep-sea mining contractors, with their combined exploration areas covering approximately 1 million square kilometers (about the same area as Ethiopia).
the Indian Ocean (under ISA)	Germany, India, China, and Korea have five exploration contracts in sum in the two regions of the Indian Ocean.
the Mid Atlantic Ridge (under ISA)	Poland, Russia, and France have three exploration contracts in sum.
the arctic regions (not under ISA)	Norway announced in June 2024 the opening of vast areas of its continental-self in the Arctic region for its first seabed mineral licensing round. The government proposed putting forward 386 blocks in the Arctic as part of the round. The area comprises about 38% of the 280,000 square kilometers approved by the parliament for exploration earlier. The country plans to grant exploration permits in the first half of 2025.
the domestically controlled waters (not under ISA)	All countries can go ahead with deep-sea mining projects in their own domestically controlled waters' seabed, for example the exclusive economic zones. In January 2024, Norway initiated a process to open its own waters for exploration of deep-sea mineral resources, likely starting in the early 2030s.

3.1 Arguments about the legal force of REMPs

There are always arguments about the legal force of REMPs. The fact is that no REMP has not clearly emerged from the institutional framework for the exploitation of the mineral resources of the "Area" (including the three sets of Exploration Regulations and the draft Mining Code that is currently being formulated). Currently, the REMP is only recognized as an environmental protection policy issued by the ISA. This directly leads to questions being raised by parties to UNCLOS and the Implementation Agreement, contractors, states, and the ISA itself as to whether the REMP is legally binding, and what liability should be incurred in the event of non-compliance. For example, the Regulations on Prospecting and Exploration for Polymetallic Nodules in the "Area" (ISA, 2013) require contractors to

TABLE 5 All abbreviations used in this article.

Abbreviations used	Original Words
REMPs	Regional Environmental Management Plans
ISA	The International Seabed Authority
NWP	Northwest Pacific
the BBNJ Agreement	the Agreement under the UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction
TMC	The Metals Company
the Implementing Agreement	the implementation of Part XI of the United Nations Convention on the Law of the Sea
UN	The Untied Nations
the Mining Code	the draft exploitation regulations for mineral resources in the international seabed area
the"Area"	the international seabed area
LTC	the Legal and Technical Commission
UNCLOS	the United Nations Convention on the Law of the Sea
CCZ	the Clarion-Clipperton Zone
APEIs	areas of particular environmental interest
COMRA	China Ocean Mineral Resources Research and Development Association
ABMTs	area-based management tools
AINPs	areas in need of precaution
JOGMEC	Japan Organization for Metals and Energy Security
REA	The regional environmental assessment
TA	the Triangle Area
EIA	the Environment Impact Assessment

submit an environmental plan when applying for a mine site. According to the plan, contractors need to assess and monitor the impacts of their activities on the marine environment of the "Area" during their activities. After that, a report is submitted to the Secretary-General of the ISA on environmental monitoring, as well as the environmental baseline data that may be used as scientific data to support the REMP. However, UNCLOS, the Implementation Agreement, and the Regulations on Prospecting and Exploration for Polymetallic Nodules in the "Area" do not explicitly require states and contractors to implement the REMP provisions of the CCZ. Therefore, as a matter of implementation, contractors within the CCZ do not currently have any obligations for the protection of the marine environment beyond the scope of the contract, and the REMP for the CCZ is only an environmental policy tool that is not legally binding on contractors. In other words, contractors are only obligated to protect the environment in the contractual area, while areas beyond the contracts in the CCZ are not protected by contractors.

3.2 Conflicts between REMPs and the BBNJ agreement

REMPs aim to implement the area-based management tools (ABMTs), and compile scientific information to accurately describes potential areas that are protected from future development activities. From the content of a series of workshops, it appears that the ISA intends to use REMP as an ABMT for the protection of the deep-sea environment in the future. One of the tasks of the 2024 REMP workshop for the NWP region is to validate and refine the design of potential ABMTs identified in the previous online workshop, and review and further improve the scientific rationale for the identification of such potential ABMTs based on agreed scientific criteria. The BBNJ Agreement is an important piece of current legislation in the field of the law of the sea, which aims to address the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction. "Areas beyond national jurisdiction" is defined by the BBNJ Agreement, which includes the International Seabed Area. However, if ISA explicitly defines the REMP as an ABMT in the future, there will be conflicts between the application of the REMP to deep-sea environmental protection in the "Area" and the ABMT set out in the BBNJ Agreement.

Firstly, in view of the ecological connectivity of the oceans, it is difficult to allocate marine organisms in areas beyond national jurisdiction to the high seas or the "Area" separately. Therefore, the REMP formulated by ISA is different from the ABMTs provided by the BBNJ Agreement, especially in aspects of their purpose, legal basis, scope and application background. Compare with the latter, the existing area-based management practice of ISA is also more abundant (including Impact Reference Zones, Preservation Reference Zones, APEIs, etc.). As a result, the environmental protection of the "Area" is faced with the problem of dealing with and choosing the relationship between multiple area management tools.

Secondly, the inter-institutional cooperation mechanisms are not clear. Although the international community has been encouraging the harmonization of policies promoting oceans, climate and biodiversity, there appears to be inertia and a tendency to maintain the status quo among parties in the governance of the ABNJ, as reflected in the BBNJ agreement and the ISA-led formulation of the REMP. If the REMP is defined as a ABMT, the current BBNJ Agreement does not provide detailed mechanisms on how to improve inter-institutional cooperation, nor does it contain specific provisions for the implementation of integration or monitoring, but rather it allows the state parties to promote coherence and complementarity in the establishment of ABMTs and ecosystem management in ABNJ.

Thirdly, there are problems in the application of Environment Impact Assessments (EIAs) established by the ISA and the BBNJ Agreement for specific EIA projects (Christiansen et al., 2022). Based on UNCLOS, Part XI and the 1994 Agreement, ISA has developed detailed and substantive provisions, regulations and recommendations related to the assessment of possible environmental impacts arising from exploration for marine minerals in the Area, which define the sort of activities that require EIAs, the form and content of such EIAs when required, as well as guidance on baseline studies, monitoring and reporting (ISA, 2019). EIA thus plays an important role in the establishment of REMP. The BBNJ Agreement also has detailed regulations on EIAs (UN, 2023). Compared with the regulations by BBNJ Agreement, the guidance of EIA formulated by ISA addresses impacts on marine biodiversity on the seabed and in the water column. One of the problems is that there is a contradiction between following the EIA by the BBNJ agreement or the ISA guidance at the time to conduct an EIA during the process of establishing REMP. The BBNJ Agreement stipulates that it is not necessary to conduct an EIA of a planned activity in areas beyond national jurisdiction if the potential impacts of the planned activity have been assessed in accordance with the requirements of other relevant legal instruments or frameworks or by relevant global, regional, subregional or sectoral bodies (UN, 2023). Under this regulation, if the EIA is completed in accordance with the guidance of ISA, another problem is that information exchange mechanism of EIA is not perfect for relevant contracting parties.

Overall, the autonomy of sectoral organizations hinders integrated management and effective cooperation in ocean governance. Deep-sea environmental protection requires comprehensive and integrated governance, but the current ABMTs were established by various international organizations in a relatively isolated legal background. The current legal force of REMP is still uncertain, and if it is given legal force in the future, the strength difference of the respective legal force between the REMP and BBNJ agreements, as well as the order of their applications, are all issues that need to be taken into account under the UNCLOS system in the "Area".

3.3 Absence of regulations for balancing exploitation and conservation

In 2022, the Council of ISA made a draft decision relating to a standardized approach for the development, approval and review of

REMPs in the "Area" (ISBA/27/C/L.5), in which the goal of REMPs has been listed. However, the draft decision were not adopted by the Assembly yet. And the construction process and top-level objectives of the REMP are not clarified in the latest relevant strategic plans, like the strategic plan for the period 2024–2028(ISBA/28/A/7). Moreover, UNCLOS obliges the ISA to take measures to ensure that the marine environment is protected from harmful effects that may arise from activities in the "Area". The provisions of the existing REMP, one of the ISA's unique environmental policies, are inadequate, especially in finding a balance between environmental protection and the exploitation of the mineral resources in the "Area".

There is a dispute among the parties to the Implementing Agreement as to whether the Mining Code currently being negotiated by the ISA should regulate REMPs (ISA, 2019). In July 2019, representatives of the United Kingdom, Germany, the Netherlands, and a number of African countries argued that REMPs should be a prerequisite for mining activities, while another voice, represented by China, emphasized that REMPs should not be a stumbling block to commercial development (ISA, 2019). REMPs are currently not explicitly regulated in the latest draft of the revised Mining Code. It is only mentioned in Fundamental Policies and Principles in Mining Code as well as the Environmental Impact Statement Regulations. However, in terms of the REMP, the criteria, guidelines, its relationship with the Mining Code, the review mechanism, and the roster of independent reviewers are also controversial among countries. No legal document has been issued on the general norms, and the draft recommendation on the standardized methodology of the REMP (ISA, 2022), which was submitted by the Legal and Technical Commission (LTC) to the Council of the ISA in 2022, is still in the review stage (Zeng and Gao, 2020). These deficiencies make it difficult to prove that REMP neither infringes upon the legitimate rights of countries to explore and exploit the mineral resources in the "Area" in accordance with the UNCLOS principle of "common heritage of mankind", nor overprotects the environment of the "Area".

The formulation of environmental rules for the "Area" and the negotiation and formulation of draft Mining Code are mutually constraining. As seen from the latest draft of the Mining Code, the environmental rules still need to be improved. The environmental management of the ISA is weak, because it only provides a more general framework for the procedures related to environmental protection, and fails to formulate relevant and effective measures and normative standards in accordance with the provisions of Article 145 of UNCLOS. It can be seen that the ISA's 2024–2028 strategy only reflects the principles for the establishment of the REMP, but the overall objectives and specific content regarding the REMP remain unclear. In a word, it is the insufficiency of REMP participation in practice and indeterminacy of the specific rights and obligations of REMP's governing organs and stakeholders that result in a slow process of REMP development.

4 Suggestions for challenges faced by REMPs

4.1 Promote national engagement in REMPs by developing and improving the mining code

Focusing on the arguments about the legal force of REMPs, the first suggestion we propose is that the ISA should add encouragement clauses to the Mining Code to encourage states parties, sponsoring states, and contractors to actively participate in the construction of REMPs.

As mentioned in Section 3.1, neither the UNCLOS Implementing Agreement nor the three Exploration Regulations contain specific provisions for the REMP. It was not until 2012 that the REMP for the CCZ was officially issued and implemented, a decade after the Kaplan project in 2002. The fact that REMPs, as an environmental protection policy, are not legally binding is one of the main challenges faced in their implementation, which was also prominent in the discussions on the establishment of the REMP for the NWP. Therefore, when it comes to the exploitation of deep seabed mineral resources, the implementation of the REMP needs to be more efficient. The Secretariat of the ISA has suggested that, as an environmental policy, the Council could decide that no contracts should be awarded in the relevant area until the REMP is established.

At present, the Mining Code is about to be introduced, and the REMPs for priority regions such as the NWP will also conduct new workshop to form the text of relevant motions. If the Mining Code includes provisions encouraging states parties, sponsoring states, and contractors to actively participate in the construction of REMPs, it can not only increase the degree of national participation and the recognition of REMPs through the expansion of national practices (Ardito and Rovere, 2022), but also provide a relatively binding legal basis for the implementation of REMPs by the States Parties and contractors, thereby solving the problem of the development procedure and legal binding force of emerging programs such as the REMP for the NWP.

4.2 Coordinate the application between REMPs and BBNJ agreement through ISA

As for the conflicts between REMPs and the BBNJ Agreement, we suggest that the ISA should play a leading role in coordinating the application between REMPs and BBNJ Agreement.

The rules formulated by ISA and the BBNJ Agreement were originally two sets of rules regimes developed in parallel under the UNCLOS system. However, conflicts have arisen between the application of the two sets of rules in the "Area", especially in the application of the ABMTs. Firstly, a fact should be recognized that there is no conflict of purpose between the REMP and the BBNJ Agreement, both of which are aimed at the protection of the deep-sea environment. On that basis, there should be a inter-institutional

coordinating organ to facilitate communication and data-sharing between the REMP and BBNJ Agreements. Up to now, the BBNJ agreement has been finalized, while many of ISA's rules are still in the process of being formulated. Given that ISA has accumulated a wealth of management experience in "Area" issues, it can be considered to be responsible for issues such as communication and data sharing with the BBNJ Agreement.

Secondly, the framework and content design of the REMP should be improved based on the BBNJ Agreement. ISA can set up a supervisory mechanism to regularly check the implementation and monitoring of the management and protection measures of the REMP, as well as cooperate and share information and data with the competent agencies of the BBNJ Agreement. At present, several APEIs have been delineated in the REMP for NWP, and the BBNJ Agreement implements ABMTs aimed at conserving biodiversity in the "Area". Based on that basis, besides prohibiting mining in APEIs, attention should also be paid to collecting relevant scientific data on biodiversity in APEIs and analyzing the influence of mining activities out of the APEIs on biodiversity in APEIs. Meanwhile, ISA should play a leading role in coordinating the REMP for NWP with the BBNJ Agreement to achieve the objectives of protecting the environment, implementing and monitoring of the ABMTs and the EIA, and making timely adjustments in accordance with the BBNJ Agreement.

4.3 Improve the regulations of REMPs with the principle of scientific evidence

To solve the problem of lacking regulations for balancing exploitation and conservation, we recommend that it is necessary to improve the regulations of REMPs with the principle of scientific evidence.

The purpose of REMP is not to prohibit deep-sea mining, but rather to protect the deep-sea environment in the face of uncertainty impacts of deep-sea mining. At a deeper level, the protection of the deep-sea environment by REMP is, in a sense, aimed at better formulating exploitation regulations and promoting sustainable development for the common interests of mankind. The principle of scientific evidence, which is generally found in international treaties in the field of environment, ecology, and health, is an important basis for action and decision-making by relevant subjects of international law in risk areas. Scientific data needs to be translated into information, and finally knowledge, that is practical and communicated to fit into existing or planned processes and procedures. A disconnect between scientists and seabed-mining policymakers may result in interactions related to science being abstract, jargon-filled (e.g., ecosystem approach), and unspecific, which can sometimes lead to miscommunication and planning error (Amon, D. J. et al., 2022).

According to the experience of the REMP for the NWP, the establishment of any new REMP requires a large amount of scientific data support. Therefore, it is of crucial importance to construct a sound environmental data collection and verification mechanisms for REMPs. In the discussion of the REMP for the NWP, it can be found that the environmental baseline data collected by contractors play an important role. However, the fact that the quality and quantity of data submitted by contractors is uneven, necessitates the establishment of a comprehensive set of criteria for the collection and certification of data in order to ensure the availability of data. Besides, the obligation of contractors to submit environmental baseline data is still limited to the scope of the contract, because contractors are not obliged to collect environmental data outside the contract area. For environmental baseline data beyond contractual obligations, the ISA needs to establish an incentive mechanism aimed at motivating contractors, sponsoring states, state parties, and other scientific institutions to actively participate in the collection of environmental data (Ginzky et al., 2020). For example, the ISA currently has a centralized database (deep data) of public and private information data on marine mineral resources obtained from various institutions around the globe. Through the incentive mechanism,

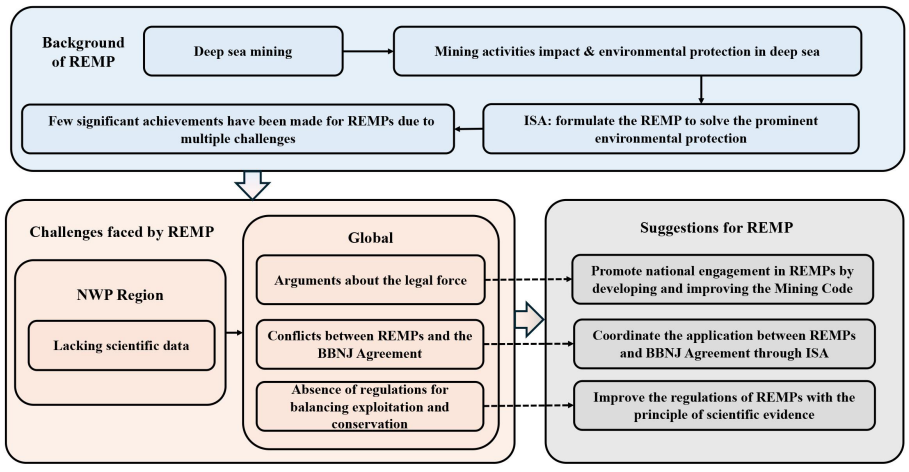


FIGURE 1
Flow chart showing all sections and new insights.

it is practicable to attract various entities to participate in the construction of the deep sea database under unified data standards, which is vital for the development of the establishments of REMPs from NWP to global.

5 Conclusion

In summary, we have systematically investigated the challenges faced by REMPs under the background of deep-sea mining. We firstly review the historical evolution of REMP. By analyzing the status of REMPs for NWP region, we find that the main difficulty for NWP REMP is the lack of deep-sea scientific data. Further, we discuss and point out three challenges faced by REMPs in global, which are arguments about the legal force of REMP, conflicts between REMPs and the BBNJ Agreement and absence of regulations for balancing exploitation and conservation. Focusing on the difficulties and challenges faced by REMPs from NWP to global, we propose three suggestions that promote national engagement to strengthen the legal force of REMPs by developing and improving the Mining Code, coordinate the application to solve the conflicts between REMPs and BBNJ Agreement through ISA and improve the regulations of REMPs with the principle of scientific evidence to balance conservation and exploitation. From a new perspective (Figure 1), we believe this work is of great value for the development of REMPs from NWP to global under the background of deep-sea mining.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

WZ: Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. TL: Data curation, Investigation, Methodology, Writing – review & editing. XQ: Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work is supported by Qingdao postdoctoral funded project "Research on new trends of 'regional' mineral resources development system and China's Countermeasures under the background of climate change" (QDBSH20240102094).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Amon, D. J., Gollner, S., Morato, T., Smith, C. R., Chen, C., Christiansen, S., et al. (2022). Assessment of scientific gaps related to the effective-environmental management of deep-seabed mining. *Mar. Policy* 138, 105006. doi: 10.1016/j.marpol.2022.105006

Anthony, K. R., and Fabricius, K. E. (2000). Shifting roles of heterotrophy and autotrophy in coral energetics under varying turbidity. *J. Exp. Mar. Biol. Ecol.* 252, 221–253. doi: 10.1016/S0022–0981(00)00237–9

Ardito, G., and Rovere, M. (2022). Racing the clock: Recent developments and open environmental regulatory issues at the International Seabed Authority on the eve of deep-sea mining. *Mar. Policy* 140, 105074. doi: 10.1016/j.marpol.2022.105074

Ashford, O., Baines, J., Barbanell, M., and Wang, Ke (2024). *What We Know About Deep-sea Mining and What We Dont*. Available online at: https://www.wri.org/insights/deep-sea-mining-explained (Accessed May 15, 2024).

Blanchard, C., and Gollner, S. (2022). Area-based management tools to protect unique hydrothermal vents from harmful effects from deep-sea mining: A review of ongoing developments. *Front. Political Sci.* 4. doi: 10.3389/fpos.2022.1033251

Burke, C. M., Montevecchi, W. A., and Wiese, F. K. (2012). Inadequate environmental monitoring around offshore oil and gas platforms on the Grand Bank of Eastern Canada: Are risks to marine birds known? *J. Environ. Manage.* 104, 121–126. doi: 10.1016/j.jenvman.2012.02.012

Carreiro-Silva, M., Andrews, A. H., Braga-Henriques, A., Matos, V., Porteiro, F. M., and Santos, R. S. (2013). Variability in growth rates of long-lived black coral Leiopathes sp. from the Azores (Northeast Atlantic). *Mar. Ecol. Prog. Ser.* 473, 189–199. doi: 10.3354/meps10052

Christiansen, S., Durussel, C., Guilhon, M., Singh, P., and Unger, S. (2022). Towards an ecosystem approach to management in areas beyond national jurisdiction: REMPs for deep seabed mining and the proposed BBNJ instrument. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.720146

Clark, M. R., Rowden, A. A., Schlacher, T., Williams, A., Consalvey, M., Stocks, K. I., et al. (2010). The ecology of seamounts: structure, function, and human impacts. Annu. *Annu. Rev. Mar. Sci.* 2, 253–278. doi: 10.1146/annurev-marine-120308–081109

Clark, M. R., Schlacher, T. A., Rowden, A. A., Stocks, K. I., and Consalvey, M. (2012). Science priorities for seamounts: research links to conservation and management. *PloS One* 7, e29232. doi: 10.1371/journal.pone.0029232

Cox, K., Brennan, L. P., Gerwing, T. G., Dudas, S. E., and Juanes, F. (2018). Sound the alarm: A meta-analysis on the effect of aquatic noise on fish behavior and physiology. *Global Change Biol.* 24, 3105–3116. doi: 10.1111/gcb.14106

Cuvelier, D., Gollner, S., Jones, D. O., Kaiser, S., Arbizu, P. M., Menzel, L., et al. (2018). Potential mitigation and restoration actions in ecosystems impacted by seabed mining. *Front. Mar. Sci.* 5. doi: 10.3389/fmars.2018.00467

De Stigter, H. (2020). *Blue Nodules Deliverable report D5.3 Report on seabed substrate alteration (publishable summary)*. Available online at: https://cordis.europa.eu/project/id/604500/reporting (Accessed July 20, 2024).

Drazen, J. C., Smith, C. R., et al. (2019). *Report of the workshop Evaluating the nature of midwater mining plumes and their potential effects on midwater ecosystems*. Available online at: https://pdfs.semanticscholar.org/eb2d/f620ef070ba0a509b8aa77081219bea95647.pdf (Accessed July 20, 2024).

Du, K., Xi, W., Huang, S., and Zhou, J. (2024). Deep-sea mineral resource mining: A historical review, developmental progress, and insights. Mining, mining. *Metallurgy Explor.* 41, 173–192. doi: 10.1007/s42461–023-00909–9

Erbe, C., Dunlop, R., and Dolman, S. (2018). "Effects of noise on marine mammals," in *Effects of Anthropogenic Noise on Animals*. Eds. H. Slabbekoorn, R. J. Dooling, A. N. Popper and R. R. Fay (Springer, Berlin, Heidelberg), 277–308.

Gillard, B., Purkiani, K., Chatzievangelou, D., Vink, A., Iversen, M. H., and Thomsen, L. (2019). Physical and hydrodynamic properties of deep sea mining-generated, abyssal sediment plumes in the Clarion Clipperton Fracture Zone (eastern-central Pacific). *Elem Sci. Anth* 7, 5. doi: 10.1525/elementa.343

Ginzky, H., Singh, P. A., and Markus, T. (2020). Strengthening the International Seabed Authority's knowledge-base: Addressing uncertainties to enhance decision-making. *Mar. Policy* 114, 103823. doi: 10.1016/j.marpol.2020.103823

Gollner, S., Kaiser, S., Menzel, L., Jones, D. O., Brown, A., Mestre, N. C., et al. (2017). Resilience of benthic deep-sea fauna tomining activities. *Mar. Environ. Res.* 129, 76–101. doi: 10.1016/j.marenvres.2017.04.010

Greenpeace. (2024). *Under the Deep Sea Treasure-A Review of the Current Status of Deep Sea Mining and its Environmental Impact Mechanisms*. Available online at: https://www.greenpeace.org.cn/report-list/deep-sea-mining-briefing/ (Accessed May 25, 2024).

Hein, J. R., Mizell, K., Koschinsky, A., and Conrad, T. A. (2013). Deep-ocean mineral deposits as a source of critical metals for high-and green-technology applications: comparison with land-based resources. *Ore Geology Rev.* 51, 1–14. doi: 10.1016/j.oregeorev.2012.12.001

Howell, K. L., Hilário, A., Allcock, A. L., Bailey, D. M., Baker, M., Clark, M. R., et al. (2020). A blueprint for an inclusive, global deep-sea ocean decade field program. *Front. Mar. Sci.* 7. doi: 10.3389/fmars.2020.584861

IISD. (2019). *Summary report, 15–26 July 2019–2nd Part of the 25th Annual Session of the International Seabed Authority (ISA)*. Available online at: https://enb.iisd.org/events/2nd-part-25th-annual-session-international-seabed-authority-isa/summary-report-15–26-july (Accessed June 8, 2024).

ISA *Maps*. Available online at: https://www.isa.org.jm/exploration-contracts/maps/ (Accessed May 30, 2024).

ISA. (2018). *ISA/COMRA Workshop on the Development of REMP for Cobalt-Rich Ferromanganese Crusts*. Available online at: https://www.isa.org.jm/events/isa-comra-workshop-on-the-development-of-remp-for-cobalt-rich-ferromanganese-crusts/ (Accessed May 25, 2024).

ISA. (2020a). *Draft data report: Produced as a background document for the workshop on the development of a regional environmental management plan for the area of the Northwest Pacific*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/12/Northwest-Pacific-REMP-Data-Report-v1.pdf (Accessed May 20, 2024).

ISA. (2020b). *Workshop on the Regional Environmental Management Plan for the Area of the Northwest Pacific*. Available online at: https://www.isa.org.jm/events/workshop-on-the-regional-environmental-management-plan-for-the-area-of-the-northwest-pacific/ (Accessed May 30, 2024).

ISA. (2020c). *Regional environmental assessment for the Northwest Pacific Ocean-Background document prepared for the workshop on the development of a regional environmental management plan for the Area of the Northwest Pacific*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/12/NW-Pacific-REA_19July_2022.pdf (Accessed June 8, 2024).

ISA. (2023). *Workshop on the development of a REMP for the Area of the Indian Ocean, with a focus on the mid-ocean ridges and central Indian Ocean basin*. Available online at: https://www.isa.org.jm/events/workshop-on-the-development-of-a-remp-for-the-area-of-the-indian-ocean-with-a-focus-on-the-mid-ocean-ridges-and-central-indian-ocean-basin/ (Accessed August 6, 2024).

ISA. (2024). *ISA Council closes the first part of its 29th session with approval of MoU with FAO and further progress in negotiations on the draft exploitation regulations*. Available online at: https://www.isa.org.jm/news/isa-council-closes-the-first-part-of-its-29th-session-with-approval-of-mou-with-fao-and-further-progress-in-negotiations-on-the-draft-exploitation-regulations/ (Accessed May 20, 2024).

ISA Assembly. (2013). *Decision of the Assembly of the International Seabed Authority regarding the amendments to the Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area, 25 July 2013, ISBA/19/A/9*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/06/isba-19a-9_0.pdf (Accessed June 6, 2024).

ISA Council. (2012). *Decision of the Council relating to an environmental management plan for the Clarion-Clipperton Zone, 26 July 2012, ISBA/18/C/22*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/06/isba-18c-22_0.pdf (Accessed June 1, 2024).

ISA Council. (2018a). *Relationship between the draft regulations on exploitation of mineral resources in the Area and regional environmental management plans, 20 December 2018, ISBA/25/C/4, paras.1–4*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/06/25c-4-e_0.pdf (Accessed May 30, 2024).

ISA Council. (2018b). *Preliminary strategy for the development of regional environmental management plans for the Area, 16 January 2018, ISBA/24/C/3*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/06/isba24-c3-e.pdf (Accessed June 6, 2024).

ISA Council. (2019). *Draft regulations on exploitation of mineral resources in the Area, 22 March 2019, ISBA/25/C/WP.1*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/06/isba_25_c_wp1-e_0.pdf (Accessed June 6, 2024).

ISA Council. (2021). *Decision of the Council of the International Seabed Authority relating to the review of the environmental management plan for the Clarion-Clipperton Zone, 10 December 2021, ISBA/26/C/58*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/06/ISBA_26_C_58_E.pdf (Accessed June 6, 2024).

ISA Council. (2022). *Guidance to facilitate the development of regional environmental management plans-report and recommendations by the Legal and Technical Commission, 10 August 2022, ISBA/27/C/37*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/12/2212509E.pdf (Accessed June 8, 2024).

ISA Council. (2024). *Report of the Chair of the Legal and Technical Commission on the work of the Commission at the first part of its twenty-ninth session, 15 March 2024, ISBA/29/C/7*. Available online at: https://www.isa.org.jm/wp-content/uploads/2024/03/2404997E.pdf (Accessed June 8, 2024).

ISA Legal and Technical Commission. (2011). *Environmental management plan for the Clarion-Clipperton Zone, 13 July 2011, ISBA/17/LTC/7*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/06/isba-17ltc-7_0.pdf (Accessed June 1, 2024).

ISA Legal and Technical Commission. (2019). *Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area, 18 April 2019, ISBA/25/LTC/6/Rev.6*. Available online at: https://www.isa.org.jm/wp-content/uploads/2023/08/2315256E.pdf (Accessed June 6, 2024).

JOGMEC. (2024). *Workshop on the Development of a Regional Environmental Management Plan for the Area of the Northwest Pacific-contributing to the International Seabed Authority's Rule-making Process*. Available online at: https://www.jogmec.go.jp/english/news/release/news_08_00015.html. (Accessed August 6, 2024)

Jones, D. O., Kaiser, S., Sweetman, A. K., Smith, C. R., Menot, L., Vink, A., et al. (2017). Biological responses to disturbance from simulated deep-sea polymetallic nodule mining. *PloS One* 12, e0171750. doi: 10.1371/journal.pone.0171750

Leitner, A. B., Neuheimer, A. B., Donlon, E., Smith, C. R., and Drazen, J. C. (2017). Environmental and bathymetric influences on abyssal bait-attending communities of the Clarion Clipperton Zone. *Deep Sea Res. Part I: Oceanographic Res. Papers* 125, 65–80. doi: 10.1016/j.dsr.2017.04.017

Ludvigsen, M., Berge, J., Geoffroy, M., Cohen, J. H., de la Torre, P. R., Nornes, S. M., et al. (2018). Use of an autonomous surface vehicle reveals small-scale diel vertical migrations of zooplankton and susceptibility to light pollution under low solar irradiance. *Sci. Adv.* 4, eaap9887. doi: 10.1126/sciadv.aap9887

Marquenie, J. M., Wagner, J., Stephenson, M. T., and Lucas, L. (2014). "Green lighting the way: Managing impacts from offshore platform lighting on migratory birds," in *SPE International Conference and Exhibition on Health, Safety, Environment, and Sustainability?* (Long Beach, California, USA: SPE), D031S048R002. doi: 10.2118/168350-MS

Montevecchi, W. (2006). "Influences of artificial light on marine birds," in *Ecological Consequences of Artificial Night Lightin Rich*. Ed. T. Longcore (Press, Washington, Island), 94e113.

Murdock, R. (2024). *Deep Sea Mining and the Green Transition. Harvard International Review*. Available online at: https://hir.harvard.edu/deep-sea-mining-and-the-green-transition/ (Accessed June 13, 2024).

New Zealand (1964). *Continental Shelf Act 1964*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/05/NZ-CSAct.pdf (Accessed July 20, 2024).

New Zealand (1996). *United Nations Convention on the Law of the Sea Act 1996*. Available online at: https://www.isa.org.jm/wp-content/uploads/2022/05/NZ.pdf (Accessed July 20, 2024).

Permanent Mission of PRC to International Seabed Authority. (2018). *International Workshop on the REMP for the Cobalt-Rich Ferromanganese Crusts in Triangle Area in the Northwest Pacific Ocean*. Available online at: http://isa.China-mission.gov.cn/xwdt/201806/t20180602_8200634.htm (Accessed May 25, 2024).

Poot, H., Ens, B. J., de Vries, H., Donners, M. A., Wernand, M. R., and Marquenie, J. M. (2008). Green light for nocturnally migrating birds. *Ecol. Soc.* 13, 47-60. doi: 10.5751/ES-02720–130247

Røstad, A., Kaartvedt, S., Klevjer, T. A., and Melle, W. (2006). Fish are attracted to vessels. *ICES J. Mar. Sci.* 63, 1431–1437. doi: 10.1016/j.icesjms.2006.03.026

Schlining, K., Von Thun, S., Kuhnz, L., Schlining, B., Lundsten, L., Stout, N. J., et al. (2013). Debris in the deep: Using a 22-year video annotation databaseto survey marine litter in Monterey Canyon, central California, USA. *Deep Sea Res. Part I: Oceanographic Res. Papers* 79, 96–105. doi: 10.1016/j.dsr.2013.05.006

Singh, P. A. (2021). The two-year deadline to complete the International Seabed Authority's Mining Code: Key outstanding matters that still need to be resolved. *Mar. Policy* 134, 104804. doi: 10.1016/j.marpol.2021.104804

Solé, M., Lenoir, M., Durfort, M., López-Bejar, M., Lombarte, A., van der Schaar, M., et al. (2013). Does exposure to noise from human activities compromise sensory information from cephalopod statocysts? *Deep Sea Res. Part II: Topical Stud. Oceanography* 95, 160–181. doi: 10.1016/j.dsr2.2012.10.006

Topçu, N. E., Turgay, E., Yardımcı, R. E., Topaloğlu, B., Yüksek, A., Steinum, T. M., et al. (2019). Impact of excessive sedimentation caused by anthropogenic activities on benthic suspension feeders in the Sea of Marmara. *J. Mar. Biol. Assoc. United Kingdom* 99, 1075–1086. doi: 10.1017/S0025315418001066

UN. (1982). United Nations Convention on the Law of the Sea, concluded on 10th December 1982, entered into force 16th November 1994, 1833 U. N. T. S. 397.

UN. (1994). Agreement Relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea, concluded on 28th July 1994, entered into force on 16th November 1994, 1836 U. N. T. S. 3.

UN. (2023). Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainabe Use of Marine Biological Diverstiy of Areas Beyound National Jurisdiction, concluded on 19 June 2023.

Valérie, ALLAIN. (2005). *Diet of large pelagic predators of the Western and Central Pacific Ocean. 1st Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission*. Available online at: https://www.wcpfc.int/node/1870 (Accessed July 20, 2024).

Vanreusel, A., Hilario, A., Ribeiro, P. A., Menot, L., and Mrtinez Arbizu, P. (2016). Threatened by mining, polymetallic nodules are required to preserve abyssal epifauna. *Sci. Rep.* 6, 26808. doi: 10.1038/srep26808

Wang, H., and Zhong, Z. (2022). Institutional experiences and insights from deep-sea country legislation. *J. Shanghai Univ. Int. Bussiness Ecnonmics* 29, 107–124. doi: 10.16060/j.cnki.issn2095–8072.2022.02.008

Weaver, P. P. E., and Billett, D. S. M. (2019). "Environmental impacts of nodule, crust and sulphide mining–an overview," in *Deep-sea mining and Environment–issues, consequences and management*. Ed. R. Sharma (Springer International Publishing AG, Switzerland), 27–62.

Widder, E. A., Robison, B. H., Reisenbichler, K. R., and Haddock, S. H. D. (2005). Using redlight for in *situ* observations of deep-sea fishes. *Deep Sea Res. Part I: Oceanographi Res. Papers* 52, 2077–2085. doi: 10.1016/j.dsr.2005.06.007

Yan, G. (2021). The progress and challenge of regional environmental management plan in the international seabed area and China's participation. *Environ. Prot.* 49, 71–76. doi: 10.14026/j.cnki.0253–9705.2021.23.015

Zeng, W., and Gao, Y. (2020). Research on updating philosophy and improving regulations within negotiation on exploitation of mineral resources in international seabed authority. *Yuejiang Xue Kan* 12, 94–105+123. doi: 10.3969/j.issn.1674–7089.2020.01.010

Zhang, K., and Zhu, Z. (2020). Review of the environmental management plan for the international seabed area—Based on the practice in the clarion-clipperton zone. *J. Boundary Ocean Stud.* 5, 16–30.

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 02 September 2024
DOI 10.3389/fmars.2024.1447272

Check for updates

OPEN ACCESS

EDITED BY
Wen-Hong Liu,
National Kaohsiung University of Science and Technology, Taiwan

REVIEWED BY
Fabiana Corami,
National Research Council (CNR), Italy
Martin Jara-Marini,
National Council of Science and Technology (CONACYT), Mexico

*CORRESPONDENCE
Chunliang Chen
18218252839@139.com

RECEIVED 11 June 2024
ACCEPTED 15 August 2024
PUBLISHED 02 September 2024

CITATION
Zhao Z, Chen C and Feng M (2024) Impacts of oyster farms on sediment-associated mercury and methylmercury concentrations and health risks in an estuarine, mangrove forest, Zhanjiang Bay, China.
Front. Mar. Sci. 11:1447272.
doi: 10.3389/fmars.2024.1447272

COPYRIGHT
© 2024 Zhao, Chen and Feng. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Impacts of oyster farms on sediment-associated mercury and methylmercury concentrations and health risks in an estuarine, mangrove forest, Zhanjiang Bay, China

Zike Zhao[1], Chunliang Chen[1]* and Mengqian Feng[2]

[1]Analysis and Test Center, Guangdong Ocean University, Zhanjiang, Guangdong, China, [2]College of Chemistry and Environment, Guangdong Ocean University, Zhanjiang, Guangdong, China

Estuarine sediments serve as significant reservoirs for mercury (Hg) and methylmercury(MeHg), which can also interconvert in the external environment. The release of Hg in response to human activities raises concerns about its potential ecological and human health effects. Sediment samples were collected in December 2021 from four locations (sites), and Hg cycling by measuring the concentrations of, and controls on, the spatial distribution of total Hg (THg) and methylmercury (MeHg) in high-tidal zone (HTZ) and mid-tidal zone (MTZ) sediments of a mangrove forest (MF) and oyster farm (OF) was examined in northwestern Zhanjiang Bay, including simultaneous determination of sediment particle size, oxidation-reduction potential (Eh), pH, total organic carbon (TOC), sulfide concentration (S2-), and sulfate reducing bacteria (SRB). The research results indicated that concentrations of both THg and MeHg ranged between 20.0–104.0 ng/g and 0.011–0.277 ng/g in the sediments, respectively. The highest methylation potentials within the MF and OF were in sediments located approximately 10–15 cm below the surface. MeHg in the HTZ of the OF was likely derived from exogenous inputs as Hg methylation appears limited, and the formation of MeHg depended not only on the amount of inorganic mercury available for methylation in SRB, but also on the TOC, pH, Eh and S^{2-} content in the sediment. A risk assessment of MeHg during the anthropogenic disturbance of this estuaries conducted on individuals eating oysters demonstrated that health risks are low.

KEYWORDS

Hg, MeHg, methylation potential, mangrove forest, oyster farm, sediment

1 Introduction

Mercury (Hg) is a persistent, priority pollutant on a global scale due, in part, to is toxic effects on human and ecosystem health, its ability to be easily transported in the Earth's near surface environment. Natural sources of Hg include volcanic eruptions, hydrothermal activity, forest fires, earthquakes, and sediment (Gonzalez-Raymat et al., 2017), whereas anthropogenic sources include fossil fuel power plants, chlor-alkali plants, and Hg amalgamation mining activities, to mention a few (Liu et al., 2021). Once released to the Earth's surface, its biogeochemical cycling is highly complex. Elemental (Hg^0) can, for example, exist as a stable gaseous species that may be converted by a wide range of redox, phase, and biologically mediated transformations into other chemical forms, including oxidized mercury (HgII), methylmercury (MeHg), dimethylmercury (DMeHg), and ethylmercury (EtHg). MeHg, an organic form of Hg, is of particular concern because of its ability to be readily absorbed and bio-accumulated in biota, where it may subsequently be bio-magnified up the food chain. In fact, the predominant pathway of human exposure in many areas is the consumption of contaminated biota, particular sea food. Once ingested, MeHg is highly toxic and can damage the central nervous system (Rice et al., 2010; Li and Cai, 2013).

MeHg is produced by the conversion of HgII to MeHg in anaerobic environments by methylating bacteria, including sulfate-reducing bacteria (SRB) and, to a much lesser degree, iron-reducing bacteria and methanogens (Regnell and Watras, 2018; Villar et al., 2020; Eckley et al., 2021). The processes of methylation are not well understood, but it is influenced by the amount of inorganic and dissolved organic matter as well as sulfur compounds in the water and sediments (Eckley et al., 2021). MeHg demethylation is a reverse process of Hg methylation. It simultaneously occurs in the sites (sediment, periphyton, and water) that methylation takes place. Within aquatic environments, some methylation may occur in anoxic waters where the water column is stratified, but the overwhelming majority of methylation takes place in anoxic sediments, particularly within the first few centimeters of the water-sediment interface, where there tends to be a relative abundance of methylating bacteria. Similar to methylation of Hg, biotic process was suggested to be the dominant pathway of Hg demethylation in sediment and periphyton, however this process has not been confirmed in natural environments. But methylation typically overrides demethylation and determines the net production of MeHg in sediment and periphyton (Li and Cai, 2013).

Due to the possible local increase in mercury input in estuaries and general coastal environments in recent years, the level of methylation in estuarine environments can be especially pronounced because of the abundance of organic matter and sulfur compounds in the underlying sediments as well as the widespread occurrence of anoxic conditions (Crane, 2006). While the cycling of Hg and MeHg production has been extensively studied in estuarine environments, the influence of localized human activities and morphological changes on estuaries and MeHg production, and their results impacts on human health, remain a relatively understudied topic. This is particularly true of mangrove forests (MF), because sediments in MF often serve as an important sink of many heavy metal pollutants (Castro et al., 2021), including MeHg, as they represent depositional environments that possess the conditions conducive to methylation, including high OM and sulfur ion (S^{2-}) concentrations and local anoxic conditions (Morel et al., 1998; Wolfenden et al., 2005; Drott et al., 2007; Fitzgerald et al., 2007). At the same time, mangrove sediments may also serve as a source of MeHg as it can be released from the sediments into the water column as a result of tidal action (Benoit et al., 2009; Seelen et al., 2021). However, investigations pertaining to the contamination of the Bay's sediments in general, and MeHg in particular, are currently lacking. One issue of particular concern is the potential for human activities to disturb MFs, such that it increases the production of MeHg and/or the remobilization of MeHg from the sediments. For example, increased nitrogen loading in estuaries is associated with increased deposition of organic carbon to the sediments due to the production and sedimentation of detrital particulate organic matter, thereby affecting the production of MeHg (Chen et al., 2021).

The primary objectives of this study were to: (1) characterize the sediments within high- to mid-tidal areas of the Zhanjiang Bay estuary within a MF and an OF in terms of the parameters that are likely to influence Hg speciation and methylation, including particle size, Eh, total organic carbon (TOC) and sulfide concentrations (S^{2-}) as well as SRB; (2) explore the influence of these factors on the concentrations and vertical distribution of Hg and MeHg within the sediments, (3) document the potential for Hg methylation within the MF and OF, and (4) determine the human health risks posed by Hg when oysters raised within an OF are consumed. This study furthers our understanding of the biogeochemical cycling of Hg in estuarine environments, and the potential risks of Hg methylation and MeHg bioaccumulation within oyster farms near mangrove forests in Zhanjiang Bay, and other coastal areas.

2 Material and methods

2.1 Study area

Zhanjiang Bay is located adjacent to the South China Sea and is surrounded by three islands that create a semi-enclosed, shallow bay. A dyke has been built on the west side of Zhanjiang Bay, connecting Donghai Island and the interior of Zhanjiang City (Figure 1B). On both sides of the dyke, there are areas of OF and MF, with an area of approximately 12 square kilometers for OF. OF near mangroves is done through poles inserted in high densities into the sediments (Figure 1C), resulting in severe siltation. Abundant organic matter from oysters' feces and MF' litter jointly create anaerobic environment for mercury methylation. However, it is currently unclear which external input or on-site production is the main source of MeHg in the research location.

2.2 Sample collection and analysis

Sediment samples were collected in December 2021 from four locations (sites), two in the high-tidal zone (HTZ) and two in the

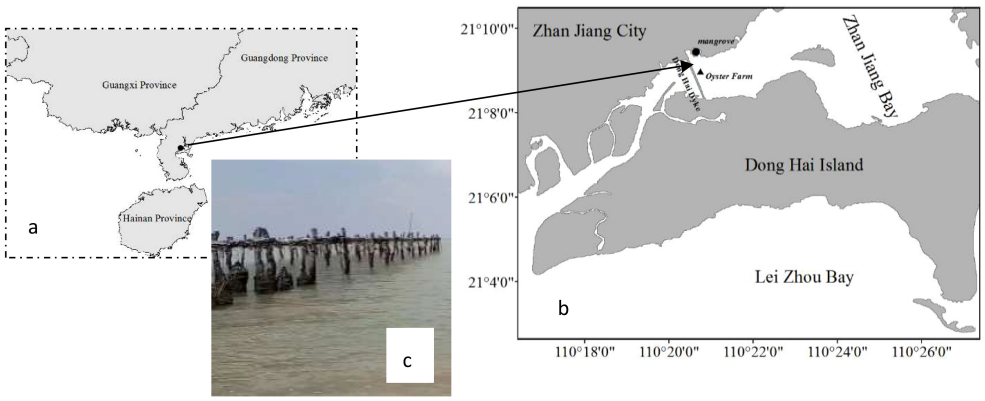


FIGURE 1
(A) Location of Zhanjiang Bay in China; **(B)** location of sampling sites within the Bay; **(C)** photograph of oyster cultivation conducted by inserting into the sediments.

mid-tidal zone (MTZ) of each "cover type", including sites HTZ-MF, MTZ-MF, HTZ-OF and MTZ-OF (Figure 1). The reason for choosing these four regions was because the HTZ was more influenced by land and human activities, while the geological and environmental types of the mid tide zone and low tide zone were similar but sampling in the mid tide zone was safer and more convenient. A stainless-steel sampling tube was used to collect a sediment profile to a depth of 25 cm. Once collected, the sediment cores (profiles) were subdivided into samples at 5 cm intervals. E_h of the pore waters was measured using a redox potentiometer (Nanjing Dropper Instrument and Equipment Co., LTD. FJA-6). The remaining samples were placed in glass bottles, and transported to the laboratory where fresh and wet samples were analyzed for sulfide (S^{2-}) content, particle size distribution, and SRB (as described below). The remaining portion of the samples were freeze-dried, ground, and passed through a 0.15 mm nylon sieve, before they were analyzed for TOC, THg, and MeHg. Six oysters of different sizes collected on-site in the OFs were randomly selected from numerous individuals about to enter the consumer market and transported to the laboratory. The oysters were washed with ultrapure water, and the size and weight of the oysters were recorded.

2.2.1 Analysis of the sediments

The particle size distribution of the sediment samples was analyzed using a Mastersizer 2000 (Malvern, UK) laser particle size analyzer. TOC concentrations were determined using the $K_2Cr_2O_7$ OX-RE-VL based, Walkley-Black (WB) titration method as described by Gaudette et al. (1974). The analysis of S^{2-} in the sediments was determined using a Sulfur Ion Selective Electrode (PXSJ-226, Shanghai Instrument and Electricity Scientific Instrument Co., Ltd.), and was carried out following the method of Wildish et al. (1999). The occurrence of SRB in the sediments was determined using a multitube fermentation technique via incubation at 29 ± 1°C for 21 d. The presence of SRB was indicated by the production of a black precipitate in the tube with a hydrogen sulfide odor. A most probably number (MPN) method was used to count the SRB in the analyzed samples. Sample blanks were also analyzed. If a blank appeared positive, the assay had been contaminated and the data were considered invalid.

2.2.2 Analysis of THg in the sediment and oyster samples

THg was analyzed using an Atomic Fluorescence Spectrometer (SK-AFS, Jinsuokun, Beijing, China) with a standard curve correlation coefficient (R^2) of 0.999. Diluted aqua regia (50%, HCl: HNO_3 = 3:1 v/v) was added to the tubes to digest the sediments (Ding et al., 2011). The quality control standard concentration for sediment was 0.048 μg/g; the analyzed value was 0.043 μg/g, with a recovery of 90.0%. Dried oyster samples, along with quality control samples, were digested using a microwave digestion system (Qiu et al., 2006). The analyzed biotic standard consisted of shrimp (GBW10050; GSB-28) with a control concentration of 0.049 μg/g; the measured value was 0.050 μg/g, with a recovery of 101.9%. Sediment and biotic samples are expressed on a dry-weight basis.

2.2.3 Analysis of MeHg in sediments and oysters

MeHg in sediments and oysters were measured using an Automated Alkyl Mercury Analyzer (Tekran 2700, Canada) (Qiu et al., 2009). Dry sediment was weighed into a 50 mL centrifuge tube, to which 1.0 ml of 2 mol/L$CuSO_4$, 5.0 ml of an acidic KBr solution and 10 ml of CH_2Cl_2 were added to extract MeHg. The MeHg in the sample solution was then ethylated using $NaBEt_4$ to form gaseous diethyl-mercury, and DMeHg was converted into gaseous methyl-ethyl-mercury. The method's detection limit was 1.0 pg. Quality control and verification were carried out at the same time using a method blank, parallel sample and a certified reference material. MeHg recovery from the sediments ranged from 90% to 110%.

Similarly, six oysters were accurately weighed and placed into their respective Teflon bottles, to which 5 ml of 250 g/L KOH-CH_3OH solution was added, and then allowed to digest in a water bath at 75°C for 3 h. The bottles were shaken every 30 minutes to ensure that the digestion solution fully reacted with the sample.

After digestion, the Teflon bottle was removed from the water bath and cooled to room temperature, after which 3 ml of concentrated HCl was added. The remainder of the procedure followed the steps described above for the analysis of MeHg in sediments. MeHg recovery for the utilized fish standard (tormart-3, DORM-4) was between 90% and 110% (Qiu et al., 2009).

2.2.4 Hg and MeHg exposure risk assessment for the consumption of oysters

An exposure risk assessment quantifies risk by combining hazard identification and dose effects to assess the probability that the contaminant will result in a health hazard for human (Feng et al., 2013). The needed parameters were calculated as follows.

$$PDIs = (C \cdot IR \cdot 10^{-3})/bw \quad (1)$$

$$HRI = PDIs/RfD \quad (2)$$

where PDIs from Equation 1 is the Probable Daily Intake, defined as the average daily intake of a contaminant by means of the food to be ingested; the average daily intake is expresses per body weight, *bw*, ($\mu g \cdot kg^{-1} \cdot d^{-1}$); *bw* was assumed here to be 60 kg; *C* is the concentration of Hg and MeHg in oysters ($ng \cdot g^{-1}$); *IR* is the intake reference, defined as the average daily intake of food ($kg \cdot d^{-1}$); here, it was assumed to be 5.5 g/d of oysters, which is based on the daily consumption of fish; *HRI* from Equation 2 is the Human Health Risk Index, and *RfD* is the reference dose, which is the amount that can be safely consumed ($\mu g \cdot kg^{-1} \cdot d^{-1}$). *HRI* is obtained from the ratio of *PDIs* and the Joint FAO/WHO Expert Committee on Food Additives recommended reference dose (*RfD*) for inorganic Hg and MeHg (Liang et al., 2015). The *RfD* for inorganic mercury is 0.57 μg/(kg·d) and for MeHg is 0.23 μg/(kg·d); the maximum allowable exposure set by the US EPA for MeHg is 0.1 $\mu g \cdot kg^{-1} \cdot d^{-1}$. If the *HRI* is >1.0, the population possesses a high health risk.

2.3 Statistical analysis

Maps of sampling stations were generated using ArcGIS 10.2. The Pearson's correlation analyses between MeHg, THg and selected environmental factors in sediments were performed using SPSS 24.0. Statistical significance of the Spearman correlations was set at a level of 0.05 ($p<0.05$) and/or 0.01 ($p<0.01$). Data plots were constructed using Origin 9.0 software.

3 Results and discussion

The environment change of water bodies caused by aquaculture not only leads to an increase in organic matter, but also causes changes in many physical and chemical parameters of water bodies, including a decrease in dissolved oxygen in water, an increase in organic matter and sulfate in sediments, hydrogen sulfide, a decrease in pH values, and the destruction of biological and microbial communities, thereby affecting the generation of MeHg (Yan and Feng, 2012). The above factors will also change with the increase of sediment depth and further affect the vertical distribution of Hg and MeHg.

The concentrations and spatial distribution of both THg and MeHg depend on the sedimentologic, geochemical, and compositional nature of the estuarine sediments. Here, we explore the sedimentologic characteristics of the sediments that are of most importance in controlling Hg concentrations at a site and compare how they differ as a function of their position within the tidal zone and between the MF and the OF. All of the collected parameter data are presented as a function of depth below the water-sediment interface. This has been done because vertical variations in these parameters, as well as in THg and MeHg, provide insights into the rates and location of methylation and the potential sources of MeHg.

3.1 Sedimentological and geochemical characteristics of the MF and OF sediments

As shown in Figure 2, sediments in the study area were dominated by silt and sand-slit sediments. Sediments of the MF possess higher clay-sized particle contents than sediments of the OF (Table 1).The sedimentology of the bottom sediments within the MF and OF differs, in part, because of the surface cover's ability to trap sediment. For example, the complex root system of mangrove trees tend to capture suspended particulate matter, resulting in the formation of sandy bottom sediments in MFs (Bouillon et al., 2004; Kristensen et al., 2008). However, sediments within the OF, devoid of mangrove trees, simultaneously receive suspended particles from tidal processes and oyster excrement. The grain size distribution of the sediments, particularly the abundance of silt- and clay-sized particles, is an especially important parameter controlling the sequestration of Hg in the deposits. This follows because of the high surface area and general reactivity of fine particles, that enhances their relative ability to sorb metals.

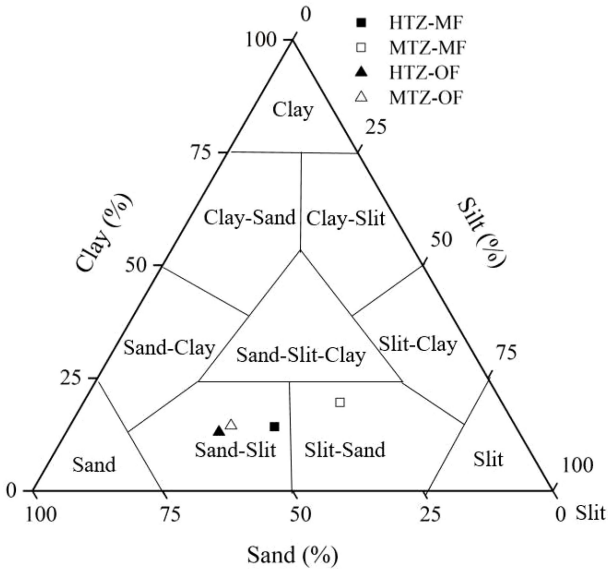


FIGURE 2
Texture of the sediments sampled within the study area. The position of each symbol in the triangle diagram is determined by the average value of the granularity.

10.3389/fmars.2024.1447272

TABLE 1 Sediment characteristics of the MF and OF samples within the intertidal zone of Zhanjiang Bay, including their particle size distribution (i.e., percent clay, silt and sand), E_h, SRB, S^{2-} and TOC.

Station	Depth	Clay (%)	Sand (%)	Silt (%)	E_h (mV)	pH	SRB (ind./g)	S^{2-} (μg/g)	TOC (mg/g)
HTZ-MF	0–5 cm	15.7	40.7	43.6	−113.3	6.51	80	25.37	14.0
	5–10 cm	13.0	51.0	35.9	−212.2	6.64	130	32.82	12.4
	10–15 cm	11.8	56.8	31.4	−147.2	6.66	50	45.58	11.4
	15–20 cm	15.3	41.0	43.7	−166.1	6.80	25	19.43	11.0
	20–25 cm	15.0	42.6	42.3	−194.2	6.35	20	11.41	30.6
Average		14.2	46.4	39.4	−166.6	6.59	61	26.92	15.9
SD		1.50	6.41	4.92	34.8	0.15	40.5	11.7	7.43
CV (%)		0.11	0.14	0.12	−0.21	0.02	0.66	0.43	0.47
Median		15.0	42.6	42.3	−166.1	6.64	50	25.37	12.4
MTZ-MF	0–5 cm	23.0	26.4	50.6	146.3	6.05	140	0.85	34.3
	5–10 cm	22.9	25.8	51.3	−126.0	6.12	80	6.31	24.0
	10–15 cm	23.9	23.7	52.4	−137.0	6.26	130	20.1	25.5
	15–20 cm	15.7	34.8	49.5	−101.2	5.92	130	6.42	42.8
	20–25 cm	12.7	44.6	42.8	−178.7	6.56	80	0.14	14.5
Average		19.6	31.1	49.3	−79.3	6.18	112	6.76	28.2
SD		4.56	7.76	3.39	115.6	0.22	26.4	7.16	9.62
CV (%)		0.23	0.25	0.07	−1.46	0.04	0.24	1.06	0.34
Median		22.9	26.4	50.6	−126.0	6.12	130	6.31	25.5
HTZ-OF	0–5 cm	12.0	57.2	30.7	91.6	7.74	45	9.12	12.5
	5–10 cm	12.2	62.5	25.3	245.9	7.84	95	50.2	11.2
	10–15 cm	9.80	69.0	21.2	252.1	7.55	25	26.1	21.2
	15–20 cm	15.6	50.8	33.6	168.9	7.87	2	7.93	21.3
	20–25 cm	15.5	48.7	35.8	−58.8	7.23	8	7.74	21.7
Average		13.0	57.6	29.3	139.9	7.65	35	20.2	17.6
SD		2.23	7.48	5.37	115.3	0.24	33.5	16.5	4.70
CV (%)		0.17	0.13	0.18	0.82	0.03	0.96	0.82	0.27
Median		12.2	57.2	30.7	168.9	7.74	25	9.12	21.2
MTZ-OF	0–5 cm	15.4	55.2	29.5	−29.8	7.48	50	56.52	14.4
	5–10 cm	16.6	51.3	32.2	−53.3	7.70	350	17.36	6.8
	10–15 cm	12.1	58.8	29.2	−117.2	8.19	35	0.67	15.2
	15–20 cm	12.1	60.0	27.9	−121.2	7.50	0	0.36	12.2
	20–25 cm	16.1	47.9	35.9	−139.1	7.07	0	1.71	3.5
Average		14.5	54.6	30.9	−92.1	7.59	87	15.3	10.4
SD		1.96	4.54	2.85	42.6	0.36	133	21.6	4.54
CV (%)		0.14	0.08	0.09	−0.46	0.05	1.53	1.41	0.44
Median		15.4	55.2	29.5	−117.2	7.50	35	1.71	12.2

The composition of the sediments not only influences the reactivity of the materials, and their ability to sequester Hg, but is believed to affect its E_h. Related studies had shown that the Eh of estuarine surface sediments typically ranges from −213 mV to 512 mV (Sunderland, 2003). In this study, except for site HTZ-OF, dominated by areas of bare sediment, the average E_h of the sediments at sites HTZ-MF, MTZ-MF and MTZ-OF averaged −166.6 mV, −79.3 mV and −92.1 mV, respectively (Table 1). The Eh values observed at site HTZ-OF were strongly positive, except for the interval between 20–25 cm. As noted in the introduction, reducing conditions are required for the significant production of MeHg by SRB. Therefore, the reducing environment of sediments in the study area met one of the conditions for MeHg formation, but whether this process was also influenced by other factors needed further investigation.

Acidic substances in MF plant litter, including tannins, resins, and low molecular weight organic acids acidify the sediments. These effects can be especially pronounced in areas characterized by high organic matter contents (Chai et al., 2020; Shi et al., 2020). The pH of MF sediments in the study area generally ranged between 6 and 6.8, although values as low as 5.92 were recorded at stie MTZ-MF. In contrast, the pH of sediments within the OF were typically above 7.00, which is similar to the pH of nearshore water bodies. Sediment pH has a significant impact on the availability, migration, and transformation of Hg by influencing its solubility, and by regulating the types and activities of microorganisms in the sediments (Correia and Guimarães, 2016, 2017). To some extent, the lower pH in the MF sediments promoted the desorption of mercury ions from the adsorption phase and further participation in methylation reactions.

3.2 Relations between S^{2-}, TOC, and SRB in sediments

Previous studies have demonstrated that TOC combined with sulfur plays an important role in controlling the production of MeHg in sediments (Shen et al., 2020). In this study area, the median TOC contents in sediments of the HTZ-MF and MTZ-MF were 12.4 and 25.5 mg/g. The differences presumably reflect a relatively high cover of vegetation and biological activity within the MF, including at site MTZ-MF. The vertical variations in TOC contents at site MTZ-MF were smaller than at site HTZ-MF, as illustrated by its coefficient of variation (Table 1). However, site MTZ-OF is affected by more significant tidal exchanges and human activities. Thus, within sediments from the OF, the vertical variations in TOC observed in the HTZ-MF were smaller than those in the MTZ-OF (see coefficient of variation for TOC, Table 1).

The cycling of sulfur can affect MeHg production by restricting the migration of Hg within the sediments (Padalkar et al., 2019). In this study, we considered S^{2-} concentrations in the sediment pore waters because (1) it can directly influence the formation of Hg sulfides, and (2) it is, in some cases, related to the magnitude of MeHg production. Table 1 shows that the average S^{2-} content of the sediments from both the MF and OF were higher in the high-tide zone than in the mid-tide zone. In general, sediment in the HTZ-MF contained more S^{2-}, and the correlation coefficient was smaller than that in other areas. The elevated levels of S^{2-} within sediments of the HTZ may be due to the enhanced exchange of sediment pore waters with seawater within the MTZ, as this process led to higher concentrations of sulfate and dissolved oxygen (Wilms et al., 2007). In addition, the breeding density of oysters within the HTZ-OF and the MTZ-OF is likely to have affected the S^{2-} content of the sediment, which, in combination with the deposition of organic matter associated with oyster feces, is more likely to form a reducing environment.

SRB can promote the methylation process of mercury, which had been confirmed by many studies (Azaroff et al., 2020). The highest SRB count (130 ind./g) was observed in sediments between a depth of 5–10 cm at site HTZ-MF. Compared with that of the OF, the higher TOC and clay-sized particle contents in the sediments of the MF create more widespread anoxic conditions that are suitable for the establishment and growth of SRB. Therefore, the median abundance of SRB in sediments from the MF was higher than in the OF.

3.3 Spatial distribution of THg in the MF and OF sediments

Concentrations of inorganic Hg exert a significant control on MeHg production. Given that most of the Hg in the sediments is inorganic, THg concentrations provide insights into the amount of inorganic Hg that is available for methylation. As shown in Figure 3, the THg content at site HTZ-MF decreased slightly with increasing depth, ranging from about 35.5 to 20.0 ng/g. Mangrove leaves absorb Hg through stomatal gas exchange, and leaf fall transfers Hg to the soil, which may exceed the direct input of Hg to the sediments by atmospheric wet deposition. Due to dense vegetation and rich biological diversity in the MTZ-MF, THg concentrations ranged from 76.0 to ~104.0 ng/g at stie MTZ-MF. Vertically, concentrations increased with depth, reaching a maximum concentration of 104.0 ng/g at a depth of 15–20 cm and a minimum concentration of 76.0 ng/g in the surface layer (0–5 cm). These values are lower than those measured for THg in MF sediments in Guangdong, Guangxi, Fujian, Zhejiang and Hainan provinces in southern China, which ranged from 50–200 ng/g (Duan et al., 2021). The lower values within Zhanjiang Bay may be due to the limited industrial development in Zhanjiang and the implementation of strict environmental protection measures. The observed trend in THg with depth may result from bioturbation that physically mixes “fresh” sediments at the surface with older sediments (Tseng et al., 2001; Benoit et al., 2009).

The THg content at site MTZ-OF ranged from 27.0 to 89.0 ng/g, whereas the MeHg content ranged from 0.031 to 0.202 ng/g. The THg concentrations in the MTZ-OF exhibited trends similar to those in the HTZ-OF. The 5–10 cm and 15–20 cm layers of sediment had relatively more silty sand than the other sediments, which may have resulted in a loss of THg and MeHg by means of *in situ* dissolution. In general, THg concentrations are elevated within

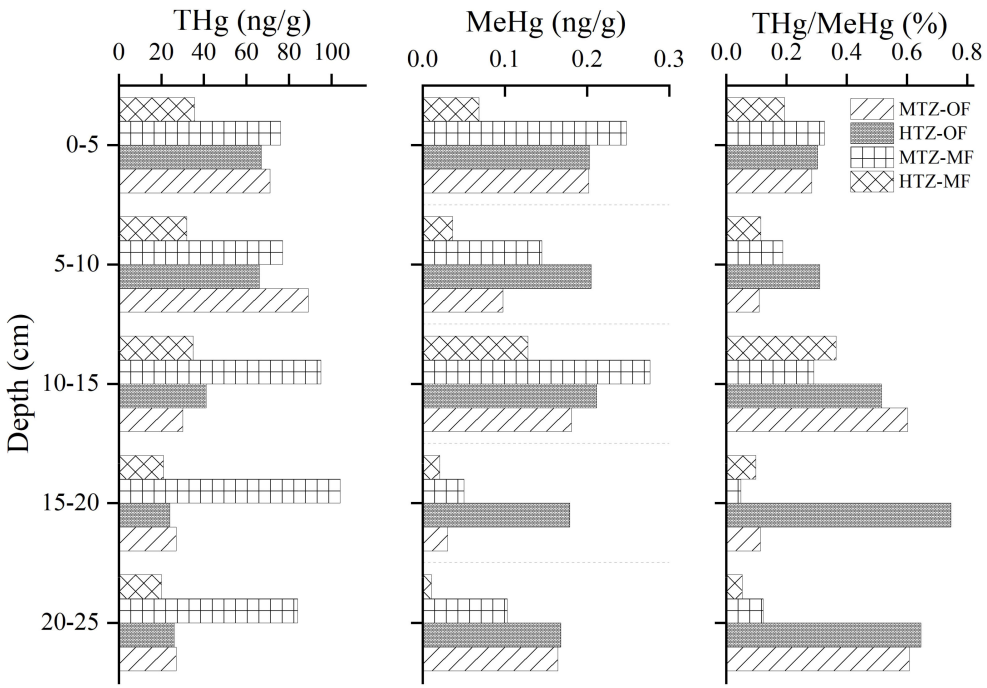


FIGURE 3
Distribution of THg and MeHg in sediments as a function of depth.

the upper 10 cm of the sediment, and subsequently, decrease with depth. The enrichment of THg in the surface sediments may be associated with the sorption of Hg to organic matter (OM) within the water column, including oyster fecal excreta, metabolites, bait residues and marine plankton carcasses, which settles on the surface of the sediments.

3.4 Controls on the distribution of MeHg in the MF and OF sediments

Concentrations of MeHg ranged from 0.011~0.128 ng/g. Spatially, MeHg at site HTZ-MF exhibited a vertical trend similar to that of THg, with the exception of a peak in concentration at a depth of 10–15 cm (Figure 3). Concentrations of MeHg above the peak are slightly higher than those below the peak. A predominance of MeHg in the surface sediment is consistent with the results of Sunderland et al. (2006) who found that MeHg production occurred mainly in the approximately 15 cm thick, active surface layer (Sunderland et al., 2006).MeHg concentrations in the MTZ-MF ranged from 0.05 to 0.277 ng/g; the maximum concentrations being more than twice as high as was found at site HTZ-MF. However, the maximum MeHg concentration at site MTZ-MF was found at a depth of 10–15 cm, as it was at site HTZ-MF. Presumably, this depth interval at both sites provided the most suitable conditions for SRB to participate in methylation reactions (Benoit et al., 1999). As shown in Figure 3, the MeHg content ranged from 0.168–0.211 ng/g at site HTZ-OF. The maximum concentrations of MeHg are about twice as high as those observed at site HTZ-MF.

3.5 Spatial distribution of methylation potential in MF and OF sediments

The ratio of MeHg to THg (%MeHg) is often used as an indicator of the Hg methylation potential (Liem-Nguyen et al., 2022). As shown in Figure 3, the methylation potential of Hg in MF and OF sediments varied from 0.05% to 0.75%, which is comparable to that estimated for nearshore sediments in the East China Sea (0.02% to 0.64%) (Zhao et al., 2019) and the estuarine sediments in New England (0.4%) (Taylor et al., 2012). It is lower, however, than that in the Southern Baltic sea (0.12–1.05%) (Bełdowski et al., 2014) and aquatic sediments across western North America (0.7%) (Fleck et al., 2016). The Hg methylation potential at site HTZ-OF increased with depth between 0 and 20 cm, reaching a maximum of 0.75% between 15–20 cm (Figure 3). Usually, only a small fraction (< 1–10%) of Hg in coastal sediments typically occurs in the form of MeHg, the majority of which is produced in the sediments. However, sediments at site HTZ-OF possessed limited quantities of SRB, and the lack of favorable conductions for Hg methylation suggests that the existing MeHg originated primarily from exogenous inputs. At site MTZ-OF, the THg contents and the quantity of SRB in some sediment layers were high. However, sediments at the site also exhibited high S^{2-} concentrations and low TOC levels, suggesting that the methylation potential, which represents the net production of MeHg, was low in some sediment layers at site MTZ-OF.

In fact, the HTZ-MF had a maximum methylation potential (an indicator of net MeHg production) of 0.37% at a depth interval of 10–15 cm; the methylation potential in the sediments at depths of 0–5 cm

10.3389/fmars.2024.1447272

TABLE 2 Correlation coefficients between THg and selected environmental factors.

Indicators	THg			
	HTZ-MF	MTZ-MF	HTZ-OF	MTZ-OF
clay	−0.478	−0.334	−0.611	0.642
sand-slit	−0.549	0.077	−0.470	0.019
sand	0.533	0.163	0.519	−0.291
E_h	0.481	−0.409	0.361	0.912*
S^{2-}	0.083	0.492	0.556	0.673
SRB	0.710	0.392	0.871	0.677
TOC	−0.565	0.467	−0.950*	−0.059

*significant correlation at the 0.05 level (two-tailed).

and 10–15 cm was relatively high, 0.33% and 0.29%, respectively. In addition to the quantity of inorganic Hg that SRB can be used for methylation, the amount of MeHg formation depends on (1) the OM, sulfate, and S^{2-} contents of the sediment, and (2) the local Eh (Ullrich et al., 2001; Benoit et al., 2003; Chen et al., 2008). Therefore, the relationship between the above factors and mercury methylation in the study area needs further confirmation.

3.6 Environmental factors controlling the vertical distribution of THg and MeHg

Table 2 shows that THg concentrations are significantly negatively correlated with TOC (r = −0.950, p<0.05) in sediments at site HTZ-OF, and significantly positively correlated with E_h (r = 0.912, p<0.05) at site MTZ-OF. THg of the MF showed no significant correlations with any of the selected environmental parameters; correlation coefficients varied across the study areas, even yielding opposing values. This finding is consistent with the work of Shi et al. (2020). They found no significant correlations between Hg contents and TOC, pH, salinity, and the amount of clay, fine chalk, coarse chalk and sand in mangrove sediments. OM often controls the spatial distribution of Hg in aquatic sediments (Li et al., 2015; Xiao et al., 2017). It is not surprising, then, that sediment THg and TOC are often significantly positively correlated (Xue et al., 2019; Zhao et al., 2019). However, we observed a significant negative correlation between THg and TOC in sediments of the OF, suggesting that OM, which contains both Hg-binding and hydrophilic groups, was combined with Hg and facilitated the transfer of Hg from the solid phase to the water column rather than the opposite process.

As shown in Table 3, MeHg in the HTZ-OF was positively correlated with sand (r = 0.930, p < 0.05) and negatively correlated with the amount of sandy, silt-sized (r = −0.902; p < 0.05) and clay-sized (r=−0.947; p < 0.05) sediments. The above results are contrary to the research of Haris et al. (2017) and Castro et al. (2021) who found that sediments with small particle sizes were significantly positively correlated with MeHg. High concentrations of fine sediments suggest a slow rate of water movement through the relatively stable bottom sediments, which allowed epiphytes (a complex consisting mainly of algal, protozoan, fungal and bacterial strains) to grow in the sediments and methylate Hg under low Eh conditions (Yáñez et al., 2013). The lack of an influence of particle size on MeHg within the study area also suggests that the MeHg at site HTZ-OF is mainly exogenous.

In the HTZ-MF, MeHg was positively correlated with S^{2-} (r = 0.880, p<0.05), and TOC was weakly or negatively correlated with MeHg contents at sites MTZ-MF and MTZ-OF. These relationships show that TOC is not a major factor influencing the methylation of Hg in estuarine wetland sediments. The poor correlation may also be due to the presence of high concentrations of other metals that compete with Hg for binding or adsorption sites on TOC (Xu et al., 2014). The oxidizing conditions induced by aquatic plants tended to cause Cd, Pb, and Zn, rather than Hg, to be bound to the Fe-Mn oxide fraction. Alternatively, it is possible that TOC provides energy and electron donors to demethylating bacteria and facilitates the demethylation of Hg. Of course, further experiments are needed to verify the above speculation. The distribution of MeHg in sediments can often be predicted by THg concentrations (Yu et al., 2021), but THg is not the only important factor determining MeHg abundance in sediments (Petranich et al., 2018). Similarly, no association had been found between THg and MeHg in the current research area. In fact, THg and MeHg were even found to be negatively correlated in the freshwater sediments of Scottish canals (Cavoura et al., 2017).

TABLE 3 Correlation coefficients between MeHg and environmental factors.

Indicators	MeHg			
	HTZ-MF	MTZ-MF	HTZ-OF	MTZ-OF
Clay	−0.656	0.806	−0.947*	0.276
Sand-slit	−0.710	0.542	−0.902*	0.262
Sand	0.698	−0.714	0.930*	−0.286
E_h	0.568	0.441	0.769	0.241
S^{2-}	0.880*	0.475	0.610	0.468
SRB	0.214	0.432	0.634	−0.197
TOC	−0.492	−0.131	−0.550	0.163
THg	0.793	−0.342	0.748	0.091

*significant correlation at the 0.05 level (two-tailed).

TABLE 4 Correlation coefficients between methylation potential and environmental factors.

MeHg%						
	THg	MeHg	TOC	S^{2-}	Eh	SRB
Correlation	−0.374	0.619**	−0.130	−0.100	0.455*	−0.413
Coefficient	0.105	0.004	0.198	0.676	0.049	0.070

*indicates significant correlation at the 0.05 level (two-tailed); **indicates significant correlation at the 0.01 level (two-tailed).

3.7 Correlation of methylation potential and various environmental factors

We further explored the influence of selected environmental factors on the distribution of the methylation potential in the sediment profiles. Table 4 shows that the correlation between THg and methylation potential is weakly negative. The highest percentages of MeHg in sediments at sites HTZ-OF and MTZ-OF have the lowest THg concentrations. This phenomenon has been recognized in other areas, and is known as the "Hg accumulation paradox" (Haris et al., 2017; Mondal et al., 2018). This paradox may be related to microbial demethylation that is induced by high THg concentrations, such that the rate of demethylation increases with increasing THg concentrations (Schaefer et al., 2004; Haris et al., 2017). The methylation potential was significantly positively correlated with MeHg (r=0.619, $p<0.01$), positively correlated with E_h (r=0.455, $p<0.05$), and weakly negatively correlated with THg, TOC, S^{2-}, and SRB. The positive correlation of methylation potential with MeHg and E_h occurs because methylation is enhanced at the interface between aerobic and anoxic zones, as these regions are most favorable to SRB activity. This interface also be used to undergo adsorption-desorption of Hg between the particulate and water phases and redox reactions (King et al., 2001; Jiang et al., 2015; Zhu et al., 2018). For example, inputs of degradable OM promoted sulfate reduction to inorganic sulfur that combined with Hg ions to form a Hg precipitate, which reduces the bioavailability of Hg ions for methylating microorganisms (Wang et al., 2022). Previous studies have shown that the highest SRB activity occurs at a redox potential of −200 mV (Wildish et al., 1999; Sunderland, 2003), which is consistent with the results of the this study in which higher methylation potentials at site MTZ-OF occurred at Eh values of −117.2 mV and −139.1 mV, respectively. However, it is unclear whether the increase of MeHg in sediments during hypoxic events, which result from the decomposition of algae by bacteria following red tides, is caused by the redox environment at the sediment–water interface that created favorable conditions for methylating bacteria, or to the release of MeHg from interstitial water within the sediments (Sunderland et al., 2006; Merritt and Amirbahman, 2008). Distinguishing these specific factors is difficult through simple statistical analysis. Nonetheless, the results demonstrate that the amount of MeHg accumulated in the study area through methylation was limited.

3.8 Risk assessment of eating MeHg contaminated oysters

Approximately 70–90% of Hg in seafood is in the form of MeHg (Canuel et al., 2006). In the research area, oysters had an annual output value of 7 billion yuan, with an annual production of up to 400000 tons, accounting for 10% of the country's total. Therefore, oysters could be used as a representative food for human consumption of seafood. The high levels of industrial and social activity in coastal areas, combined with the influx of Hg from sewage and dry and wet atmospheric deposition, result in high Hg inputs to estuaries. Part of this Hg may be transformed into MeHg, and accumulated by biota, thereby posing a risk to coastal dwellers eating sea food. Therefore, Hg monitoring and the assessment of potential ecological and human health risks of MeHg exposure are needed (Wiener et al., 2007).

The oyster, a shellfish that feeds on OM in water, can be used as a sentinel organism due to its nutritional value and significant, widespread consumption. As presented in Table 5, the THg and MeHg contents of six oysters were found to range from 128.74 to 187.04 ng/g and 0.71 to 6.63 ng/g, respectively. Using formulas (1) and (2) provided in the Methods section, the HRI values of THg and MeHg obtained from consuming oysters in the study area were much lower than 1.0, there was no correlation between the MeHg, and the potential health risk of Hg. However, there are still potential flaws in the calculation results of mercury exposure risk. Especially, it should be taken into account that the underrepresentation caused by the small number of experimental individuals, as well as the fact that oysters may have different mercury concentrations due to their different life states, size classes, and other environmental factors.

TABLE 5 THg and MeHg concentrations in oyster bodies and human risks.

	Body length (cm)	Body width (cm)	Body weight (g)	Mercury (ng/g)	MeHg (ng/g)	THg *HRI* ($\times10^{-2}$)	MeHg *HRI* ($\times10^{-2}$)
1	10.5	7.5	16.47	187.05	6.63	3.01	0.26
2	10.0	7.5	16.62	174.61	2.16	2.81	0.09
Average	10.3	7.5	16.55	180.83	4.40	2.91	0.18
3	13.3	7.5	20.37	140.19	1.44	2.25	0.06
4	12.5	7.5	19.58	152.02	3.05	2.44	0.12
Average	12.9	7.5	19.98	146.10	2.25	2.35	0.09
5	14.5	8.0	21.15	166.87	0.77	2.68	0.03
6	14.0	9.0	24.67	128.74	0.71	2.07	0.03
Average	14.3	8.50	22.91	147.81	0.74	2.38	0.03
Exposure risk assessment						3.01	0.26

Therefore, it is necessary to further study the potential factors mentioned above in the future to correct possible errors in the results.

4 Conclusion

MeHg contents were generally higher in OF sediment than sediments of the MF. Neither THg or MeHg significantly correlated with the environmental factors (except S^{2-}) within the MF that were suspected to have controlled their concentrations in sediments. A correlation analysis indicates that the amount of MeHg accumulated through methylation was limited in the study area. Thus, we conclude that MeHg in the HTZ-OF was likely to be derived from exogenous inputs. Although the risk assessment based on existing research results indicates that the potential health risks associated with eating oyster containing MeHg in this area is low, attention should be paid to the individual differences in mercury content in oysters caused by external inputs in OF, changes in sedimentary environment, and other factors leading to additional ingestion.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

ZZ: Writing – original draft. CC: Writing – review & editing. MF: Data curation, Methodology, Writing – original draft.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by the Science and Technology Special Project of Zhanjiang City (2019B01009) and Innovation and Entrepreneurship Training Program for College Students of Guangdong Ocean University (CXXL2022180).

Acknowledgments

We thank LetPub (www.letpub.com) for linguistic assistance and pre-submission expert review. The authors would like to thank all volunteers for their help with fieldwork and the technical staff for their fantastic support.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Azaroff, A., Goñi Urriza, M., Gassie, C., Monperrus, M., and Guyoneaud, R. (2020). Marine mercury-methylating microbial communities from coastal to Capbreton Canyon sediments (North Atlantic Ocean). *Environ. Pollut.* 262, 114333. doi: 10.1016/j.envpol.2020.114333

Bełdowski, J., Miotk, M., Bełdowska, M., and Pempkowiak, J. (2014). Total, methyl and organic mercury in sediments of the Southern Baltic Sea. *Mar. Pollut. Bull.* 87, 388–395. doi: 10.1016/j.marpolbul.2014.07.001

Benoit, J. M., Gilmour, C. C., Heyes, A., Mason, R. P., and Miller, C. L. (2003). Geochemical and biological controls over methylmercury production and degradation in aquatic ecosystems, in: Biogeochemistry of Environmentally Important Trace Elements, ACS Symposium Series. *Am. Chem. Soc.* 19, 262–297. doi: 10.1021/bk-2003-0835.ch019

Benoit, J. M., Gilmour, C. C., Mason, R. P., and Heyes, A. (1999). Sulfide controls on mercury speciation and bioavailability to methylating bacteria in sediment pore waters. *Environ. Sci. Technol.* 33, 951–957. doi: 10.1021/es9808200

Benoit, J. M., Shull, D. H., Harvey, R. M., and Beal, S. A. (2009). Effect of bioirrigation on sediment-water exchange of methylmercury in Boston Harbor, Massachusetts. *Environ. Sci. Technol.* 43, 3669–3674. doi: 10.1021/es803552q

Bouillon, S., Moens, T., and Dehairs, F. (2004). Carbon sources supporting benthic mineralization in mangrove and adjacent seagrass sediments (Gazi Bay, Kenya). *Biogeosciences* 1, 71–78. doi: 10.5194/bg-1-71-2004

Canuel, R., de Grosbois, S. B., Atikessé, L., Lucotte, M., Arp, P., Ritchie, C., et al. (2006). New evidence on variations of human body burden of methylmercury from fish consumption. *Environ. Health Perspect.* 114, 302–306. doi: 10.1289/ehp.7857

Castro, S., Luiz-Silva, W., MaChado, W., and Valezio, E. (2021). Mangrove sediments as long-term mercury sinks: Evidence from millennial to decadal time scales. *Mar. Pollut. Bull.* 173, 113031. doi: 10.1016/j.marpolbul.2021.113031

Cavoura, O., Brombach, C. C., Cortis, R., Davidson, C. M., Gajdosechova, Z., Keenan, H. E., et al. (2017). Mercury alkylation in freshwater sediments from scottish canals. *Chemosphere* 183, 27–35. doi: 10.1016/j.chemosphere.2017.05.077

Chai, M., Li, R., Qiu, Z., Niu, Z., and Shen, X. (2020). Mercury distribution and transfer in sediment-mangrove system in urban mangroves of fast-developing coastal region, Southern China. *Estuarine Coast. Shelf Sci.* 240, 106770. doi: 10.1016/j.ecss.2020.106770

Chen, C., Amirbahman, A., Fisher, N., Harding, G., Lamborg, C., Nacci, D., et al. (2008). Methylmercury in marine ecosystems: Spatial patterns and processes of production, bioaccumulation, and biomagnification. *EcoHealth* 5, 399–408. doi: 10.1007/s10393-008-0201-1

Chen, C. Y., Buckman, K. L., Shaw, A., Curtis, A., Taylor, M., Montesdeoca, M., et al. (2021). The influence of nutrient loading on methylmercury availability in Long Island estuaries. *Environ. Pollut.* 268, 115510. doi: 10.1016/j.envpol.2020.115510

Correia, R. R. S., and Guimarães, J. R. D. (2016). Impacts of crab bioturbation and local pollution on sulfate reduction, Hg distribution and methylation in mangrove sediments, Rio de Janeiro, Brazil. *Mar. Pollut. Bull.* 109, 453–460. doi: 10.1016/j.marpolbul.2016.05.028

Correia, R. R. S., and Guimarães, J. R. D. (2017). Mercury methylation and sulfate reduction rates in mangrove sediments, Rio de Janeiro, Brazil: The role of different

microorganism consortia. *Chemosphere* 167, 438–443. doi: 10.1016/j.chemosphere.2016.09.153

Crane, J. L. (2006). *Phase iv gis-based sediment quality database for the St. Louis riverarea of concern-wisconsin focus. Overview of sediment quality conditions in the St. Louis river area of concern*. (St. Paul, MN: Minnesota Pollution Control Agency, Environmentalanalysis and Outcomes Division). Available online at: http://www.pca.state.mn.us/publications/tdr-fg06-04a.pdf (Accessed January 19, 2020).

Ding, Z., Wu, H., Feng, X., Liu, J., Liu, Y., Yuan, Y., et al. (2011). Distribution of Hg in mangrove trees and its implication for Hg enrichment in the mangrove ecosystem. *Appl. Geochem.* 26, 205–212. doi: 10.1016/j.apgeochem.2010.11.020

Drott, A., Lambertsson, L., Björn, E., and Skyllberg, U. (2007). Importance of dissolved neutral mercury sulfides for methyl mercury production in contaminated sediments. *Environ. Sci. Technol.* 41, 2270–2276. doi: 10.1021/es061724z

Duan, D., Lei, P., Lan, W., Li, T., Zhang, H., Zhong, H., et al. (2021). Litterfall-derived organic matter enhances mercury methylation in mangrove sediments of South China. *Sci. Total Environ.* 765, 142763. doi: 10.1016/j.scitotenv.2020.142763

Eckley, C. S., Luxton, T. P., Knightes, C. D., and Shah, V. (2021). Methylmercury production and degradation under light and dark conditions in the water column of the Hells Canyon reservoirs, USA. *Environ. Toxicol. Chem.* 40, 1827–1837. doi: 10.1002/etc.5041

Feng, X. B., Qiu, G. L., Wang, S. F., Li, P., and Meng, B. (2013). Risk assessments and exposure pathways of inorganic mercury and methylmercury to populations from mercury mining regions in China. *Geochimica* 42, 205–211. doi: 10.3969/j.issn.0379-1726.2013.03.002

Fitzgerald, W. F., Lamborg, C. H., and Hammerschmidt, C. R. (2007). Marine biogeochemical cycling of mercury. *Chem. Rev.* 107, 641–662. doi: 10.1021/cr050353m

Fleck, J. A., Marvin-DiPasquale, M., Eagles-Smith, C. A., Ackerman, J. T., Lutz, M. A., Tate, M., et al. (2016). Mercury and methylmercury in aquatic sediment across western North America. *Sci. Total Environ.* 568, 727–738. doi: 10.1016/j.scitotenv.2016.03.044

Gaudette, H. E., Flight, W. R., Toner, L., and Folger, D. W. (1974). An inexpensive titration method for the determination of organic carbon in recent sediments. *J. Sediment. Res.* 44, 249–253. doi: 10.1306/74D729D7-2B21-11D7-8648000102C1865D

Gonzalez-Raymat, H., Liu, G., Liriano, C., Li, Y., Yin, Y., Shi, J., et al. (2017). Elemental mercury: Its unique properties affect its behavior and fate in the environment. *Environ. Pollut.* 229, 69–86. doi: 10.1016/j.envpol.2017.04.101

Haris, H., Aris, A. Z., and bin Mokhtar, M. (2017). Mercury and methylmercury distribution in the intertidal surface sediment of a heavily anthrophogenically impacted saltwater-mangrove-sediment interplay zone. *Chemosphere* 166, 323–333. doi: 10.1016/j.chemosphere.2016.09.045

Jiang, T., Skyllberg, U., Wei, S., Wang, D., Lu, S., Jiang, Z., et al. (2015). Modeling of the structure-specific kinetics of abiotic, dark reduction of Hg(II) complexed by O/N and S functional groups in humic acids while accounting for time-dependent structural rearrangement. *Geochimica Cosmochimica Acta* 154, 151–167. doi: 10.1016/j.gca.2015.01.011

King, J. K., Kostka, J. E., Frischer, M. E., Saunders, F. M., and Jahnke, R. A. (2001). A quantitative relationship that demonstrates mercury methylation rates in marine sediments are based on the community composition and activity of sulfate-reducing bacteria. *Environ. Sci. Technol.* 35, 2491–2496. doi: 10.1021/es001813q

Kristensen, E., Bouillon, S., Dittmar, T., and Marchand, C. (2008). Organic carbon dynamics in mangrove ecosystems: A review. *Aquat. Bot.* 89, 201–219. doi: 10.1016/j.aquabot.2007.12.005

Li, Y., and Cai, Y. (2013). Progress in the study of mercury methylation and demethylation in aquatic environments. *Chin. Sci. Bull.* 58, 177–185. doi: 10.1007/s11434-012-5416-4

Li, Y., Duan, Z., Liu, G., Kalla, P., Scheidt, D., and Cai, Y. (2015). Evaluation of the possible sources and controlling factors of toxic metals/metalloids in the Florida Everglades and their potential risk of exposure. *Environ. Sci. Technol.* 49, 9714–9723. doi: 10.1021/acs.est.5b01638

Liang, P., Feng, X.-B., Zhang, C., Zhang, J., Cao, Y., You, Q.-Z., et al. (2015). Human exposure to mercury in a compact fluorescent lamp manufacturing area: By food (rice and fish) consumption and occupational exposure. *Environ. Pollut.* 198, 126–132. doi: 10.1016/j.envpol.2014.12.036

Liem-Nguyen, V., Wild, B., Gustafsson, Ö., Semiletov, I., Dudarev, O., and Jonsson, S. (2022). Spatial patterns and distributional controls of total and methylated mercury off the Lena River in the Laptev Sea sediments. *Mar. Chem.* 238, 104052. doi: 10.1016/j.marchem.2021.104052

Liu, M., Zhang, Q., Maavara, T., Liu, S., Wang, X., and Raymond, P. A. (2021). Rivers as the largest source of mercury to coastal oceans worldwide. *Nat. Geosci.* 14, 672–677. doi: 10.1038/s41561-021-00793-2

Merritt, K. A., and Amirbahman, A. (2008). Methylmercury cycling in estuarine sediment pore waters (Penobscot River estuary, Maine, USA). *Limnol. Oceanogr.* 53, 1064–1075. doi: 10.4319/lo.2008.53.3.1064

Mondal, P., de Alcântara Mendes, R., Jonathan, M. P., Biswas, J. K., Murugan, K., and Sarkar, S. K. (2018). Seasonal assessment of trace element contamination in intertidal sediments of the meso-macrotidal Hooghly (Ganges) River Estuary with a note on mercury speciation. *Mar. Pollut. Bull.* 127, 117–130. doi: 10.1016/j.marpolbul.2017.11.041

Morel, F. M. M., Kraepiel, A. M. L., and Amyot, M. (1998). The chemical cycle and bioaccumulation of mercury. *Annu. Rev. Ecol. System.* 29, 543–566. doi: 10.1146/annurev.ecolsys.29.1.543

Padalkar, P. P., Chakraborty, P., Chennuri, K., Jayachandran, S., Sitlhou, L., Nanajkar, M., et al. (2019). Molecular characteristics of sedimentary organic matter in controlling mercury (Hg) and elemental mercury (Hg0) distribution in tropical estuarine sediments. *Sci. Total Environ.* 668, 592–601. doi: 10.1016/j.scitotenv.2019.02.353

Petranich, E., Covelli, S., Acquavita, A., Faganeli, J., Horvat, M., and Contin, M. (2018). Evaluation of mercury biogeochemical cycling at the sediment–water interface in anthropogenically modified lagoon environments. *J. Environ. Sci.* 68, 5–23. doi: 10.1016/j.jes.2017.11.014

Qiu, G., Feng, X., Wang, S., Fu, X., and Shang, L. (2009). Mercury distribution and speciation in water and fish from abandoned Hg mines in Wanshan, Guizhou province, China. *Sci. Total Environ.* 407, 5162–5168. doi: 10.1016/j.scitotenv.2009.06.007

Qiu, G., Feng, X., Wang, S., and Xiao, T. (2006). Mercury contaminations from historic mining to water, soil and vegetation in Lanmuchang, Guizhou, Southwestern China. *Sci. Total Environ.* 368, 56–68. doi: 10.1016/j.scitotenv.2005.09.030

Regnell, O., and Watras, C. J. (2018). Microbial mercury methylation in aquatic environments: A critical review of published field and laboratory studies. *Environ. Sci. Technol.* 53, 4–19. doi: 10.1021/acs.est.8b02709

Rice, G. E., Hammitt, J. K., and Evans, J. S. (2010). A probabilistic characterization of the health benefits of reducing methyl mercury intake in the United States. *Environ. Sci. Technol.* 44, 5216–5224. doi: 10.1021/es903359u

Schaefer, J. K., Yagi, J., Reinfelder, J. R., Cardona, T., Ellickson, K. M., Tel-Or, S., et al. (2004). Role of the bacterial organomercury lyase (MerB) in controlling methylmercury accumulation in mercury-contaminated natural waters. *Environ. Sci. Technol.* 38, 4304–4311. doi: 10.1021/es049895w

Seelen, E. A., Chen, C. Y., Balcom, P. H., Buckman, K. L., Taylor, V. F., and Mason, R. P. (2021). Historic contamination alters mercury sources and cycling in temperate estuaries relative to uncontaminated sites. *Water Res.* 190, 116684. doi: 10.1016/j.watres.2020.116684

Shen, J., Feng, Q., Algeo, T. J., Liu, J., Zhou, C., Wei, W., et al. (2020). Sedimentary host phases of mercury (Hg) and implications for use of Hg as a volcanic proxy. *Earth Planet. Sci. Lett.* 543, 116333. doi: 10.1016/j.epsl.2020.116333

Shi, C., Yu, L., Chai, M., Niu, Z., and Li, R. (2020). The distribution and risk of mercury in Shenzhen mangroves, representative urban mangroves affected by human activities in China. *Mar. Pollut. Bull.* 151, 110866. doi: 10.1016/j.marpolbul.2019.110866

Sunderland, E. M. (2003). Development of a marine mercury cycling model for Passamaquoddy Bay, New Brunswick. Simon Fraser University, Burnaby, British Columbia.

Sunderland, E. M., Gobas, F. A. P. C., Branfireun, B. A., and Heyes, A. (2006). Environmental controls on the speciation and distribution of mercury in coastal sediments. *Mar. Chem.* 102, 111–123. doi: 10.1016/j.marchem.2005.09.019

Taylor, D. L., Linehan, J. C., Murray, D. W., and Prell, W. L. (2012). Indicators of sediment and biotic mercury contamination in a southern New England estuary. *Mar. Pollut. Bull.* 64, 807–819. doi: 10.1016/j.marpolbul.2012.01.013

Tseng, C. M., Amouroux, D., Abril, G., Tessier, E., Etcheber, H., and Donard, O. F. X. (2001). Speciation of mercury in a fluid mud profile of a highly turbid macrotidal estuary (Gironde, France). *Environ. Sci. Technol.* 35, 2627–2633. doi: 10.1021/es001750b

Ullrich, S. M., Tanton, T. W., and Abdrashitova, S. A. (2001). Mercury in the aquatic environment: A review of factors affecting methylation. *Crit. Rev. Environ. Sci. Technol.* 31, 241–293. doi: 10.1080/20016491089226

Villar, E., Cabrol, L., and Heimbürger-Boavida, L.-E. (2020). Widespread microbial mercury methylation genes in the global ocean. *Environ. Microbiol. Rep.* 12, 277–287. doi: 10.1111/1758-2229.12829

Wang, Y., Wang, Z., Zheng, X., and Zhou, L. (2022). Influence of Spartina alterniflora invasion on mercury storage and methylation in the sediments of Yangtze River estuarine wetlands. *Estuarine Coast. Shelf Sci.* 265, 107717. doi: 10.1016/j.ecss.2021.107717

Wiener, J., Bodaly, R., Brown, S., Lucotte, M., Newman, M., Porcella, D., et al. (2007). "Monitoring and evaluating trends in methylmercury accumulation in aquatic biota," *Ecosystem Responses to Mercury Contamination* (CRC Press), 87–122. doi: 10.1201/9780849388897.ch4

Wildish, D. J., Akagi, H. M., Hamilton, N., and Hargrave, B. T. (1999). A recommended method for monitoring sediments to detect organic enrichment from mariculture in the Bay of Fundy. Canadian technical report of fisheries and aquatic sciences/Rapport technique canadien des sciences halieutiques et aquatiques. Imprint varies, 2286, p.34.

Wilms, R., Sass, H., Köpke, B., Cypionka, H., and Engelen, B. (2007). Methane and sulfate profiles within the subsurface of a tidal flat are reflected by the distribution of sulfate-reducing bacteria and methanogenic archaea. *FEMS Microbiol. Ecol.* 59, 611–621. doi: 10.1111/j.1574-6941.2006.00225.x

Wolfenden, S., Charnock, J. M., Hilton, J., Livens, F. R., and Vaughan, D. J. (2005). Sulfide species as a sink for mercury in lake sediments. *Environ. Sci. Technol.* 39, 6644–6648. doi: 10.1021/es048874z

Xiao, C., Jian, H., Chen, L., Liu, C., Gao, H., Zhang, C., et al. (2017). Toxic metal pollution in the Yellow Sea and Bohai Sea, China: distribution, controlling factors and potential risk. *Mar. Pollut. Bull.* 119, 381–389. doi: 10.1016/j.marpolbul.2017.03.027

Xu, J., Kleja, D. B., Biester, H., Lagerkvist, A., and Kumpiene, J. (2014). Influence of particle size distribution, organic carbon, pH and chlorides on washing of mercury contaminated soil. *Chemosphere* 109, 99–105. doi: 10.1016/j.chemosphere.2014.02.058

Xue, W., Kwon, S. Y., Grasby, S. E., Sunderland, E. M., Pan, X., Sun, R., et al. (2019). Anthropogenic influences on mercury in Chinese soil and sediment revealed by relationships with total organic carbon. *Environ. Pollut.* 255, 113186. doi: 10.1016/j.envpol.2019.113186

Yan, H., and Feng, C. (2012). Resesrcher necessity and advances about influence on methlylation of mercury in aquatic ecosystem from the aquaculture. *Environ. Chem.* 31, 1782–1786.

Yáñez, J., Guajardo, M., Miranda, C., Soto, C., Mansilla, H. D., and Flegal, A. R. (2013). New assessment of organic mercury formation in highly polluted sediments in the Lenga estuary, Chile. *Mar. Pollut. Bull.* 73, 16–23. doi: 10.1016/j.marpolbul.2013.06.015

Yu, C., Xiao, W., Xu, Y., Sun, X., Li, M., Lin, H., et al. (2021). Spatial-temporal characteristics of mercury and methylmercury in marine sediment under the combined influences of river input and coastal currents. *Chemosphere* 274, 129728. doi: 10.1016/j.chemosphere.2021.129728

Zhao, L., Wang, R., Zhang, C., Yin, D., Yang, S., and Huang, X. (2019). Geochemical controls on the distribution of mercury and methylmercury in sediments of the coastal East China Sea. *Sci. Total Environ.* 667, 133–141. doi: 10.1016/j.scitotenv.2019.02.334

Zhu, W., Song, Y., Adediran, G. A., Jiang, T., Reis, A. T., Pereira, E., et al. (2018). Mercury transformations in resuspended contaminated sediment controlled by redox conditions, chemical speciation and sources of organic matter. *Geochimica Cosmochimica Acta* 220, 158–179. doi: 10.1016/j.gca.2017.09.045

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 04 September 2024
DOI 10.3389/fmars.2024.1447277

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Mehran Idris Khan,
University of International Business and Economics, China
Sumedh Lokhande,
Auro University, India

*CORRESPONDENCE
Minna Yu
helloymn@126.com

RECEIVED 11 June 2024
ACCEPTED 15 August 2024
PUBLISHED 04 September 2024

CITATION
Yu M and Yue X (2024) Reflections on the reform of multi-tiered sea use right in China. *Front. Mar. Sci.* 11:1447277. doi: 10.3389/fmars.2024.1447277

COPYRIGHT
© 2024 Yu and Yue. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Reflections on the reform of multi-tiered sea use right in China

Minna Yu[1,2]* and Xinkai Yue[1]

[1]Law School, Ocean University of China, Qingdao, China, [2]Institute of Marine Development of Ocean University of China, Qingdao, China

As China's marine economy continues to flourish, the scarcity of offshore marine space has become increasingly apparent. The establishment of multi-tiered sea use right in 2023 represents an effective solution to facilitate the scientific allocation and effective protection of marine resources, thereby promoting high-quality development of marine economy. This paper offers a comprehensive and analytical overview of China's multi-tiered sea use right reform in the context of current status of ocean multi-use research and practice worldwide. China's multi-tiered sea use is an innovative practice of ocean multi-use in western countries. This paper adopts the methods of literature analysis, normative analysis, empirical analysis and case study. On the basis of comparative analysis of multi-tiered sea use in China and ocean multi-use in western countries, benefits and challenges of China's multi-tiered sea use right reform were summarized and analyzed, and suggestions from multiple perspectives are provided for implementing and developing multi-tiered sea use right in China.

KEYWORDS

multi-tiered sea use right, ocean multi-use, sustainable development, marine ecological civilization, marine industry transformation

1 Introduction

1.1 Background

Since building the country into a maritime power was formally designated as a national strategy on the 18th National Congress of the Communist Party of China in 2012 (Hu, 2012), President Xi Jinping has made a series of important statements concerning developing marine economy, promoting marine science and technology innovation, protecting marine environment, constructing the 21st-Century Maritime Silk Road, and building a maritime community with a shared future, etc (National Development and Reform Commission, 2024). Chinese government has implemented a number of effective policies to implement the maritime power strategy, particularly the consecutive *Five-Year Plans for Developing National Marine Economy including the*

12th[1], *the 13th*[2] and *the 14th*[3]. In 2023, the National People's Congress promulgated the new version of *Marine Environment Protection Law*. In recent years, China's marine industry has maintained rapid growth in general, and marine-related economic activities have continued to improve. In 2023, China's gross ocean production (GOP) was 9,909.7 billion yuan, representing a 6% increase over the previous year, and this growth rate was 0.8 percentage points higher than that of GDP. Furthermore, the GOP accounted for 7.9% of GDP, an increase of 0.1 percentage points over the previous year's share (The State Council, 2024).

However, the scarcity of marine space is becoming increasingly prominent. In response to the demand for sustainable exploration of ocean resources and efficient use of marine space, China's marine industry is currently in a critical period of transformation. Promoting the high-quality development of marine economy and developing the resource-conserving and environment friendly marine industry are key objectives and missions of the reform of China's sea use right (SUR) system. To be more specific, the scientific allocation of marine resources is the foundation for the sustainable development of marine economy. The traditional sea use right system is based on the "single-tiered" model of sea use and administration, which means that there is a single sea use right within the given sea area[4], which cannot fully leverage the multi-tiered and multifunctional marine space resources, which caused low utilization efficiency of marine space and conflict of interests among different parties (Ministry of Natural Resources of China, 2023). In order to address this issue, some coastal regions in China have been encouraged to explore experiences in multi-tiered sea use and launched a number of pilot projects. Successful local experiences reveal that the multi-tiered utilization of sea area is an effective approach for maximizing the potential of marine resources and resolving the issue of overlapping sea use (The Department of Natural Resources of Hebei Province, 2022). In November 2023, China's Ministry of Natural Resources issued the "*Circular on Exploring and Promoting the Establishment of Multi-tiered Sea Use Right*"[5] (hereinafter "*Circular of Multi-tiered Sea Use Right*"), which listed Some sea use activities including building bridges, aquaculture, warm drainage, installing submarine cables and pipelines, submarine tunnels, and other activities that have been rigorously demonstrated to be suitable for the establishment of multi-tiered sea use right. Such activities can co-exist and obtain the sea use right certificate in the same sea area as long as they would not impinge upon national defense security, marine transportation security, engineering security, and disaster prevention and mitigation, etc.

All in all, the establishment of multi-tiered sea use right in China represents a significant step in transforming the ocean single use into the ocean multi-use. It is of great significance in promoting intensive use and effective protection of marine resources, advancing sustainable marine economy development, and achieving the goal of China's marine ecological civilization construction (Ren et al., 2024). It also represents China's efforts to promote the achievement of the United Nations 2030 Sustainable Development Goals (SDGs)[6], particularly the SDG 12 "Ensure sustainable consumption and production patterns" and SDG 14 "Conserve and sustainably use the oceans, seas and marine resources".

1.2 Literature review

Multi-tiered sea use is not a novel concept. It essentially is the concrete practice of ocean multi-use. Multi-use refers to the intentional joint use of resources in close geographic proximity (MUSES Project, 2020), which represents a radical change from exclusive resource rights towards inclusive resource sharing by one or more users (Zaucha et al., 2017). The concept of multi-use was put forward by American conservationists in forestry management in 1940s, and it was introduced into the maritime realm by western scientists in 1970s (Smith, 1970). The earliest research clarified that human activities increased stress on maritime space and emphasized the importance for new maritime spatial planning policies and new maritime space management models (Sheail, 1986). In 2004, a German research group examined the potential sustainable schemes for ocean multi-use by analyzing the co-existence of open ocean aquaculture and offshore wind farms in the Exclusive Economic Zone of Germany

1 The 12th Five-Year Plan for Developing National Marine Economy was adopted by the State Council on September 16, 2012 and entered into force immediately. The full text is available at the official website of the State Council, https://www.gov.cn/zhengce/zhengceku/2013-01/17/content_2572.htm (in Chinese).

2 The 13th Five-Year Plan for Developing National Marine Economy was adopted by the National Development and Reform Commission and the State Oceanic Administration on May 4, 2017 and entered into force immediately. The full text is available at the official website of the National Development and Reform Commission, https://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=419 (in Chinese).

3 The 14th Five-Year Plan for Developing National Marine Economy was adopted by the National Development and Reform Commission and the Ministry of Natural Resources on December 15, 2021 and entered into force immediately. The full text is available at the official website of the State Council, https://www.gov.cn/zhengce/content/2021-12/27/content_5664783.htm (in Chinese).

4 It is called single use in some scenarios, compared to multi use of the sea.

5 Circular on Exploring and Promoting the Establishment of Multi-tiered Sea Use Right was adopted by Ministry of Natural Resources of China on November 13, 2023 and entered into force immediately. The full text is available at the official website of the State Council, https://www.gov.cn/zhengce/zhengceku/202311/content_6916283.htm (in Chinese).

6 The 2030 Agenda for Sustainable Development was adopted by all United Nations Member States in 2015 to meet the urgent environment, political, and economic challenges that our world faces. Details of SDGs are on the website of United Nations, https://sdgs.un.org/goals.

(Buck et al., 2004). In the next two decades, the concept of ocean multi-use was gradually embraced by European marine scientists, planners, and policy makers (Guyot-Téphany et al., 2024). In 2012, the European Union presented the Blue Growth Strategy which emphasized that creating synergies between economic activities and addressing tensions clearly helps in realizing the blue growth potential (Ecorys, Deltares, and Oceanique Developement et al., 2012). In 2014, the Directive 2014/89/EU of the European Parliament and of the Council defined maritime spatial planning as a means of identifying and encouraging multi-purpose uses of sea area (European Parliament and of the Council, 2014). In this context, large-scale collaborative projects, such as MERMAID[7], TROPOS[8], H2Oceans[9], and MARIBE[10], funded by European Union through Horizon 2020 (2014-2020) and Horizon Europe (2021-2027) research and innovation funding programmes have worked on analyzing and exploring promising ocean multi-use combinations or models. Based on different levels of connectivity between the involved users and users, scholars summarized four major types of ocean multi-use, namely, multi-purpose, symbiotic use, co-existence, and subsequent use (Schupp et al., 2019).

In China, study related to the ocean multi-use are more recent. Two decades ago, scarcity of offshore marine space and spatial conflicts between different sea use activities in China were gradually manifesting, and some literature focused on discussion of the feasibility of multi-tiered sea use from perspectives of law (Ruan, 2005; Zhang and Li, 2008) and property rights theory (Zhao et al., 2016) emerged. They provided theoretical basis for the establishment of multi-tiered sea use right. In 2015, the State Oceanic Administration[11] solved two cases concerning marine space conflicts between cross-sea bridge and warm drainage of nuclear power plant in Fuding city and Lianyungang city through multi-tiered sea use method for the first time (The People's Government of Fuding City, 2016). The successful practice led to the proliferation of academic research and practical exploration of multi-tiered sea use. Chinese scholars have carried out extensive research on the supporting systems of multi-tiered sea use (Yang et al., 2022; Li et al., 2023; Zhou et al., 2024), including spatial conflict and management (Li et al., 2023), market-based sea use system, and three-dimensional marine cadastre (Cui et al., 2022), etc.

Despite ocean multi-use has gained momentum discussion among marine scientists and planners in the past decade, however, as an innovative practice of ocean multi-use, western academia paid no attention on multi-tiered sea use, and Chinese scholars have not systematically study the newly established multi-tiered sea use right in November 2023.

1.3 Purpose and structure

The principle purpose of this article is to make a comprehensive study on the reform of China's multi-tiered sea use right. The authors firstly adopts the methods of normative analysis and empirical analysis to study the reform process and current status of the multi-tiered sea use right in China. Then, by using the method of case study, authors will seek to examine the practical effects and benefits of multi-tiered sea use right by analyzing the Shuangjiantu Project, Sanmen project, and Guangdong practice. Next, authors outline practical challenges in the implementation of multi-tiered sea use right. Finally, recommendations are provided to better reflect the current requirements for the development of multi-tiered sea use right.

2 Development status of the multi-tiered sea use right in China

2.1 Overview of the sea use management system in China

China, as a State party to the United Nations Convention on the Law of the Sea (UNCLOS)[12], enjoys sovereignty over its internal waters

7 The MERMAID project has explored multi-use offshore platforms through a participatory design process, integrating both technical and visionary perspectives. The project examined innovative combinations of structures and entirely new designs. It focused on multi-use platforms that integrate wind turbines with aquaculture or wave energy generators in the Baltic Sea, the North Sea, the Mediterranean Sea, and the Atlantic Ocean. For details of MARMAID, see (Stuiver et al., 2016).

8 The TROPOS project aims to develop a modular, multi-use platform for deployment in deep waters, particularly focusing on the Mediterranean, tropical, and subtropical regions. These platforms are designed to enhance synergies and compatibility among various uses, including transport, energy production, aquaculture, and leisure activities. For details of TROPOS, see (Quevedo et al., 2013).

9 The H2OCEAN project explores proof-of-concepts for a multi-use ocean platform capable of harvesting and storing energy in the form of compressed H2, while also integrating multi-trophic aquaculture and bio-waste treatment, alongside drinkable water production. For details of H2OCEAN, see (Urbano and Rocco, 2019).

10 The MARIBE project is on a mission to explore collaboration opportunities for companies that seamlessly merge various sectors within the Blue Growth and Blue Economy domains, adopting the method of tapping into the vast potential of multi-use space in the Blue Economy. Details of MARIBE are on the website of Europe Union, https://www.maribe.info/.

11 In 2018, according to the State Council's *Proposal for Reviewing the Reform Scheme of the State Council's Institutions*, the Ministry of Land and Resources, State Oceanic Administration and the National Administration of Surveying, Mapping and Geographic Information, were no longer retained and the Ministry of Natural Resources was established, within which, the function of State Oceanic Administration is maintained. The full text of *Proposal for Reviewing the Reform Scheme of the State Council's Institutions* is available at the official website of the State Council, https://www.gov.cn/gongbao/content/2018/content_5280572.htm (in Chinese).

12 United Nations Convention on the Law of the Sea (UNCLOS), 1833, *UNTS* 3. This Convention was opened for signature at Montego Bay on 10 December 1982 and it entered into force on 16 November 1994.

and territorial sea. In domestic law, the *Sea Areas Administration Law of the People's Republic of China* (hereinafter "*Sea Areas Administration Law*")[13] provides legal basis and regulatory framework of the sea use right in China, which marks the first time when property rights of marine spaces, the paid-use management system, and marine functional zoning system were defined in law (Yang et al., 2020). To be more specific, the *Sea Areas Administration Law* clearly stipulated that "sea area" refers to the interior waters, the surface, body, seabed and bottom soil of the territorial seas;[14] the sea area shall belong to the state; the right to use sea area shall be lawfully obtained by any entity or individual on the paid basis, and the payment are referred to as royalties for using sea areas[15]. In 2006, the State Oceanic Administration of China promulgated *Provisions on the Administration of sea use Rights*[16], along with a series of supporting documents, including the *Specifications for Marine Cadastral Surveys*[17], *Technical Specifications for the Compilation and Drawing of Marine Cadastral Charts*[18], and the *Classification of the Use of Sea Areas*[19]. China's sea area management system was established based on these legal documents.

Overall, China's sea area management system consists of two parts: marine spatial planning system and sea use right system. The marine spatial planning system is a top-down spatial management system centered on coastal spatial planning with a combination of zoning and access rules (Gao et al., 2024). Marine spatial planning is formulated by the government *ex officio* and is divided into national macro-zoning and local functional zoning. Marine functional zones and their regulatory requirements delineated in marine spacial planning at the macro level serve as the basis for the sea use right system, which specifically regulates and allocates marine development activities in specific marine spaces at the micro level. The sea use right system is implemented by the administrative authorities, who examine and grant private entities the right to use the sea area. Therefore, the marine spatial planning system and the sea use right system operate independently and in conjunction with each other at the macro-planning and micro-allocation levels.

2.2 Reform process: from pilot projects to department regulation

Over the past decade, increasing types of offshore marine industries have resulted in density of the development and utilization of China's sea area. The prevalence of construction projects such as submarine cables and pipelines, offshore wind power equipment, and cross-sea bridges has grown. The construction of submarine tunnels, bay bridges, and other marine facilities often involves passing through original offshore aquaculture area and other functional zones. The traditional single-tiered sea use right system is inadequate for addressing the growing demand for multi-dimensional use of the sea. Meanwhile, advancements of three-dimensional marine cadastral survey technology have laid foundation for the multi-dimensional development and utilization of sea area. Driven by the economic development demands of the integration and intensification of the marine industry, and guided by the public policy objectives of achieving sustainable development of the oceans and protecting the marine environment, some coastal provinces of China have explored the transformation to multi-tiered marine space utilization and management.

In response to the conflicts arising from the demand for multi-tiered sea use and the absence of legal basis, particularly exacerbated by the overlap between the use of the sea for cross-sea bridges and nuclear power water intakes, Lianyungang, a city in Jiangsu Province, and Fuding, a city in Fujian Province, initiated pilot projects for the multi-tiered use of sea area and the establishment of multi-tiered sea use right in 2014 and 2016 respectively. In Jiangsu Province, through demonstrating the compatibility of cross-sea bridge construction with warm drainage of nuclear power plants, the State Oceanic Administration approved to confer sea use right of different tier of the same sea area to the two companies, specifically, the constructor of the sea-crossing bridge was granted sea use right to the surface, while the nuclear power plant was permitted to use the water body of the same sea area. The Jiangsu

13 Sea Areas Administration Law of the People's Republic of China was adopted at the 24th session of the Standing Committee of the Ninth National People's Congress on October 27, 2001 and entered into force on January 1, 2002. The full text is available at the official website of Ministry of Ecology and Environment of the People's Republic of China, https://english.mee.gov.cn/Resources/laws/environmental_laws/202012/t20201211_812661.shtml.

14 Article 2 of Sea Areas Administration Law of the People's Republic of China.

15 Articles 3, 33 of Sea Areas Administration Law of the People's Republic of China.

16 Provisions on the Administration of sea use Rights was adopted by the State Oceanic Administration of China on October 13, 2006 and entered into force on January 1, 2007. The full text is available at the official website of Ministry of Natural Resources of the People's Republic of China, https://gc.mnr.gov.cn/201806/t20180615_1796682.html (in Chinese).

17 Specifications for Marine Cadastral Surveys was adopted by the State Oceanic Administration of China on May 6, 2008 and entered into force on July 1, 2008. The full text is available at the official website of Ministry of Natural Resources of the People's Republic of China, https://gc.mnr.gov.cn/201806/t20180614_1795677.html (in Chinese).

18 Technical Specifications for the Compilation and Drawing of Marine Cadastral Charts was adopted by the State Oceanic Administration of China on May 3, 2016 and entered into force on June 1, 2016. The full text is available at the official website of Ministry of Natural Resources of the People's Republic of China, https://gk.mnr.gov.cn/zc/zxgfxwj/202103/t20210326_2618389.html (in Chinese).

19 Classification of the Use of Sea Areas was adopted by the State Oceanic Administration of China on May 6, 2008 and entered into force on July 1, 2008. The full text is available at the official website of Ministry of Natural Resources of the People's Republic of China, https://gc.mnr.gov.cn/201806/t20180614_1795677.html (in Chinese).

practice established a successful precedent and reference for other provinces and cities in China. In 2016, the State Oceanic Administration issued the *Opinions on Further Regulating the Management of Sea Use Right for Offshore Wind Power*[20], which encouraged the co-existence of offshore wind power projects and other compatible sea use activities in the same marine space and confirm their rights separately. More pilot projects of multi-tiered sea use right were launched on a larger scale across the country. For example, Guangdong province issued the *Notice of the Department of Natural Resources of Guangdong Province on Promoting the Establishment of Multi-tiered Sea Use Rights*[21] based on local experience, detailed criteria has been established for examining the compatibility between different sea use activities in the same sea area within Guangdong Province.

Based on the successful practices, in 2019 and 2021 respectively, the General Office of the State Council issued the *Guiding Opinions on Coordinated Reform of the Property Rights System of Natural Resource Assets*[22] and the *Overall Plan for Pilot Programs of Comprehensive Reform in Factor Market-based Allocation*[23], which emphasized the importance of the reform of sea use right system and advocated the model of multi-tiered sea use right. Under the guidance of the Central Committee of the Communist Party of China and the State Council, in 2023, the Ministry of Natural Resources issued *Circular of Multi-tiered Sea Use Right*. It contains the technical standard *Guidelines for Defining the Scope of Marine Cadastre for Multi-tiered Sea Use Right in Sea Areas (for trial implementation)* as an appendix. *The Circular* officially confirmed the legitimacy of multi-tiered sea use rights of existed pilot projects, and promote the implementation of multi-tiered sea use right in China.

At present, some provinces and coastal cities have formulated detailed policies to implement *The Circular* based on the specific conditions of sea area in each province or city. For example, in April 2024, Shenzhen issued a trial version of Notice on Promoting the Establishment of Multi-tiered Sea Use Right for two years. It constitutes a useful supplement for *The Circular* and serves as a useful template for other provinces.

3 Benefits of multi-tiered sea use right reform in China

3.1 Improving intensive utilization of marine space

For the time being, some coastal regions including Shandong province, Zhejiang province, Guangdong province have implemented the multi-tiered sea use right system and accumulated rich experiences. Typical combination of marine development activities have been established in practice, which are "construction of sea-ponds+cables or pipelines", "aquaculture+photovoltaic power generation" (Figure 1), "cross-sea bridge+aquaculture," and "photovoltaic power generation+warm drainage".

Taking "aquaculture+photovoltaic power generation" model as an example, it reveals the scientific compatibility between two different types of sea area development activities. On one hand, aquaculture and photovoltaic power generation occupy different tiers of sea area, which indicates the spatial compatibility; on the other hand, there is no temporal or spatial conflict between different right holders when using the sea, which suggests a low risk of conflicts of interest. Specifically speaking, photovoltaic power generation projects mainly occupy and use the space above the mean sea level until the upper edge of the photovoltaic panels, while aquaculture projects need to use of the water body of sea area, i.e., the sea areas between the mean sea level and the seabed. Additionally, the supporting columns of the photovoltaic panel would not interfere with the aquaculture located in the same sea area.

Zhejiang province has more than 260000 square kilometers sea area, which ranks top five in China. It promulgated the *Technical Specification for the demarcation of sea area under multi-tiered sea use right*[25] (hereinafter "*Technical Specification*") in January 2024, which is the first local standard at the provincial level. The implementation of *Technical Specification* and related policies has greatly improved the efficiency of marine resource allocation and increased the sea area that could be used. For example, the Daishan Shuangjiantu Project operated by CR Power change the way of

20 Opinions on Further Regulating the Management of Sea Use Right for Offshore Wind Power was adopted by the State Oceanic Administration of China on October 31, 2016 and entered into force immediately. The full text is available at the official website of Ministry of Natural Resources of the People's Republic of China, https://gc.mnr.gov.cn/201806/t20180615_1796693.html (in Chinese).

21 Notice of the Department of Natural Resources of Guangdong Province on Promoting the Establishment of Multi-tiered Sea Use Rights was adopted by Department of Natural Resources of Guangdong Province on September 18, 2023 and entered into force immediately. The full text is available at the official website of Department of Natural Resources of Guangdong Province, https://www.gd.gov.cn/zwgk/gongbao/2023/26/content/post_4262429.html (in Chinese).

22 Guiding Opinions on Coordinated Reform of the Property Rights System of Natural Resource Assets was adopted by General Office of the Communist Party of China Central Committee and General Office of the State Council on April 14, 2019 and entered into force immediately. The full text is available at the official website of the State Council, https://www.gov.cn/zhengce/2019-04/14/content_5382818.htm (in Chinese).

23 Overall Plan for Pilot Programs of Comprehensive Reform in Factor Market-based Allocation was adopted by General Office of the State Council on December 21, 2021 and entered into force immediately. The full text is available at the official website of the State Council, https://www.gov.cn/gongbao/content/2022/content_5669421.htm (in Chinese).

25 Technical Specification for the demarcation of sea area under multi-tiered sea use right was adopted by Department of Natural Resources of Zhejiang Province on November 17, 2022 and entered into force immediately. The full text is available at the official website of Department of Natural Resources of Zhejiang Province, https://zrzyt.zj.gov.cn/art/2022/11/21/art_1289924_59009224.html?eqid=a5cead470034a8e300000002647d2e7b (in Chinese).

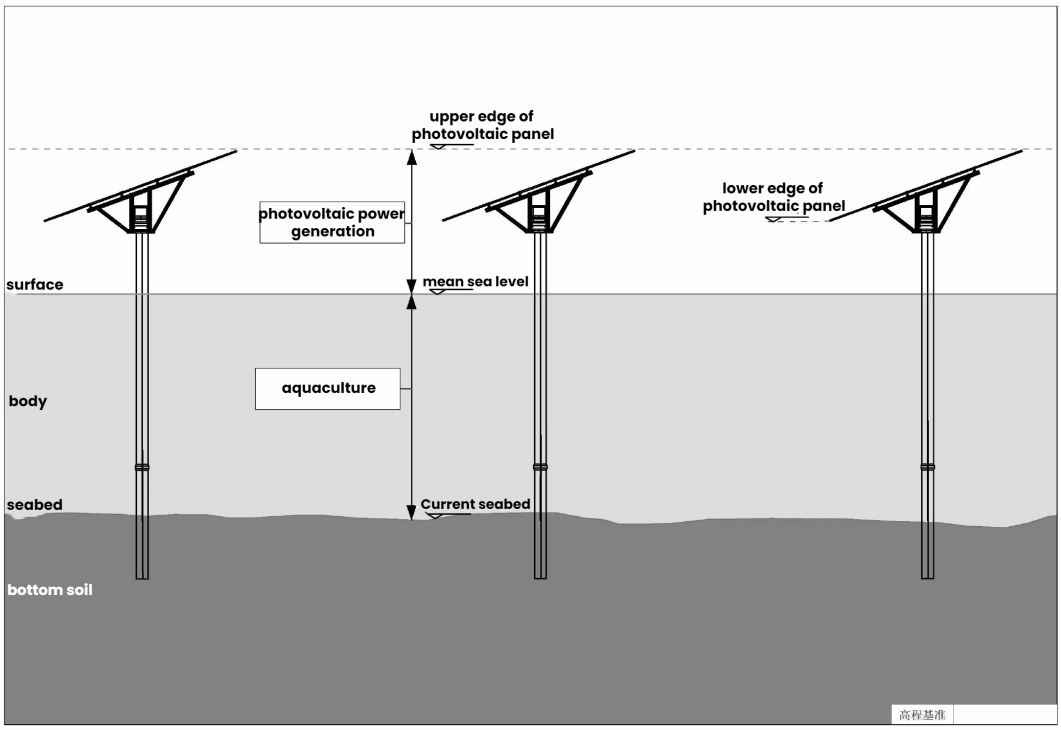


FIGURE 1
Aquaculture + photovoltaic power generation[24]

using sea area. The 75.56 hectares sea area used for aquaculture has been transformed to the "aquaculture+photovoltaic power generation" model. The water body of 75.56 hectares remains dedicated to marine aquaculture, while the 69.93 hectare surface of marine space is used for the photovoltaic power generation project. This resulted in an increase of the utilized sea area by 92.5% (The People's Government of Zhejiang Province, 2024).

3.2 Promoting green transformation of marine industries

Among the typical models of the multi-tiered utilization of sea area, represented by "aquaculture+photovoltaic power generation" and "photovoltaic power generation+warm drainage", presents a novel approach to integrating photovoltaic power generation, wind power generation, and tidal power generation with traditional marine uses. It promotes the construction of clean and renewable energy infrastructures. The promotion of energy-related multi-tiered utilization of sea areas can help reduce the energy pressure on coastal areas, improve the proportion of renewable energy in China's energy structure, and accelerate improvements in energy efficiency. This not only satisfies the requirements of the United Nations 2030 SDGs but also contributes to the high-quality development of China's energy economy.

Take the typical combination of "photovoltaic power generation +warm drainage" as an example, which has yielded positive outcomes. CNNC Sanmen 200MW beach photovoltaic project realized the first grid-connection of 100MWp capacity, marking the first "nuclear light storage multi-energy coupling" in China and the first independent development and construction of CNNC beach photovoltaic project officially connected to the grid. The project uses the thermal drainage area of Sanmen nuclear Power plant to build a photovoltaic project, which provides a demonstration for subsequent "nuclear +" development model, and promotes the management mode of the sea area from "plane" to "three-dimensional", which is of great significance for promoting the economical and intensive utilization and effective protection of marine resources and promoting the high-quality development of the marine economy. The multi-energy coupling of nuclear energy+photovoltaic+energy storage has been formed at the power supply end of the regional power grid, which has a demonstration role in the construction of a power system with the basic characteristics of clean and low-carbon, safe and controllable, flexible and efficient, intelligent and friendly, open and interactive, supported by the interaction of charge and storage of the source network and multi-energy complementarity (CNNP Rich Energy Co. LTD, 2023).

3.3 Supporting sustainable development of marine economy

There is an old saying in China, "take from the sea, use to the sea." It has been fully reflected in the evolution of China's sea use

24 Department of Natural Resources of Zhejiang Province (2023). Technical Specification for the demarcation of sea area under multi-tiered sea use right. Available at: https://zrzyt.zj.gov.cn/art/2022/11/21/art_1289924_59009224.html

right system, especially in the management of the royalties for using sea area. The *Sea Area Administration Law* explicitly stipulates that China practices the system of using sea area on the paid basis. In other word, the sea area use royalties should be paid by the users, which is based on the experience of other countries, such as the Republic of Korea, Japan and the United Kingdom. Notably, core consideration of the market-based sea use right system is the sustainable development of marine economy, which means ecological environment has been placed at least on the same important position with economic development.

The collection of sea area use royalties is an important element in improving the public revenue system. Taking Guangdong Province, a major maritime province in China, as example, the financial collections of sea area use royalties during the Eleventh Five-Year Plan period reached to 2.641 billion yuan, of which 704 million yuan was collected in 2010, a year-on-year increase of 28%, or 22 times the 2006 revenue (Ministry of Finance of China, 2011). In the past decade, with the reform process of multi-tiered sea use right, some coastal regions are exploring adaptive ways of the management of sea area use royalties. In 2022, Guangdong province released the amended *Criteria for Collection of Sea Area Use Royalties in Guangdong Province*, aiming at promoting the sustainable development of marine economy with the regulatory role of sea area use royalties (Department of Finance of Guangdong Province, 2022). For instance, lowering the royalties of sea area used for aquaculture, and the Guangdong standard is the lowest criteria now in China. Undoubtedly, it promotes the construction of sea farms in Guangdong Province and is beneficial for the transformation of fishery industry. Besides, the expenditure of sea area use royalties are mainly on the protection and restoration of marine ecology environment. In 2009, the Ministry of Finance and the State Oceanic Administration jointly decided that the funds collected from sea area use royalties would be included in the budget and used for the management and protection of sea area (Ministry of Finance, and The State Oceanic Administration, 2009). Specifically, The sea area use royalties collected in the current year will be arranged for use in the budget of the following year by the Ministry of Finance. The specific scope of use includes making policies, regulations, and standards for the sea area use management; formulating marine spatial planning; conducting surveys, surveillance, monitoring, and management of sea area use; upgrading maritime law enforcement equipment and information system; classifying and evaluating sea area resources; regulating, restoring, and protecting sea areas, islands, and coastal zones; constructing the technical support system for sea area utilization and management; collecting and administering sea area use royalties; and undertaking other projects related to the protection and management of sea areas as determined by the Ministry of Finance and the State Oceanic Administration.

To sum up, China's multi-tiered sea use right reform has made achievements in improving the efficiency of sea area utilization, alleviating scarcity of marine space, and under the premise of sustainable development, the economic benefits of marine space have been fully brought into play. The multi-tiered use of sea area and the reform of sea use right in China adhere to the principles of conservation, intensiveness, and prioritization of ecological protection. It considers the carrying capacity of marine environment, the actual requirement of multi-tiered development of sea area and potential impacts on marine ecology. It divides sea area into multiple tiers, and establishes different types of sea use right on different tiers based on different features of marine development activities. The compatibility of various types of sea use rights could be ensured by the rigorous investigation, demonstration and examination procedure. Besides, the market-based sea use right system puts a big spotlight on ecological protection, which is conducive to optimizing marine industrial distribution and promoting marine economic integration, and improving the efficiency of marine resource utilizing.

4 Challenges faced by multi-tiered sea use right reform in China

4.1 Relevant laws and regulations lags behind

There is a lack of detailed regulatory framework of relevant laws and regulations on multi-tiered sea use right. The reform of multi-tiered sea use right has lasted over ten years, and adopted the approach of bottom-up. Existing laws and regulations need to improve to adapt to the needs of current status and future development of multi-tiered sea use right.

The *Sea Areas Administration Law* has applied for 22 years, and it does not have specific regulations on multi-tiered sea use right. For example, the *Sea Area Administration Law* provides that the entities or individuals applied to use sea area should submit the sea area use demonstration report, which is the scientific basis for approving the application and transferring of sea use right. Ministry of Natural Resources has issued a series of legal documents to standardize the management of sea area use demonstration. The applicant should formulate the sea area use demonstration report following the principles of justice, science and good faith, and relevant laws and regulations, technical standards and norms of sea area use demonstration (Ministry of Natural Resources of China, 2021). The demonstration of sea area use shall be based on a detailed survey of the ecology, development and utilization of marine resources in the area where the project is located, and guided by the principle of ecological priority, conservation and intensification. Specifically, it should cover the scientific and objective analysis of the necessity of the project, the rationality of site selection and scale, the impacts on marine resources and ecology, and the coordination of stakeholders, etc. China has established sea area use information platform[26] to increase the

26 Details of the sea area use information platform are on the official website of Ministry of Natural Resources, https://www.hysylz.org.cn (in Chinese).

disclosure of sea area use demonstration information, and strengthen the supervision over the sea use activities. However, there is no clear provision in these legal documents concerning the management of sea area use demonstration of multi-tiered sea use.

Some coastal and local governments have noticed the problem of existing laws and regulations lags behind the development of multi-tiered sea use right, and have been exploring to make targeted policies to make up the shortages of relevant laws and regulations. In conclusion, relevant laws and regulations require improvements to adapt to the needs of multi-tiered sea use right.

4.2 Conflicts of marine spatial planning and multi-tiered sea use right

Marine spatial planning system and sea use right system constitute China's sea area management system. With the reform and implementation of multi-tiered sea use right, the highly flexible and practical sea use right system may conflict with the stable marine spatial planning system.

Firstly, the current marine spatial planning in China is based on the plane management mode of sea area, making it challenging to meet the practical requirements for establishing multi-tiered sea use right. Specifically, marine spatial planning uses the traditional industry-oriented planning method, which divides sea area into various functional zones and confirms their dominant use. The multi-tiered utilization of marine space, to a large extent, depends on the evaluation and demonstration of private entities, namely, the applicant. A rigorous review process would be needed to ensure that the compatible marine uses that differ from the dominant marine uses in the sea area would not affect its dominant function. The demonstration and examination process is cumbersome and involves high invisible costs (Ciravegna et al., 2024). As a result, private entities tend to use the functional areas exclusively and independently according to the designated dominant use, rather than adopting multi-tiered utilization for compatible development.

Secondly, marine spatial planning is a form of macro-planning that lacks precision and specificity. Marine spatial planning mainly serves public policy objectives, such as marine sustainable development and marine environment protection. It needs to be considered based on overall planning, so its spatial scale is larger and the details are rough. However, this is not completely consistent with the objectives of multi-tiered sea-use rights, which aim to achieve specific spatial arrangements that consider the economic demands of all interested parties in a particular area.

Thirdly, marine spatial planning is a long-term planning with insufficient timeliness and flexibility. In China, the coastal spatial planning usually takes place on 15-year cycle. But with the rapid development of marine technology and constant emergence of marine industries, marine uses show the trend of diversified development. the implementation of multi-tiered sea use right can respond to the diverse market demands arising from rapid changes in the marine sector. Comparatively, the marine spatial planning system cannot respond well to the development trend because of its pursuit of stability.

5 Suggestions for implementing multi-tiered sea use right in China

5.1 Improve relevant laws and regulations

To promote the implementation of multi-tiered sea use right, the government should strengthen the top-level design of multi-tiered sea use and improve relevant laws and regulations. Due to the development model of bottom-up, the multi-tiered sea use right reform to some extent guided by local governments. Lacking uniform standards of supporting management system and technical standard present serious obstacle to the development of multi-tiered sea use. Therefore, The government should update existing legal documents or formulate new ones based on existing practical experience.

Take the sea area use demonstration report of multi-tiered sea use right as an example, in local practice, Zhoushan requires the applicant to bear the obligation of demonstrating the compatibility of different sea use activities in the same sea area. An extra chapter is required to be added in the sea are use demonstration report, focusing on the necessity and feasibility of the establishment of the multi-tiered sea use right. The applicant should specify the types of sea use activities, the scope of each kind of sea use activity, and overlapping scope of marine space, and prove the compatibility of different sea use activities and its compliance with the requirements of marine spatial planning. If the application involves the sea area where exists original sea use right, to avoid potential conflict, an agreement should be reached between the original right holder and the new applicant to specify their separate types of sea use activities, geographical range, overlapping scope, limitations of rights, and period of each sea use right, etc (Zhoushan Natural Resources and Planning Bureau, 2023). The government should enact new regulations or amend existing legal documents to unify the standard of sea area use demonstration report of multi-tiered sea use right.

5.2 Adopt marine spatial detailed planning

Marine spatial detailed planning can be regarded as an approach to coordinate the conflicts between marine spacial planning and multi-tiered sea use. Pilot projects are underway in three cities, Shenzhen, Sanya, and Qingdao (First institute of Oceanography of Ministry of Natural Resources, 2022). Marine spatial detailed planning serves as a system between the marine spatial planning and sea use right system, and it incorporates elements of both systems. By cross-dealing with the conflicts and contradictions between marine spatial planning and sea use right system, marine spatial detailed planning aims to achieve the goal of system coordination and has stronger feasibility. Specifically, the Natural Resource Administrative authorities should be responsible for formulating and releasing marine detailed planning, which would further divide the function zone determined by marine spatial planning, and pre-planning various compatible marine uses in the same sea area. The marine spatial detailed planning should be formulated based on marine geology, resource

distribution, and marine environment carrying capacity of specific sea area. Finally, the Natural Resource Administrative authorities would draw the boundaries of marine spaces, enabling their allocation through applications by private parties, tender and auction.

With the implementation of China's multi-tiered sea use right, the marine spatial planning system is also undergoing a new series of reforms. Practical exploration of marine spatial detailed planning is currently in its nascent stage of development and requires further refinement at least in the following two key aspects.

On one hand, the natural resource administrative authorities should play a leading role in investigating whether there is scientific compatibility and practical feasibility of implementing the multi-tiered sea use right for which the dominant function have already been specified by marine spatial planning. If it is appropriate to implement multi-tiered sea use right system, marine spatial detailed planning should be formulated accordingly to identify other compatible marine uses and boundaries for different marine uses should be delineated. In other word, the Natural Resource Administrative authorities rather than private entities should play the leading role in investigating and determining the sustainable combinations of different demands of sea use in the same are area. By reducing the burden of private entities and reducing transaction costs, the multi-tiered sea use right would be able to develop. On the other hand, in sea areas reserved for development in the marine spatial planning, demonstration area for multi-tiered utilization should be established according to marine spatial detailed planning (Gao et al., 2024). It is obvious that the approach differs from directly designating functional areas and their dominant uses through the marine spatial planning (Bocci et al., 2019). Notably, based on the responsibility of the natural resource administrative authorities and other government departments for supervision, the market has become a decisive force in the process of allocating marine space. Therefore, in the process of formulating marine spatial detailed planning, opinions of private entities should be taken into consideration.

Based on above analysis, marine spatial detailed planning should be promoted in order to fill in the gaps between marine spatial planning and multi-tiered sea use right. Timeliness, pertinence, multi-dimension should be crucial factors of the marine spatial detailed planning. Market-oriented allocation of sea area and marine resources under the supervision of government would be the feasible path.

5.3 Promote marine environmental benefits

Promoting marine environmental benefits is the key objective and core consideration of multi-tiered utilization of sea area. China's exploration and practice of multi-tiered sea use is insufficient, and more possible combinations should be developed.

On one hand, investment and support in scientific research should be increased. Multi-use of sea is not exclusively better than single-use of sea. It is important to carefully consider local conditions when making a decision whether to favor single or multi use in a given location and what combination should be the best choice (MUSES Project, 2020). But now in China, there is insufficient scientific survey both on coastal marine environment and on sustainable combination of marine utilization activities. On the other hand, development of renewable energy and relevant combinations should be promoted. Analysis of China's pilot projects on multi-tiered sea use reveals that renewable energy including wind, solar, wave, and tidal energy is the driving sectors for multi-tiered sea use in China in the near future. It is therefore reasonable that multi-tiered sea use is strengthened around the renewable energy. In this perspective, renewable energy-based combination should be the focus of multi-tiered sea use in China and renewable infrastructure should be preferably paired with other marine uses.

5.4 Foster synergistic effects

Synergies refer to the mutually beneficial utilization of the same sea area or marine resources, but equally to shared infrastructure, technology or human resources. A key driver for synergy between sectors is the expected efficiency gains and mutual benefits, so that the effect arising from the combination of uses is greater than the sum of their individual effects (ICES, 2023). Currently, China's multi-tiered sea use is in the stage of co-existence of different marine utilization activities in the same area and have not achieved the synergistic effects. In the future, more efforts should be made to promote positive interaction of different activities, and achieve the comprehensive benefits of "1 + 1>2".

Multi-purpose platforms (MPP) could be a solution in practice. Achieving synergies through MPP, which build offshore platforms that serve the needs of multiple offshore industries, such as energy and aquaculture, and manage the tensions arising from their co-existence (Abhinav et al., 2020). Specifically, the natural resource administrative authorities shall, through the marine spatial detailed planning, assess in advance the types of marine activities that have synergies with the dominant functions of the sea area, and give priority to the granting of sea area use right for such sea use activities. As for the sea area reserved for development, the natural resource administrative authorities should, through the marine spatial detailed planning, plan the establishment of MPP in advance according to the needs of market players, and encourage the construction of a fully integrated MPP. During the process of planning and constructing MPP, experience from Europe can be drawn upon. For instance, in the multi-use combination of "wave energy+aquaculture", aquaculture farms and wave energy can be combined, either physically connected, or shared side by side, so that wave energy is directly used in aquaculture. Similarly, in the combination of "offshore wind+marine renewable energy generation", offshore wind energy can be jointly deployed with wave energy and tidal energy as part of the same physical platform, or indirectly connected through the same cable array, by promoting the synergistic effect between the different marine projects, so as to improve the comprehensive benefits of sea area development.

6 Conclusion

Ocean multi-use was proposed by western scholars as an economic tool, which aims to alleviate the scarcity of marine space and improve utilization efficiency of sea area. The concept of multi-tiered sea use right proposed by China is an specific innovative practice of ocean multi-use, which marks a significant transition from a single-tier approach to a multi-tiered one in the spatial planning, utilization, and management of coastal sea area. Sustainable development of marine economy is the core objective of China's multi-tiered sea use right reform, rather than mere economic goal. To date, China's multi-tiered sea use right reform and implementation has been undergoing rapid development. A series of practical problems and challenges are emerging, such as the inadequate supporting legal system, conflicts between marine spatial planning system and multi-tiered sea use right system, insufficient experience and scientific research results, etc. In the future, with more pilot projects launched, Chinese government should improve compatible legal framework and management regimes, adopt the approach of marine spatial detailed planning to coordinate the conflicts between marine spatial planning system and sea use right system, develop more possible combinations of sea use activities to promote marine environmental benefits and achieve synergistic effects.

Author contributions

MY: Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Writing – review & editing. XY: Conceptualization, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was funded by China Postdoctoral Science Foundation (No. 2021M703027), Fundamental Research Funds for the Central Universities (No. 202213010) and research project of Office of Foreign Affairs Committee of the CPC Shandong Provincial Committee (No. 22CKFJ19).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Abhinav, K. A., Collu, M., Benjamins, S., Cai, H. W., Hughes, A., Jiang, B., et al. (2020). Offshore multi -purpose platforms for a Blue Growth: A technological, environmental and socio-economic review. *Sci. Total. Environ.* 734, 15. doi: 10.1016/j.scitotenv.2020.138256

Bocci, M., Sangiuliano, S. J., Sarretta, A., Ansong, J. O., Buchanan, B., Kafas, A., et al. (2019). Multi-use of the sea: A wide array of opportunities from site-specific cases across Europe. *PloS One* 14, 36. doi: 10.1371/journal.pone.0215010

Buck, B. H., Krause, G., and Rosenthal, H. (2004). Extensive open ocean aquaculture development within wind farms in Germany: the prospect of offshore co-management and legal constraints. *Ocean. Coast. Manage.* 47, 95–122. doi: 10.1016/j.ocecoaman.2004.04.002

Ciravegna, E., van Hoof, L., Frier, C., Maes, F., Rasmussen, H. B., Soete, A., et al. (2024). The hidden costs of multi-use at sea. *Mar. Policy* 161, 10. doi: 10.1016/j.marpol.2024.106017

CNNP Rich Energy Co. LTD (2023). China's first "nuclear light storage multi-energy coupling" beach photovoltaic project connected to the grid. Available online at: https://www.cnnchn.com.cn/zhhnyxgs/xwzx31/jtdt/1385588/index.html. (accessed August 29, 2024).

Cui, W., Chen, M., Zhong, H., and Li, R. (2022). Research on the path of property rights management multi-tiered sea use of the sea area. *Mar. Dev. Manage.* 35, 4–11 + 47. doi: 10.19676/j.cnki.1672-6995.000776

Department of Finance of Guangdong Province (2022). Guangdong Province released the Criteria for Collection of Sea Area Use Royalties in Guangdong Province. Available online at: http://czt.gd.gov.cn/zcjd/content/post_3958019.html. (accessed August 29, 2024).

Ecorys, Deltares, and Oceanique Developement (2012). Blue Growth Scenarios and drivers for Sustainable Growth from the Oceans, Seas and Coasts Final Report. Available online at: https://maritime-forum.ec.europa.eu/contents/blue-growth-study-scenarios-and-drivers-sustainable-growth-oceans-seas-and-coasts_en. (accessed August 29, 2024).

European Parliament and of the Council (2014). Preamble of the Directive 2014/89/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 July 2014, establishing a framework for maritime spatial planning. Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.257.01.0135.01.ENG%20. (accessed August 29, 2024).

First institute of Oceanography of Ministry of Natural Resources (2022). The research team of our institute focused on the pilot project of Detailed planning of Qingdao Coastal Zone. Available online at: https://www.fio.org.cn/science/xshd-detail-12205.htm. (accessed August 29, 2024).

Gao, J., An, T., Zhang, K., and Zhao, R. (2024). Development and reform of marine spatial planning in China under the new territorial spatial planning system. *Mar. Dev.* 2, 2. doi: 10.1007/s44312-024-00014-5

Guyot-Téphany, J., Trouillet, B., Diederichsen, S., Juell-Skielse, E., Thomas, J.-B. E., McCann, J., et al. (2024). Two decades of research on ocean multi-use: achievements, challenges and the need for transdisciplinarity. *NPJ Ocean. Sustainabil.* 3, 8. doi: 10.1038/s44183-024-00043-z

Hu, J. (2012). Report of Hu Jintao to the 18th National Congress of the Communist Party of China. Available online at: http://www.China.org.cn/China/18th_cpc_congress/2012-11/16/content_27137540.htm. (accessed August 29, 2024).

ICES (2023). Report of the Workshop on Co-existence and Synergies in Marine Spatial Planning (WKCSMP), in *Workshop on Co-existence and Synergies in Marine Spatial Planning* (Edinburgh, UK: ICES). doi: 10.17895/ices.pub.8236

Li, Y., Chen, Y., Liu, D., and Fan, M. (2023). Spatial conflict and management of three-dimensional and layered utilization of sea areas: Based on the perspective of spatio-temporal behavior. *J. Natural Resour.* 38 (10), 2475–2489. doi: 10.31497/zrzyxb.20231004

Ministry of Finance, and The State Oceanic Administration (2009). Provisional Regulations on the Management of Sea Use Charges. Available online at: https://gc.mnr.gov.cn/201806/t20180614_1795712.html. (accessed August 29, 2024).

Ministry of Finance of China (2011). Regulating the management of collection of sea area use royalties, and promote rapid development of marine economy. Available online at: http://zhs.mof.gov.cn/zonghexinxi/201108/t20110831_590662.htm. (accessed August 29, 2024).

Ministry of Natural Resources of China (2021). Notice on the preparation of demonstration materials for regulating the use of sea areas. Available online at: https://www.hysylz.org.cn/news/1/b687cc15-bb56-4fbd-82e3-94527bcc2f4c. (accessed August 29, 2024).

Ministry of Natural Resources of China (2023). The Ministry of Natural Resources advances the establishment of multi-tiered sea use rights. Available online at: https://www.mnr.gov.cn/dt/hy/202311/t20231121_2807194.html. (accessed August 29, 2024).

MUSES Project (2020). Ocean Multi-Use Action Plan Executive Summary. Available online at: https://sites.dundee.ac.uk/muses/wp-content/uploads/sites/70/2020/06/MUSES-Multi-Use-Action-Plan-Executive-Summary.pdf. (accessed August 29, 2024).

National Development and Reform Commission (2024). The theoretical context and practical path of developing marine economy and promoting the construction of maritime power. Available online at: https://www.ndrc.gov.cn/xwdt/ztzl/NEW_srxxgcjjpjjsx/jjsxyjqk/sxlt/dt/202403/t20240307_1364685_ext.html. (accessed August 29, 2024).

Quevedo, E., Cartón, M., Delory, E., Castro, A., Hernández, J., Llinás, O., et al. (2013). "Multi-use offshore platform configurations in the scope of the FP7 TROPOS Project," in *2013 MTS/IEEE OCEANS-Bergen* (Bergen, Norway: IEEE), 1–7.

Ren, W. H., Xu, Y. H., and Xiao, H. (2024). Research on the impact of marine ecological civilization demonstration zone policies on the green development level of China's marine economy: A quasi natural experiment based on coastal cities. *Mar. Policy* 161, 14. doi: 10.1016/j.marpol.2024.106048

Ruan, C. (2005). *Exploration of the issue of multi-tiered sea use right, p.89-95 (in Chinese)* (Beijing, China: Law Press of China).

Schupp, M. F., Bocci, M., Depellegrin, D., Kafas, A., Kyriazi, Z., Lukic, I., et al. (2019). Toward a common understanding of ocean multi-use. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00165

Sheail, J. (1986). An historical perspective on the development of a marine resource: The whitstable oyster fishery. *Mar. Environ. Res.* 19, 279–293. doi: 10.1016/0141-1136(86)90020-6

Smith, D. A. (1970). *Philosophical foundations and conceptual bases of administrative procedures of multiple use management of natural resources* (Vancouver, Canada: University of British Columbia).

Stuiver, M., Soma, K., Koundouri, P., van den Burg, S., Gerritsen, A., Harkamp, T., et al. (2016). The governance of multi-use platforms at sea for energy production and aquaculture: challenges for policy makers in european seas. *Sustainability* 8, 19. doi: 10.3390/su8040333

The Department of Natural Resources of Hebei Province (2022). Study on property rights management paths for multi-tiered utilization of sea area. Available online at: https://zrzy.hebei.gov.cn/heb/gongk/gkml/kjxx/kjfz/1078332087563816064.html. (accessed August 29, 2024).

The People's Government of Fuding City (2016). Fuding City's first practice of multi-tiered sea use right. Available online at: http://www.fuding.gov.cn/zwgk/bsyw/201601/t20160108_649891.htm. (accessed August 29, 2024).

The People's Government of Zhejiang Province (2024). Zhejiang's utilization of sea area enters into three-dimensional era. Available online at: https://www.zj.gov.cn/art/2024/2/22/art_1554467_60200008.html. (accessed August 29, 2024).

The State Council (2024). China's marine economy advanced in both quantity and quality as gross ocean product grew by 6.0% in 2023. Available online at: https://www.gov.cn/yaowen/liebiao/202403/content_6940912.htm. (accessed August 29, 2024).

Urbano, G., and Rocco, E. (2019). "Fuelling regional growth: still a dream or a concrete possibility," in *Offshore Mediterranean Conference and Exhibition* (Ravenna, Italy: OMC), OMC-2019-1112.

Yang, Z., Sun, H., Yang, M., and Zhang, Y. (2022). Discussion on the multi-tiered sea use right and the supporting system for sea area management. *Mar. Dev. Manage.* 39, 79–83. doi: 10.20016/j.cnki.hykfygl.20220330.002

Yang, L. J., Wu, L. L., and Yan, S. Q. (2020). Market-based sea use management in China: Features and countermeasures. *Mar. Policy* 120, 8. doi: 10.1016/j.marpol.2020.104091

Zaucha, J., Bocci, M., Depellegrin, D., Lukic, I., Buck, B., Schupp, M., et al. (2017). *Analytical Framework (AF)–Analysing Multi-Use (MU) in the European Sea Basins* (Edinburgh, Scotland, UK: MUSES project). Available at: https://sites.dundee.ac.uk/muses/wp-content/uploads/sites/70/2017/06/MUSES-AF-Version-10_22.pdf.

Zhang, H., and Li, Y. (2008). Scope of sea areas as objects of property rights. *J. Yantai. Univ. (Philosophy. Soc. Sci. Edition).* 02, 31–35. doi: 10.13951/j.cnki.issn1002-3194.2008.02.016

Zhao, M., Yue, Q., and Xu, W. (2016). Feasibility research on the multi-tiered sea use right. *Mar. Dev. Manage.* 33, 70–73 + 117. doi: 10.20016/j.cnki.hykfygl.2016.07.014

Zhou, D., Zhao, X., Li, P., Jin, F., Li, S., Li, H., et al. (2024). Assessing territorial space conflicts in the coastal zone of Wenzhou, China: A land-sea interaction perspective. *Sci. Total. Environ.* 926, 14. doi: 10.1016/j.scitotenv.2024.171826

Zhoushan Natural Resources and Planning Bureau (2023). Notice on Promoting and standardizing the multi-tiered sea use right. Available online at: http://zsblr.zhoushan.gov.cn/art/2023/2/16/art_1229339421_1650556.html. (accessed August 29, 2024).

frontiers | Frontiers in Marine Science

TYPE Perspective
PUBLISHED 11 September 2024
DOI 10.3389/fmars.2024.1405312

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
University of International Business and Economics, China

REVIEWED BY
Athanasios Kampas,
Agricultural University of Athens, Greece

*CORRESPONDENCE
Yue Dong
dongyue@ouc.edu.cn

RECEIVED 22 March 2024
ACCEPTED 19 August 2024
PUBLISHED 11 September 2024

CITATION
Hu M and Dong Y (2024) China's shipping emissions governance: status and prospects under the dual carbon goal.
Front. Mar. Sci. 11:1405312.
doi: 10.3389/fmars.2024.1405312

COPYRIGHT
© 2024 Hu and Dong. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

China's shipping emissions governance: status and prospects under the dual carbon goal

Mai Hu and Yue Dong*

School of Law, Ocean University of China, Qingdao, China

In the context of the global response to climate change, the shipping industry is facing unprecedented pressure and challenges to reduce emissions. Under the unified leadership of International Maritime Organization (IMO), the international community has begun to take actions to promote the development of the shipping industry in a more environmentally friendly and sustainable direction. As an IMO category (a) member, China is promulgating a series of emission reduction policies to guide the green transformation of its shipping industry. This study first examines China's recent shipping emission reduction policy post "dual carbon" proposal, assessing its key focus and the current efficacy of China's shipping emission reduction governance. Based on this, the study examines the challenges China face in reducing shipping emissions. By drawing on global emission reduction practices, we suggest policy measures for China to enhance its efforts and help the shipping industry move towards achieving net-zero emissions.

KEYWORDS

shipping emission reduction, China, maritime policy, dual carbon, carbon emissions trading system

1 Introduction

The shipping industry is the artery of global trade and plays an important role in promoting world economic and trade development and stabilizing the global supply chain. However, as the impact of climate change on human beings becomes increasingly severe, the international community has begun to re-examine the shipping industry, which was once considered an "environmentally friendly" means of transportation. According to IMO "Fourth Greenhouse Gas Study 2020", The greenhouse gas (GHG) emissions — including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), expressed in CO_2e — of total shipping (international, domestic and fishing) have increased from 977 million tons in 2012 to 1,076 million tons in 2018 (IMO, 2020). The international community has recognized the need to take relevant

measures to control greenhouse gas emissions from the shipping industry and has proposed the goal of achieving net-zero emissions from the shipping industry by 2050. China is a major maritime and shipbuilding country. China has a fleet of 249.2 million gross tons, and maritime transport accounts for about 95% of China's foreign trade transportation volume (The State Council of The People's Republic of China, 2023a). As an IMO category (a) member and a party to the Paris Agreement, China is actively participating in emission reductions in the global shipping industry. Under the guidance of China's "dual carbon" goal, China has promulgated a series of policies and regulations for shipping emission reduction to guide the green transformation of the shipping industry. This study provides clear policy guidance for China in ship construction, clean energy research and development, pollution monitoring and prevention and control, and participation in international emission reduction cooperation by sorting out and analyzing the latest policies on China's shipping emission reduction. At the same time, the study found that China's shipping companies are implementing relevant policies to reduce shipping emissions. China's shipping emissions reduction has achieved remarkable results, but there is still a certain gap between achieving the goal of net-zero emissions. Therefore, this study summarizes the advanced experiences in international shipping emission reduction, and proposes to promote the formulation of laws addressing climate change, accelerate the inclusion of shipping industry research into the national carbon emission trading system, and introduce incentive policies to encourage, support, and guide the innovation and development of green and low-carbon shipping technologies. This is to further advance the process of emission reduction in China's shipping industry.

2 Latest trends in China's shipping emission reduction policies

Since China proposed the "dual carbon" goals of achieving carbon peak and carbon neutrality, China has begun to strengthen top-level design, incorporating climate change response into the overall layout of ecological civilization construction and the overall development of the economy and society. The green development of the shipping industry is an important direction of the new round of technological revolution and industrial transformation in global maritime affairs, and it is also an inevitable path for China's shipping industry to achieve high-quality development and realize the "dual carbon" goals. Against the backdrop of addressing climate change and seeking sustainable development, China is implementing a series of emission reduction policies to promote the green and low-carbon development of the shipping industry.

2.1 The necessity of reducing carbon emissions in China's shipping industry

As an important component of the integrated transportation system, the shipping industry serves as a vital support for the economic and social development, major national strategies, and the realization of Chinese-style modernization. Currently, China's waterway freight volume and goods turnover volume account for 16.9% and 53.5%, respectively, of the integrated transportation system. At the same time, the shipping industry handles about 95% of China's foreign trade transportation volume. Looking at port freight volume, China's port cargo throughput and container throughput have ranked first in the world for many consecutive years. Among the top ten ports in the world in terms of cargo and container throughput, China accounts for eight and seven seats, respectively. In 2022, the national port cargo throughput reached 15.685 billion tons, and the container throughput was 296 million TEUs. Looking at inland waterway freight volume, China's inland waterway freight volume has been the world's largest for many consecutive years, with the longest navigable mileage in the world. The Yangtze River mainline has been the busiest and largest golden waterway in global inland water transportation for many consecutive years. In 2022, China's inland water transport completed a freight volume of 4.402 billion tons and a goods turnover volume of 1.9 trillion ton-kilometers (Ministry of Transport of the People's Republic of China, 2023).

The shipping industry plays a significant role in ensuring the safety, stability, and smooth operation of both international and domestic logistics supply chains in China. However, the industry has not yet achieved the ideal state of net-zero emissions. According to statistics, Chinese shipping companies' vessels emit about 78 million tons of carbon dioxide annually. Of this, domestic shipping vessels in China emit about 34 million tons of carbon dioxide per year, while vessels operated by Chinese shipping companies for international voyages emit about 44 million tons of carbon dioxide annually (Peng, 2022). China's shipping emission reduction is facing dual pressures: domestically, to achieve the "dual carbon" goals, and internationally, to achieve the net-zero emissions target by 2050 for the shipping industry (Liu et al., 2023). Based on the responsibility to promote the construction of a community with a shared future for mankind, jointly address climate change, and the need to enhance its voice in global climate governance, China actively participates in international shipping emission reduction and has introduced corresponding policies to align with international shipping emission reduction rules.

2.2 Analysis of the content of China's shipping emission reduction policies

Policy and strategic planning are the greatest driving forces behind the reduction of greenhouse gas emissions in the shipping industry. Among the key tasks in the "Action Plan for Carbon Peaking Before 2030", it explicitly requires the implementation of "Ten Actions for Carbon Peaking", including actions for green and low-carbon transportation (The State Council of The People's Republic of China, 2021a). Under the overall guidance of the "dual carbon" goal, China has promulgated a series of shipping emission reduction policies.

2.2.1 Overall goal: achieve green and low-carbon development of the shipping industry and establish a high-quality shipping development system

Implementing the new development concepts of innovation, coordination, green, openness, and sharing is key to the transportation development in the new era of China. The "Guidelines on Vigorously Promoting the High-Quality Development of the Maritime Industry" in China clearly set the overall requirements: by 2025, to fundamentally establish a high-quality development system for the maritime industry, and by 2050, to fully achieve the modernization of the maritime governance system and governance capabilities (Ministry of Transport of the People's Republic of China, 2020).

As a developing country, China, despite still facing the important task of economic development and the need to maintain the pivotal role of shipping in trade development, has shifted away from the extensive shipping development model of the past. It now places more emphasis on enhancing the comprehensive competitiveness and innovation capability of the shipping industry, considering green, intelligent, and safe development as its important dimensions. Currently, a series of related policies for the low-carbon and green development of the shipping industry, such as the "Marine Environment Law of the People's Republic of China" "Regulations on the Prevention and Control of Marine Environmental Pollution by Ships and Their Related Operations," "Green Development Action Plan for Shipbuilding Industry (2024—2030)," and "Opinions on Accelerating the Green and Intelligent Development of Inland Vessels," have been intensively introduced or updated. The overall development principle is to focus on carbon reduction in shipping as a strategic direction, promote the synergistic increase of pollution reduction and carbon reduction, and achieve a comprehensive green transformation of the shipping industry while promoting the steady development of the shipping economy.

2.2.2 Optimize the energy structure and give full play to the supporting role of scientific and technological innovation in emission reduction

Clean fuels are widely considered to be the fundamental solution for the shipping industry to meet emission reduction targets on schedule (Hoang et al., 2022; Vakili et al., 2022; Wang and Wright, 2021). China's shipping emission reduction policies encourage the development of new energy and clean energy-powered vessels, vigorously promote the use of shore power by ships while at port, and encourage the acceleration of the construction and renovation of port shore power facilities and ship power receiving facilities, aiming to increase the coverage and utilization rates of shore power facilities. In January 2022, China's Ministry of Transport released the "14th Five-Year Plan for Water Transport Development," proposing the establishment of a clean, low-carbon energy system for ports and ships, promoting the normalized use of shore power facilities, and encouraging the research and application of new energy and clean energy vessels powered by liquefied natural gas (LNG), electricity, hydrogen, etc (Ministry of Transport of the People's Republic of China, 2022). Furthermore, to promote the clean, low-carbon, safe, and efficient use of energy, China also considers the utilization of clean energy as an important means of prevention and control in the three major ship emission control areas. According to the provisions of the "Implementation Plan for Ship Emission Control Areas," ships can use clean energy, new energy, onboard energy storage devices, or exhaust gas after-treatment and other alternative measures to meet the ship emission control requirements (Ministry of Transport of the People's Republic of China, 2018).

China's shipping policies emphasize the role of technological innovation in supporting and leading emission reduction efforts. China takes major scientific and technological projects as the leverage, aiming at the forefront of green, low-carbon, and intelligent technologies, and strongly supports research institutions, universities, and enterprises in forming innovative consortia. Together, they engage in research and development on onboard marine carbon capture, utilization and storage (CCUS), ship exhaust gas cleaning systems, and the optimization design of ship propulsion systems, while also driving the coordinated development of upstream and downstream industries along the supply chain.

2.2.3 Accelerate the green transformation of the shipbuilding industry, enhancing the green and low-carbon levels throughout the entire lifecycle of ships

On January 1, 2023, the mandatory measures of the IMO came into effect, introducing new requirements for the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII). To support the IMO's efforts in reducing emissions from shipping, the China Maritime Safety Administration issued the "Management Measures for Ship Energy Consumption Data and Carbon Intensity," which also set new requirements for the manufacturing of ships in China (Maritime Safety Administration of the People's Republic of China, 2022).

China is strengthening the top-level design of the green and low-carbon development standard system for the shipbuilding industry and establishing a comprehensive standard system. The "Green Development Action Plan for the Shipbuilding Industry (2024—2030)" clearly sets the goal of essentially establishing a green development system for the shipbuilding industry by 2030. It not only proposes to make full use of advanced energy-saving and emission-reduction technologies and to implement technological transformations of traditional power vessels to effectively enhance the green level of existing operational ships but also suggests accelerating the green transformation of the shipbuilding industry's product systems, manufacturing systems, and supply chain systems. Additionally, it calls for promoting green development throughout the entire industrial chain of ship design, manufacturing, repair, and dismantling (The State Council of The People's Republic of China, 2023b).

2.2.4 Adhere to the principle of common but differentiated responsibilities (CBDR) and actively participate in international shipping emission reduction cooperation

The principle of CBDR is a foundational principle in addressing climate change and is also an international principle that should be implemented in the reduction of shipping emissions. The principle of CBDR is a specific application of the principle of equity, its core

idea being that while recognizing the shared responsibility of developed and developing countries in reducing emissions, it fully considers comprehensive conditions such as historical carbon emissions, economic strength, technological level, and emission reduction capabilities, to bear different emission reduction responsibilities (Gao, 2018). As a developing country, China has always insisted and called on all countries to take climate actions to address climate change based on the principles of equity and CBDR, in accordance with their national circumstances, and to incorporate this principle into all areas of climate governance, including the reduction of shipping emissions. In the white paper "Policies and Actions for Addressing Climate Change," China reaffirmed the principle of CBDR, insisting on actively participating in global climate governance in accordance with the principles of openness, transparency, broad participation, party-driven, and consensus (The State Council of The People's Republic of China, 2021b).

Addressing climate change is a matter that concerns the fate of all humanity and cannot be achieved without the efforts of every individual (Mao and Zhang, 2024). Therefore, international cooperation is an essential path to achieving the overall goal of global shipping emission reduction. "International cooperation" is almost included as an important component in all of China's shipping emission reduction policies. For example, China's "14th Five-Year Plan for Green Transportation Development" explicitly identifies "improving cooperation mechanisms, deepening international exchanges and cooperation" as one of its main tasks. It proposes to deeply participate in international negotiations on the reduction of greenhouse gas emissions from maritime transport, strengthen international cooperation on low-carbon ship technology, and guide the alignment of international rules with domestic development goals; to consolidate the existing international cooperation network, and to continue to play a positive role in bilateral and regional cooperation mechanisms such as China-US, China-Germany, and China-Japan-Korea (Ministry of Transport of the People's Republic of China, 2021). The "Guidelines on Vigorously Promoting the High-Quality Development of the Maritime Industry" highlight the importance of strengthening cooperation with the IMO, actively participating in global maritime governance, and contributing China's wisdom and strength. It emphasizes enhancing research on maritime safety, green and intelligent technologies, increasing technological contributions, and promoting the alignment of maritime regulations, policies, rules, and standards with countries and regions along the Belt and Road Initiative (Ministry of Transport of the People's Republic of China, 2020).

3 Governance achievements and challenges of China's shipping emissions reduction

3.1 The governance achievements of China's shipping emission reduction

Under the guidance of shipping emission reduction policies, China has continuously achieved new breakthroughs in reducing emissions from shipping. Chinese shipowners are actively fulfilling the mission of green development in shipping, actively planning for carbon emission reduction, reducing carbon emissions through technological energy saving, management energy saving, and technological innovation, vigorously promoting green shipping, and improving the level of energy efficiency management. Since 2021, a batch of 23,000 TEU dual-fuel powered container ships has been delivered, and the first 174,000 cubic meters liquefied natural gas floating storage and regasification unit has been delivered. Bulk carriers powered by 210,000 tons of LNG, dual-fuel stainless steel chemical ships, 7,000-car dual-fuel car carriers, 150,000-ton Suezmax ammonia-fuel ready oil tankers, and methanol-powered dual-fuel MR-type oil tankers and other green-powered vessels have been undertaken in batches (Xie et al., 2022). According to statistics from the China Classification Society, as of June 2022, the completion rate of shore power receiving facility modifications for coastal domestic dry bulk carriers reached 71%. The Energy Efficiency Operational Indicator (EEOI) of China's shipping industry has decreased by about 20% compared to 2010. At the same time, the emissions of NOx and SOx in China's shipping industry have decreased by about 30% and 40%, respectively, compared to 2010 (Xie, 2023). "Shipping Pioneers 2022: A Study on the Progress of Shipping Pollution Reduction and Carbon Reduction" shows that by the end of November 2022, the proportion of new ship orders applying energy-saving technologies and alternative fuels reached up to 40.6% and 37% of the shipping capacity, respectively (Clean Air Asia, 2022a).

Chinese ports are also undergoing a green transformation, with the application of renewable energy in ports having initially developed, and port shipping logistics operations and the fuel technology of gathering and distributing equipment are exploring greening. Represented by the construction of the "China Hydrogen Port" in Qingdao Port, the progress of green port construction ranks among the top in the world, having formed a momentum that leads the global construction of new energy ports (Shan, 2023); Ningbo Port has adopted the international standard ISO 14001 environmental management system and, in combination with local actual conditions, has developed a series of supporting management and operation regulations; Tianjin Port's Beijiang Port Area utilizes an "integrated wind-solar-storage-load" smart green energy system to achieve grid-connected power generation (Wang and Zhang, 2022); Shanghai Port is actively exploring technologies such as "oil to electricity" conversion for cranes, "oil to gas" and "oil to electricity" conversions for container trucks, energy feedback technology, and supercapacitors. By 2022, it has completed the electrification transformation of 75% of crane equipment. "Blue Port Pioneers 2022: Evaluation of Air and Climate Synergy in China's Typical Ports" shows that in 2021, the shore power coverage rate for specialized berths in China's inland ports basically reached 100%, effectively controlling the emission of air pollutants and greenhouse gases from auxiliary engines of ships at port. The process of cleaning up some ports is accelerating, with Qingdao Port, Jiujiang Port, Ningbo-Zhoushan Port, and Wuhan Port having more than 50% of their energy consumption coming from electricity (Clean Air Asia, 2022b).

Overall, China has achieved significant emission reduction results in the shipping sector through a series of innovative

policies and technological measures. China has successfully reduced the carbon emissions of the shipping industry, promoting a green and low-carbon transformation of the industry. These efforts not only help alleviate the pressure of climate change but also lay a solid foundation for the sustainable development of China's shipping industry.

3.2 Challenges facing China's shipping emissions reduction

Emission reduction in shipping poses a protracted and difficult challenge. Although China has already achieved significant results, it is important to note that the overall level of emission reduction in China's shipping industry has not yet reached the world-leading standard. Key emission reduction technologies such as the application of clean energy, efficient engines, and new ship design methods are still in the hands of traditional maritime powers like Europe, America, Japan, and South Korea. Moreover, given the massive scale of China's shipping industry, the country still faces significant pressure and challenges in the process of reducing emissions in shipping.

On one hand, current international shipping policies and regulations are becoming increasingly stringent. The 75th meeting of the IMO Marine Environment Protection Committee approved a mandatory document, namely the draft amendments to MARPOL Annex VI regarding the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII) among other short-term measures for reducing emissions in the shipping industry. These amendments, from a technical perspective, have reduced the leeway of developing countries in global greenhouse gas reduction, to some extent constituting a violation of the principle of CBDR, which has significantly increased the pressure on shipping emission reduction for developing countries like China (Lee, 2012). Furthermore, different regions and industries, such as the European Union, the International Association of Classification Societies, and others, are actively promoting the reduction of greenhouse gas emissions in international shipping, raising emission reduction standards to accelerate the emission reduction process.

On the other hand, there are also challenges related to policy, economy, and technology for shipping emission reduction within China. Firstly, the current policies for emission reduction in China's shipping sector have not yet formed a unified system, with legal norms regulating green shipping being at a lower level and the means for reducing emissions in shipping being relatively singular. The regulation of carbon reduction in shipping in China is mainly concentrated in the low-level departmental normative documents and other policies, which has strong characteristics of soft-law (Yang et al., 2023). Secondly, the green transformation of shipping involves precise technological research and development as well as substantial financial investment. China's efforts to reduce emissions in shipping need to take into account the basic national conditions and the needs of economic development, while also appropriately considering the cost of green transformation for shipowners. For example, the International Renewable Energy Agency's publication, "Pathways to Decarbonize Shipping by 2050," provides predictive analyses on the costs, implementation periods, and safety aspects of various fuels and energy sources for shipping emission reduction. It is not difficult to see from the report that reducing emissions in shipping requires substantial financial investment, high technical requirements, and significant time costs (DNV, 2021).

4 Recommendations for the development path of emission reduction in China's shipping industry

Considering the governance effectiveness and challenges faced by China in reducing shipping emissions, this section, based on summarizing the advanced policy management experiences of international shipping emission reduction from the European Union, the United States, Norway, South Korea, and other countries, proposes recommendations for China to further promote its path to shipping emission reduction.

4.1 Research and formulate a climate change response law, and incorporate shipping emission reduction into it

After the Paris Agreement entered the substantive implementation phase, the focus of global climate governance has shifted from international legislation to domestic legislation. Promoting the process of addressing climate change through the construction of legal systems has become a consensus among many countries (Tian and Zheng, 2020). Currently, many countries including the United Kingdom, Japan, and South Korea have enacted climate change laws, completing the transformation from national climate policies to national climate legislation. However, China has only introduced specific laws such as the "Air Pollution Prevention and Control Law" and the "Energy Conservation Law," without establishing a unified climate change law. Formulating a climate change law could lead the various legislations on climate change response in China, further perfecting China's legal system for addressing climate change (Li, 2010). Therefore, it is necessary to draw on the legislative experience from abroad to formulate a climate change law that regulates carbon emissions, integrating fragmented relevant regulations. This approach will better guide the emission reduction process across all sectors, including the shipping industry, to achieve the "dual carbon" targets.

To formulate a climate change law with Chinese characteristics, it is first necessary to scientifically establish the legislative objectives, purposes, and principles. It is recommended to incorporate the "dual carbon" targets into the legislative objectives, comprehensively integrate fragmented regulations of key areas and industries, and make specific provisions in dedicated chapters. Secondly, it is necessary to improve the corresponding supporting measures, establish a carbon budget system and monitoring and evaluation systems, clearly define the responsibilities of each department and the coordination among them, and set up a cross-sectoral climate change

committee to revise and adjust the emission reduction targets and regularly assess the effects of emission reduction.

4.2 Integrate the shipping industry into the national carbon emissions trading system

The carbon emissions trading system is considered an important mechanism for addressing climate change. China's carbon emissions trading system officially went into operation in 2021. Studies have shown that the carbon emissions trading system can effectively decrease the total carbon emissions (Li et al., 2024). However, China's carbon emissions trading system mainly covers key industrial sectors such as steel, power, chemicals, building materials, paper-making, and non-ferrous metals, and does not include the shipping industry.

According to the IMO's "Initial Strategy on the Reduction of Greenhouse Gas Emissions from Ships," market mechanisms have been widely discussed as a medium to long-term emission reduction policy. In this regard, the European Union appears to be more aggressive. According to the EU Directive 2023/959, starting from January 1, 2024, the shipping industry will be included in the EU carbon emissions trading system. The EU advocates market-based mechanisms alongside technological and operational measures for the shipping industry. This is because the future increase in global trade will be positively correlated with increasing carbon emissions caused by an increasing number of ships, which could offset the reduction in carbon emissions resulting from the improved energy efficiency of ships (Mao et al., 2023). Currently, Shanghai, China, has initiated a pilot project to include the shipping industry in the carbon trading market system, based on the completion of preliminary research and the solicitation of opinions from relevant departments and enterprises. China should promptly, based on the actual effects of the Shanghai pilot, draw on the experience of the European Union to accurately develop a complete shipping carbon emission trading system. This includes setting the total amount of shipping carbon emissions, devising a reasonable initial carbon emission allocation plan, improving the carbon emission rights regulation system, implementing a unified and flexible compliance mechanism for carbon emission rights, etc., and integrating it into the national carbon emissions trading system.

4.3 Formulate incentive policies to encourage, support, and guide the innovative development of green and low-carbon shipping

Incentivizing market entities to rationally allocate environmental resources driven by the pursuit of maximizing their own interests can truly activate the carbon emission reduction market in shipping. Research shows that government incentives for both ports and shipping enterprises can increase the emission reduction efforts of both parties (Meng et al., 2022). Longer term, deeper decarbonization will require strong financial incentives (Paul et al., 2019).

The International Chamber of Shipping (ICS) stated at the Global Sustainable Transport Forum held in Beijing on September 26, 2023, that if the IMO wants to achieve the zero emissions goal, it is urgently necessary to adopt a "fund and incentive" mechanism to encourage the production of green ship fuels. The United Kingdom, the European Union, and other countries have invested substantial funds to support the development of shipping zero emissions and green maritime technologies. Currently, economic incentives for China's shipping industry have not been fully implemented nationwide, with only some provinces and cities having introduced economic incentives for shipping, such as the "Interim Measures for the Management of Subsidy Funds for the Construction of Green and Low-Carbon Ports in Shenzhen" and the "Shanghai Port Shore Power Construction Scheme," among others. Furthermore, the financial support mechanism for green shipping in our country is relatively scarce, which is not conducive to the research, development, and innovation of energy-saving and emission-reduction technologies. Some policy documents and local legislations are only principled regulations, lacking guidance on specific content (Jiang, 2022). Therefore, it is essential for China to issue incentive policies at the national level, exploring diverse and comprehensive green shipping financial service schemes to encourage, support, and guide the innovative development of green and low-carbon shipping. It is particularly necessary to mobilize enthusiasm across all aspects and the entire industry chain of shipping emission reduction, including research and development of clean energy, optimization of ship and port construction, among others.

5 Conclusions

Amid the increasingly severe global climate change, achieving carbon neutrality has become a common goal for the global shipping industry. As one of the most important shipping markets in the world, China plays a crucial role in the emission reduction governance of the shipping industry. This study explores the current status and prospects of China's shipping emission reduction governance and finds that under the dual drive of the "dual carbon" goals and global shipping emission reduction targets, the Chinese shipping industry has begun to take active measures, such as optimizing the energy structure, accelerating the green transformation of the shipbuilding industry, and participating in international cooperation on emission reduction. These efforts have significantly reduced carbon emissions and made an important contribution to the global shipping industry's emission reduction. However, compared to the ultimate goal of achieving net-zero emissions in the global shipping industry, China's efforts in shipping emission reduction still face numerous challenges in terms of policy, economy, and technology. This study suggests that, while continuing to uphold the IMO's leadership in global shipping emission reduction, China should, based on its own national conditions and the development status of the shipping industry, draw on the advanced experiences of current international, regional, and national emission reductions. By improving legislation, extending the national carbon emission trading system to the shipping industry, and establishing incentive systems, China can provide clearer guidance and stronger support for the green transformation of its shipping industry.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

MH: Conceptualization, Writing – original draft. YD: Conceptualization, Supervision, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by the Major Project of National Social Science Fund of China [Grant No. 23VHQ004].

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Clean Air Asia (2022a). Shipping Pioneer: Research on the progress of pollution reduction and carbon reduction in shipping. Available online at: http://allaboutair.cn/uploads/soft/230308/1-23030Q10431.pdf (Accessed 18 March 2024).

Clean Air Asia (2022b). Green Port Pioneers 2022: Evaluating Synergies betweenClean Air and Decarbonization Actions of Ports in China. Available online at: http://allaboutair.cn/uploads/soft/230706/greenportpioneers.pdf (Accessed 20 March 2024).

DNV (2021). Maritime forecast to 2050. Available online at: https://www.dnv.com/maritime/publications/maritime-forecast-to-2050-download (Accessed 18 March 2024).

Gao, H. (2018). The jurisprudential analysis and China's countermeasures to EU ETS. *Oriental Law* 4, 23–31. doi: 10.19404/j.cnki.dffx.2018.04.003

Hoang, A., Foley, A., Nizetic, S., Huang, Z., Ong, H., Olcer, A., et al. (2022). Energy-related approach for reduction of CO_2 emissions: A critical strategy on the port-to-ship pathway. *J. Clean. Prod* 335, 131772. doi: 10.1016/j.jclepro.2022.131772

IMO (2020). Fourth greenhouse gas study 2020. Available online at: https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx (Accessed 13 March 2024).

Jiang, C. (2022). The development history, actual challenge and future prospect of China's green shipping laws and policies. *J. Ocean Univ. Zhejiang (Soc. Sci. Ed.)* 39, 24–30.

Lee, C. (2012). New development of international legislation on greenhouse gas emission reduction of ships and its enlightenment. *Stud. Law Bus.* 6, 141–147. doi: 10.16390/j.cnki.issn1672-0393.2012.06.021

Li, K., Luo, Z., Hong, L., Wen, J., and Fang, L. (2024). The role of China's carbon emission trading system in economic decarbonization: Evidence from Chinese prefecture-level cities. *Heliyon* 1, e23799. doi: 10.1016/j.heliyon.2023.e23799

Li, Y. (2010). Legislations to cope with climate change: A comparetive study and its enlightenment to China. *J. Renmen Univ* 4, 58–66.

Liu, H., Mao, Z., and Li, X. (2023). Analysis of international shipping emissions reduction policy and China's participation. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1093533

Mao, Z., Ma, A., and Zhang, Z. (2023). Towards carbon neutrality in shipping: Impact of European Union's emissions trading system for shipping and China's response. *Ocean Coast. Manag* 249, 107006. doi: 10.1016/J.OCECOAMAN.2023.107006

Mao, Z., and Zhang, Z. (2024). Taking the "UN Decade of Ocean Science for Sustainable Development" as an opportunity to help build a "Community with a Shared Future between China and Pacific Island Countries. *Mar. Policy* 159, 105943. doi: 10.1016/J.MARPOL.2023.105943

Maritime Safety Administration of the People's Republic of China (2022). Ship energy consumption data and carbon intensity management measures. Available online at: https://www.msa.gov.cn/page/article.do?articleId=E40C898D-11DD-41E4-8D97-72062C28D65B. (Accessed March 18, 2024)

Meng, L., Wang, J., Yan, W., and Han, C. (2022). A differential game model for emission reduction decisions between ports and shipping enterprises considering environmental regulations. *Ocean Coast. Manag* 225, 106221. doi: 10.1016/j.ocecoaman.2022.106221

Ministry of Transport of the People's Republic of China (2018). Implementation plan for ship air pollutant discharge control area, Article 14. Available online at: https://www.gov.cn/zhengce/zhengceku/2018-12/31/content_5444672.htm (Accessed 18 March 2024).

Ministry of Transport of the People's Republic of China (2020). Guiding Opinions on vigorously Promoting high-quality development of the maritime industry, Article 1. Available online at: https://www.gov.cn/zhengce/zhengceku/2020-02/03/content_5474228.htm (Accessed 18 March 2024).

Ministry of Transport of the People's Republic of China (2021). Green transportation "14th Five-Year" development plan, Article 3.7. Available online at: https://www.gov.cn/zhengce/zhengceku/2022-01/21/content_5669662.htm (Accessed 18 March 2024).

Ministry of Transport of the People's Republic of China (2022). Water transport "14th Five-Year" development plan. Available online at: https://xxgk.mot.gov.cn/2020/jigou/zhghs/202204/t20220407_3649837.html (Accessed 18 March 2024).

Ministry of Transport of the People's Republic of China (2023). Statistical bulletin on development of transport industry in 2022. Available online at: https://www.gov.cn/lianbo/bumen/202306/content_6887539.htm (Accessed 13 March 2024).

Paul, B., James, B., Chester, L., Line, S., Jamie, S., Adam, H., et al. (2019). How to decarbonise international shipping: Options for fuels, technologies and policies. *Energy Conversion Manage.* 182, 72–88. doi: 10.1016/j.enconman.2018.12.080

Peng, C. (2022). Current situation and trend of green shipping development in China. *China Maritime Saf.* 6, 19–23. doi: 10.16831/j.cnki.issn1673-2278.2022.06.006

Shan, T. (2023). Basic elements, realistic defects and practical approaches of global green maritime governance – on China's participation strategy. *J. Dalian Maritime Univ. China (Soc. Sci. Ed.)* 22, 1–12.

The State Council of The People's Republic of China (2021a). Action plan for carbon dioxide peaking before 2030. Available online at: https://english.www.gov.cn/policies/latestreleases/202110/27/content_WS6178a47ec6d0df57f98e3dfb.html (Accessed 13 March 2024).

The State Council of The People's Republic of China (2021b). Responding to climate change: China's policies and actions. Available online at: https://www.gov.cn/zhengce/2021-10/27/content_5646697.htm (Accessed 18 March 2024).

The State Council of The People's Republic of China (2023a). China ranks first in ship ownership globally: Ministry of Transport. Available online at: https://english.www.gov.cn/news/202309/12/content_WS65006492c6d0868f4e8df61b.html#:~:text=SHANGHAI%2C%20Sept.%2012%20–%20China%20has%20become%20the,upcoming%20North%20Bund%20Forum%20in%20east%20China%27s%20Shanghai (Accessed 13 March 2024).

The State Council of The People's Republic of China (2023b). Action plan for green development of shipbuilding industry, (2024-2030). Available online at: https://www.gov.cn/zhengce/zhengceku/202312/content_6923175.htm (Accessed 18 March 2024).

Tian, D., and Zheng, W. (2020). Progress and enlightenment of foreign climate change legislations. *Climate Change Res.* 4, 526–534.

Vakili, S., Ölçer, A., Schönborn, A., Ballini, F., and Hoang, A. (2022). Energy-related clean and green framework for shipbuilding community towards zero-emissions: a

strategic analysis from concept to case study. *Int. J. Energ Res.* 46, 20624–20649. doi: 10.1002/er.7649

Wang, X., and Zhang, J. (2022). Exploring the green and zerocarbon design of new generation intelligent container terminals. *Port Technol.* 59, 94–96 + 111. doi: 10.16403/j.cnki.ggjs20220421

Wang, Y., and Wright, L. (2021). A comparative review of alternative fuels for the maritime sector: economic, technology, and policy challenges for clean energy implementation. *World* 4, 456–481. doi: 10.3390/world2040029

Xie, B. (2023). Present situation and trend of green development of port and navigation in China. *Maritime Safety.* 15, 10–12.

Xie, Y., Sun, C., and Yin, Q. (2022). China shipbuilding industry in 2021 development review and future prospects. *World Shipping* 45, 1–6. doi: 10.16176/j.cnki.21-1284.2022.02.001

Yang, W., Chen, X., and Liu, Y. (2023). Review and reflections of legislation and policies on shipping decarbonization under China's "dual carbon" target. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1131552

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 12 September 2024
DOI 10.3389/fmars.2024.1389169

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
University of International Business and Economics, China

REVIEWED BY
Brian R. MacKenzie,
Technical University of Denmark, Denmark
Agustina Merdekawati,
Gadjah Mada University, Indonesia

*CORRESPONDENCE
Wanping Zeng
katharinezwp@gmail.com

RECEIVED 21 February 2024
ACCEPTED 20 August 2024
PUBLISHED 12 September 2024

CITATION
Zeng W and Wang G (2024) A study on the governance pathways of the Law of the Sea in response to climate change.
Front. Mar. Sci. 11:1389169.
doi: 10.3389/fmars.2024.1389169

COPYRIGHT
© 2024 Zeng and Wang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

A study on the governance pathways of the Law of the Sea in response to climate change

Wanping Zeng[1,2]* and Guihua Wang[1,3]

[1]Department of Atmospheric and Oceanic Sciences, Fudan University, Shanghai, China, [2]Shanghai Key Laboratory of Ocean-Land-Atmosphere Boundary Dynamics and Climate Change, Fudan University, Shanghai, China, [3]Fujian Key Laboratory of Severe Weather, and Key Laboratory of Straits Severe Weather, China Meteorological Administration, Fuzhou, China

The legal systems for ocean governance and climate change governance are based on the United Nations Convention on the Law of the Sea and the United Nations Framework Convention on Climate Change, respectively. However, due to differences in their negotiation backgrounds, legal scope, goals, and tasks, there is a lack of interaction between the two at the legal system level. The ocean plays a crucial role in regulating the Earth's climate system, yet its value is often underestimated in the United Nations Framework Convention on Climate Change. The aim of this study is to analyze the effectiveness of the United Nations Convention on the Law of the Sea in addressing climate change. Specifically, we will examine the Convention's ability to mitigate and adapt to climate change, and identify areas where it falls short, such as inadequate regulation of sea level rise, ocean acidification, and ocean fertilization. Based on this, proposals for governance paths from the perspective of the United Nations Convention on the Law of the Sea include developing the Agreement relating to the climate change and ocean governance and reinterpreting the United Nations Convention on the Law of the Sea in accordance with the Paris Agreement. The content should be adapted more flexibly to current climate change challenges, and provisions related to sea level rise and maritime boundaries should be reinterpreted to fill legal gaps. In addition, it is important to establish coordinated regulatory rules and framework agreements to address the issues of ocean fertilization and ocean acidification. Finally, to remedy the shortcomings in proving causation, scientific theories and due diligence obligations should be attributed. Through these measures, effective ocean law governance paths that address climate change can be explored.

KEYWORDS

UNCLOS, climate change, governance pathways, marine environmental protection, UNFCCC

1 Introduction

In December 2022, the Climate Change and International Law for Small Island States Initiative (COSIS), led by a coalition of small island states including Antigua, Barbuda, and Tuvalu, filed a significant legal request with the International Tribunal for the Law of the Sea (ITLOS). This request aims to interpret the legal obligations of States under the Article 192 of the UNCLOS to prevent pollution, address the adverse impacts of climate change on the marine environment, and protect the oceans from issues such as ocean warming, sea level rise, and ocean acidification (LSE, 2023). On May 21, 2024, the ITLOS issued an advisory opinion on climate change and international law. This is the first time that an international tribunal has issued an advisory opinion on the obligations of states to mitigate climate change. The Advisory Opinion addresses several key issues relating to the application of the UNCLOS in the context of climate change, including the interaction between UNCLOS and the global climate change regime, as well as the specific obligations of States to reduce climate-warming greenhouse gas emissions (GHG). However, a crucial question arises: How can the ITLOS, as a judicial body with global jurisdiction over disputes related to the law of the sea, contribute to addressing the challenges posed by climate change?

From the perspective of the convention, there are two parallel lines of development in climate change governance and ocean governance approaches, as shown in Figure 1. In the realm of climate change governance, there are three primary conventions: UNFCCC, the 1997 Kyoto Protocol, and the 2015 Paris Agreement. The UNFCCC serves as the overarching agreement to address climate change, while the Kyoto Protocol and Paris Agreement complement, strengthen, and refine the UNFCCC, facilitating the transition from a framework to implementation. In contrast, UNCLOS aims to address all issues related to the oceans. A comparative analysis of the content of the conventions reveals that the UNFCCC and the Kyoto Protocol devote minimal attention to the oceans and seas. This is evidenced by the fact that only a reference is made in the preamble. Furthermore, the legal provisions lack practicality and effectiveness. Additionally, climate change is not directly addressed in the UNCLOS, which was developed in 1982, a time when the issue of climate change was not a prominent one in the international arena. (Carolina et al., 2023) The oceans, while suffering from climate change impacts such as acidification and rising sea levels due to the absorption of greenhouse gases, also play a crucial role in mitigating climate change by sequestering these gases, highlighting an undeniable connection between oceans and climate that has driven governmental dialogues since 2020 (Siegel, 2019; UNFCCC, 2023).

In 2021, the Conference of the Parties to UNFCCC requested the Subsidiary Body for Scientific and Technological Advice (SBSTA) to convene an annual dialogue on oceans and climate. The SBSTA was also asked to consider enhanced action on mitigation and adaptation within the oceans–climate relationship (IPCC, 2023). To date, the Conference of the Parties has held three dialogues on oceans and climate change. It is evident that the Conference of the Parties is interested in integrating the oceans into the climate regime.

However, incorporating climate change considerations into the law of the sea regime would be more beneficial for the resolution of oceanic issues resulting from climate change for two reasons. Firstly, there is no mandatory dispute settlement jurisdiction under the UNFCCC, the dispute settlement mechanism in UNCLOS could be invoked to fulfil these climate change-related obligations by holding States accountable for failing to meet their commitments or for causing damage to the marine environment through inadequate mitigation or adaptation measures, which making the UNCLOS dispute settlement system an appealing alternative (Klein, 2020). Secondly, Article 194 of the United Nations Convention on the Law of the Sea establishes the general framework of the obligations of states to protect and preserve the marine environment. The incorporation of climate change responses into this framework would facilitate the resolution of marine issues arising from climate change. The legal support of UNCLOS for the climate change regime, particularly in the areas of climate change mitigation and adaptation, is a key consideration (Marciniak, 2017).

The current body of research places a strong emphasis on the institutional interaction between the law of the sea and climate change law (Klerk, 2023). However, the majority of studies in this

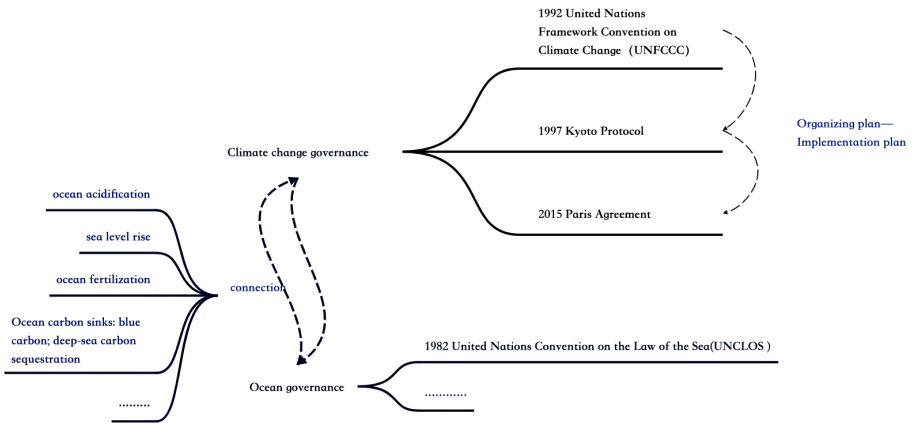


FIGURE 1
Climate change governance and ocean governance.

field focus on "point" analyses, such as the incorporation of sea level rise (O'Donnell, 2021), ocean fertilization, and ocean acidification into the legal framework for climate change or the governance framework of the UNCLOS, and adjustments to the dispute settlement regime of the UNCLOS to respond to climate change. While previous studies have analyzed the various aspects of the law of the sea that deal with climate change in a bullet-point manner, the present study builds on the fact that anthropogenic greenhouse gases are marine pollutants before it can begin to address other issues. In order to study this issue, a comprehensive and systematic approach is required. This paper fills this gap by synthesizing and analyzing the provisions of the UNCLOS relevant to climate change mitigation and adaptation. The paper critically examines the challenges faced by UNCLOS in this context and proposes solutions that are consistent with and extend the existing governance framework. Building on and interacting with the governance frameworks discussed in previous studies, the paper makes a new contribution to the field, aiming to enhance the overall response of the law of the sea to climate change.

2 Provisions of the United Nations Convention on the Law of the Sea on climate change mitigation and adaptation

The Third United Nations Conference on the Law of the Sea (1973–1982) did not deal with climate change, as it was not yet part of the international environmental agenda at that time, and therefore 1982 UNCLOS did not make direct references to climate change (Lin, 2020). 1982 UNCLOS considers climate issues indirectly, mainly in the context of oceans and seas, and supports States Parties in taking action on climate change mitigation and adaptation in three main ways (Hassan and Soininen, 2015). Firstly, by defining the jurisdiction of particular States over parts of the oceans and seas, UNCLOS delineates which States can take action on climate change. Secondly, UNCLOS provides a framework for cooperation among States in addressing climate change. Finally, Advisory Opinion 31 of the ITLOS unambiguously identifies anthropogenic emissions of carbon dioxide as marine pollutants and the obligation of States to combat climate change. This provides the basis for the theory presented in this article. Consequently, Chapter 3 examines the challenges of UNCLOS in addressing climate change, with a particular focus on the difficulties associated with addressing the impact of climate change on the marine environment and the procedural issues encountered in implementing UNCLOS in this context. Chapter 4 then presents potential solutions to these challenges.

2.1 Clarifying jurisdiction

UNCLOS identifies marine areas and boundaries, such as the territorial sea, the exclusive economic zone (EEZ), and the continental shelf. Each of these areas grants specific rights and jurisdiction to coastal and other states (Treves, 2015). The convention provides a framework for the jurisdiction of these states over different marine areas. The territorial sea area is an example where the coastal state has sovereignty up to 12 nautical miles from the baselines (Article 3). The impacts of climate change can be mitigated by the implementation of conservation measures, such as the establishment of Marine Protected Areas (MPAs), within specific marine areas. MPAs can enhance biodiversity, improve reproductive output, and enhance the socio-ecological system sustainability of coastal communities (Gillingham et al., 2024). By protecting key ecosystem services, such as carbon sink functions, these areas help reduce atmospheric carbon dioxide concentrations and combat global warming (Jankowska et al., 2022). Furthermore, MPAs can function as buffer zones to mitigate the impacts of climate change on marine life. This can be achieved, for instance, through the protection and restoration of coastal wetlands and macroalgae (Arafeh-Dalmau et al., 2023). Clarity of jurisdiction is crucial in determining which States and entities have the right and decision-making power to take action to mitigate and adapt to climate change in specific maritime areas. UNCLOS complements the UN climate regime by clarifying most of the rules on maritime jurisdiction.

2.2 Provisions for mitigation of or adaptation to climate change

Although the UNCLOS does not contain direct references to global climate change in its text, its content on mitigation of and adaptation to climate change can be interpreted from a number of perspectives. First, it should be noted that the UNCLOS was developed in the context of the early 1980s, when awareness of the potential seriousness of climate change was just beginning to surface. As such, the UNCLOS does not contain direct provisions on climate change. Nevertheless, the UNCLOS indirectly reflects concern about climate change through its provisions on the protection of the marine environment.

Under the UNFCCC, States are required to take measures to reduce greenhouse gas emissions in order to mitigate the effects of climate change (Broberg, 2020). Such measures include, but are not limited to, energy efficiency, the use of renewable energy sources and changes in land management practices. Although the UNCLOS is primarily concerned with the legal aspects of the oceans, it indirectly supports efforts to mitigate climate change through the protection and enhancement of marine carbon sinks. For example, through various geoengineering programs that promote better absorption of carbon dioxide and other greenhouse gases from the Earth's atmosphere into the oceans and forests (Warner, 2004). Second, UNCLOS, through its provisions for marine protected areas, provides space for marine ecosystems to adapt to the impacts of climate change. These protected areas help to conserve biodiversity and maintain ecosystem health and functioning, thereby helping the oceans to better adapt to the challenges posed by climate change (Bodansky, 2021). Furthermore, although UNCLOS does not directly refer to climate change, it indirectly supports the oceans' increased resilience to climate change through the promotion of marine scientific research and technological development (Harrison, 2017). Finally, Part XII of the UNCLOS,

which deals with the protection and preservation of the marine environment beyond areas of national jurisdiction, provides a certain legal framework for responding to changes in the marine environment brought about by climate change (Oral, 2018). This framework includes obligations for States to prevent, reduce, and control pollution of the marine environment from various sources, cooperate on a global and regional basis, and conduct environmental impact assessments. These provisions are crucial for fostering international collaboration and implementing measures to mitigate and adapt to the impacts of climate change on marine ecosystems.

Its primary focus is on the legal aspects of the oceans and seas, rather than directly addressing climate change (Boyle, 2016). However, as part of the international legal regime for the oceans, UNCLOS provides an important legal framework and guiding principles for addressing ocean-related climate change issues. This means that while UNCLOS sets out comprehensive regulations for maritime activities and environmental protection, it does not explicitly target climate change mitigation or adaptation measures. However, as part of the international legal regime for the oceans, UNCLOS provides an important legal framework and guiding principles that can be interpreted to address ocean-related climate change issues. The challenge lies in the fact that these provisions are often broad and require further specification and implementation through additional treaties, national legislation, or international cooperation. This indirect approach results in gaps and inconsistencies in the application of UNCLOS to climate change, highlighting the need to interpret the relevant elements of the treaty or to develop a new agreement to more directly and effectively tackle these urgent issues. Therefore, while UNCLOS forms a foundation, there is a pressing need to interpret its relevant provisions or to create new agreements that comprehensively address the multifaceted impacts of climate change on marine environments.

2.3 Anthropogenic greenhouse gas emissions as a form of pollution of the marine environment

Article 192 of Part XII of UNCLOS establishes an affirmative general obligation to "protect and preserve the marine environment." In accordance with Article 194(3), Contracting Parties must take measures to prevent, reduce, and control "all sources of pollution" of the marine environment. The United Nations Convention on the Law of the Sea (UNCLOS) defines pollution as the introduction of substances or energy into the marine environment by humans which cause or are likely to cause "harmful effects" on the marine environment [Article 1(1)(4)]. In addition, UNCLOS specifically emphasizes the obligation to prevent marine pollution in relation to "rare or fragile ecosystems" such as coral reefs (Article 194(5)). Furthermore, Part XII of UNCLOS establishes the obligation of states to adopt legislation and regulations to prevent, reduce, and control pollution of the marine environment from land-based sources (articles 194, 207, and 213) and from or through the atmosphere, in accordance with "internationally agreed rules, standards, and recommended practices" (article 212). Such measures must include "measures designed to prevent, reduce, and control pollution of the marine environment from land (articles 194, 207, and 213) and from or through the atmosphere." These measures must include measures "designed to minimize to the maximum extent practicable" "discharges of toxic, noxious or poisonous substances from land-based sources" as well as "pollution from ships or offshore installations" [art. 194(3)]. Therefore, in general, UNCLOS does not explicitly identify GHG emissions as a specific pollutant.

3 Challenges of the UNCLOS in addressing climate change

Climate change is currently one of the most significant challenges facing UNCLOS. The relevance of the oceans to climate change is evident through a variety of mechanisms, including warming and acidification of the oceans, ocean-atmosphere interactions, changes in primary productivity and carbon sequestration, sea-level rise, and changes in ocean carbon sinks. For instance, the exchange of heat, water, gases, particles, and momentum between the ocean and the atmosphere plays a pivotal role in regulating global climate (Bigg et al., 2003). Changes in ocean circulation driven by factors such as increasing CO2 concentrations can significantly affect the distribution of heat globally, thereby influencing surface climate patterns (Winton et al., 2013). Furthermore, the ocean's capacity to absorb CO2 represents a significant sink for anthropogenic CO2, influencing the global carbon budget (Garuba et al., 2018). Additionally, sea-level rise can affect the determination of maritime jurisdiction, potentially undermining existing maritime boundaries and turning some islands into "rocky outcrops incapable of sustaining human habitation or economic life of their own" or low-tide elevations, significantly impacting the rights of States to their maritime zones (Minas, 2019). These various impacts of climate change on the marine environment underscore the necessity for UNCLOS to address these challenges explicitly. The following chapter will delve into how UNCLOS provisions currently tackle these issues and explore the gaps and potential avenues for enhancing the Convention's effectiveness in responding to climate change.

3.1 Ocean fertilization: regulatory inconsistency and lack of scientific certainty

Ocean fertilization (OF) is a theoretical method for removing CO2 that involves stimulating phytoplankton growth by adding trace or large amounts of nutrients, such as iron or urea, to waters with low biological productivity (ORG, 2021). The newly grown phytoplankton absorbs atmospheric carbon dioxide and sinks to the seafloor when it dies, storing the carbon on the seafloor (Schulz and Maher, 2023). Over the past 30 years, at least 16 open ocean fertilization experiments have been conducted (Geoengineering Monitor, 2021). However, these experiments have failed to demonstrate the effectiveness of ocean fertilization as a method of carbon storage (Silverman-Roati et al.,

2022). The regulation of ocean fertilization activities is primarily governed by the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention), the 1996 Protocol to the London Convention, the Convention on Biological Diversity (CBD), as well as UNCLOS and UNFCCC and the Kyoto Protocol (Kordi, 2023). The London Convention and the Protocol to the London Convention provide international standards to guide and limit ocean fertilization activities. In 2008, the International Maritime Organization adopted a non-binding resolution that permits only ocean fertilization activities falling within the scope of legitimate scientific research. The Convention on Biological Diversity opposes the use of ocean fertilization as a method of mitigating climate change and recommends limiting ocean fertilization activities until the potential risks are better understood. The only exception is for "coastal waters or small-scale research" for specific scientific research purposes (Valckenaere, 2022).

The Paris Agreement, as stated by the UNFCCC, aims to globally regulate the increase in average global temperature. However, it does not permit or authorize the use of ocean fertilization technologies. While UNCLOS does not explicitly mention geoengineering technologies, some of its principles and concepts may be relevant to ocean fertilization activities. Ocean fertilization experiments are typically categorized as marine scientific research by the United Nations and other international organizations (Congressional Research Service, 2022). As such, they must adhere to the guidelines set forth in Part XII of UNCLOS, which aim to protect and preserve the marine environment. However, due to the lack of specificity in the Convention's definition of "pollution" regarding environmental harm and biological tolerance levels, it may not be feasible to classify all future ocean fertilization experiments as pollution. In addition, some consider ocean fertilization to contribute to the protection of the marine environment from the impacts of climate change (Gattuso et al., 2018; Scott, 2014; Keating-Bitonti, 2022). This is because it adds nutrients to the surface of the oceans, removes carbon dioxide from the atmosphere, and sequesters it in the deep ocean. Differences in the regulation of ocean fertilization activities under different legal regimes have led to several problems (Kordi, 2023). Legal uncertainty may arise if one regime considers ocean fertilization as a form of pollution while another does not, or if different regimes interpret harm thresholds differently. This uncertainty can reduce future investment in ocean fertilization technologies and may even undermine the scientific frameworks that have been put in place to provide an effective and transparent review process (Oliver, 2019).

Inconsistencies in the regulation of different regimes may slow down or even abandon opportunities to mitigate the impacts of climate change through ocean fertilization technologies (Johansen, 2020a; Johansen, 2020b). To ensure that ocean fertilization technology is an effective tool for climate change governance, it is important to prevent its misuse and increase its accuracy and predictability, while also reducing potential disruptions and eliminating unknown sequelae. Therefore, it is crucial to carefully consider and coordinate the overlap of different regulatory approaches.

3.2 Ocean acidification: a complex of regimes

The oceans have become more acidic due to the uptake of carbon dioxide, which poses a serious threat to marine species such as plankton and coral reefs (Union of Concerned Scientists, 2019). Although knowledge of ocean acidification is increasing, laws and policies have not kept pace with scientific progress. It appears that there are no existing international legal regimes or agreements that address ocean acidification directly. However, a number of measures that may indirectly impact ocean acidification can be inferred from the existing international legal framework and practice. One notable example is the 1999 Protocol to Reduce Acidification, Eutrophication, and Ground-level Ozone. However, it is important to note that the number of states parties to the protocol is only 51. It is evident that the Protocol has not been universally accepted by the international community. One of the critical gaps in the Protocol, which the UNFCCC also shares, is the lack of specific measures addressing ocean acidification. While the UNFCCC provides the legal basis for reducing greenhouse gas emissions, its primary focus remains on climate change, rather than on ocean acidification per se. Consequently, in practice, the UNFCCC has had limited effect in directly reducing the CO2 emissions that contribute to ocean acidification (Oral, 2018). Furthermore, the 1992 Convention on Biological Diversity, through target 10 of the 2010 Aichi Biodiversity Targets, identified obligations related to ocean acidification. However, it is clear that the objectives of target 10 have not been achieved. Similarly, the UNCLOS does not contain specific provisions directly referring to ocean acidification within its framework for environmental protection. Nonetheless, it provides a comprehensive set of tools for marine environmental protection that extends beyond mere pollution control. These tools include general principles such as precaution and environmental impact assessment, and specialized tools such as spatial and integrated planning and area protection (Pandey, 2021). All of these principles and tools are applicable to varying degrees, but are not directly specific to ocean acidification.

Provisions addressing ocean acidification are considered a "regime complex", consisting of parallel regimes and institutions with overlapping functions that are not hierarchical and interact with each other in their respective areas of operation (Scott, 2020). Soft law norms are emerging at the intersection of these regimes, while also connecting and evolving within them to address changes in ocean pH. However, there are structural limitations to relying on non-binding documents as the foundation for binding regimes. Some suggest that ocean acidification should be explicitly addressed alongside climate change in the regulatory scope of the UNFCCC. However, the UNFCCC's ultimate goal is to reduce and maintain carbon dioxide emissions at a level that only slows down the rate of ocean acidification, without addressing the existing ocean acidification (Harrould-Kolieb, 2012). Neither the climate regime nor the law of the sea regime directly addresses ocean acidification or provides a clear set of tools to do so (Kim, 2023). It is important to note that this issue is not adequately covered by either regime, and therefore requires further attention.

3.3 Sea level rise: legal gaps

Global mean sea level rise is primarily caused by two factors related to global warming: the addition of new water due to the melting of land-based ice sheets and glaciers, and the expansion of seawater as it warms, thus adding more water to the oceans (NASA, 2023). Sea-level rise will not significantly impact the high seas, but it will increase the likelihood of disasters in low-lying islands, coasts, and communities. These disasters include more frequent or severe coastal flooding and increased coastal erosion, among other hazards. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states that global mean sea level has risen faster since 1900 than in any of the past 3,000 centuries. The report predicts that global mean sea level could rise between 0.44 and 0.76 meters by 2100 under a medium GHG emissions scenario, but 1.01 meters under a very high emissions scenario (IPCC, 2023). According to satellite data, it has already risen by 100.5 millimeters from 1933 to 2023, as shown in Figure 2.

Sea level rise creates legal uncertainty regarding the baselines of national territorial seas and the ocean space measured from them. Baselines in the law of the sea serve to establish the point from which the outer limits of the maritime zones of coastal states are measured. As sea levels rise, the low-water mark on many coasts will move inward, destabilizing existing boundaries between states (Freestone, 2020). Sea-level rise may pose a significant challenge to the sustainability of the international legal system. As of 2006, less than half of the world's maritime boundaries were delimited, leading to numerous maritime delimitation disputes and an incomplete maritime political landscape (Dundua, 2006). This situation has persisted, with Østhagen (2020) confirming that a significant portion of maritime boundaries remains unresolved, continuing to contribute to geopolitical tensions (Østhagen, 2020). Sea-level rise further complicates the issue of maritime delimitation. While the phenomenon of sea-level rise may result in the downgrading of the status of some islands from that of States with exclusive economic zones and continental shelves to that of rocks,this does not necessarily entail a loss of maritime rights. Established maritime zones, once set, are generally not affected by changes in baselines due to natural phenomena. The UNCLOS define islands and rocks as distinct entities based on their natural attributes and their capacity to support the natural existence of humans. Islands exhibit a more intricate geological structure and ecological conditions, while rocky reefs are primarily composed of rock and lack these characteristics (Hayashi, 2020). However, which could lead to challenges in maintaining island state status under UNCLOS and the 1933 Montevideo Convention. This status requires a defined territory, a resident population, an effective government, and the ability to establish relations with other states (Millicent, 2019).

In addressing legal uncertainties arising from changes in coastlines, the International Law Association (ILA) has established the Baselines Committee and the Sea Level Rise Committee (International Law Commission, 2023). The International Law Commission (ILC) has started studying the impact of climate change on baselines and maritime boundaries and has suggested legal reforms to prevent destabilization. However, it is uncertain whether UNCLOS will be amended to address these challenges or if new approaches and cooperation within the current legal framework will suffice. Although the UNFCCC provides a general framework for adaptation, it does not specifically cover the legal issues related to sea-level rise. As a result, neither regime has fully addressed the legal issues associated with sea-level rise.

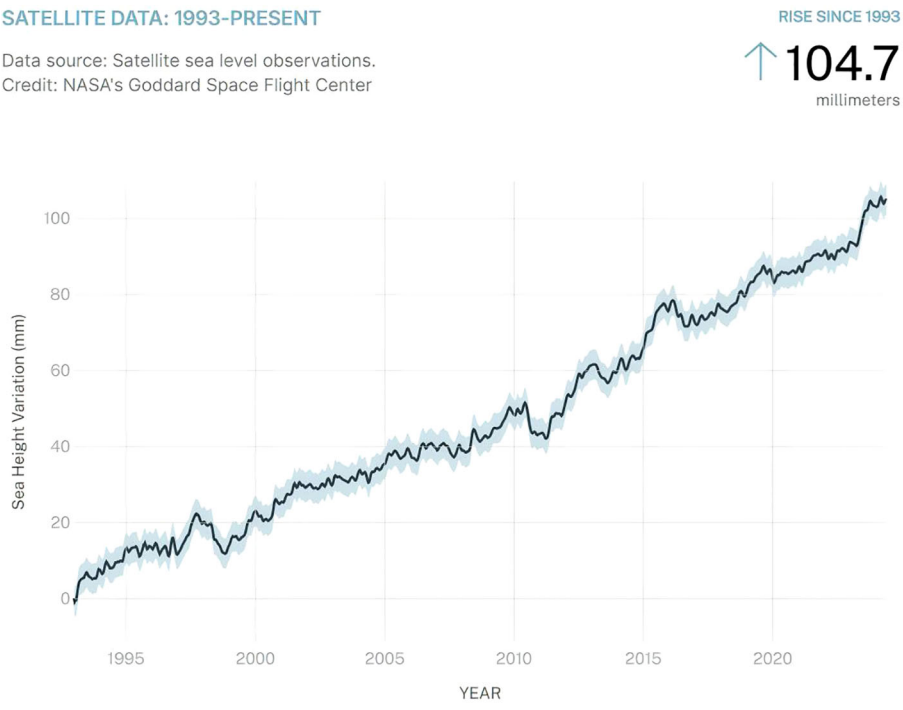


FIGURE 2
Change in global sea level height, 1993–2023. Source: Reproduced from NASA (2023). Not subject to copyright in the United States.

3.4 Problems with the application of dispute settlement procedures in UNCLOS

Part XV of UNCLOS provides a comprehensive framework for the settlement of disputes related to the law of the sea and includes compulsory jurisdiction. This means that parties agree to submit disputes related to UNCLOS matters to international adjudication. If UNCLOS can extend the statutory obligations of the Contracting Parties to include requirements for mitigating the effects of climate change, it would provide a unique opportunity for States heavily impacted by climate change. This would give these countries the right to bring international litigation against major climate polluters to force them to fulfill their climate change obligations under UNCLOS. However, UNCLOS faces several procedural and substantive hurdles to effectively address climate change (Lin, 2020).

3.4.1 Jurisdiction and mandatory dispute settlement procedures

The jurisdictional pathway under Part XV of UNCLOS is established through the interplay of several articles, such as Articles 279, 280, 281, 287, and 288, as shown in Figure 3.

To apply this dispute settlement mechanism to climate change, the issue of jurisdiction must first be addressed. Article 281(1) of UNCLOS outlines the mandatory dispute mechanism in Part XV. This mechanism is only utilized if the parties involved do not reach a dispute settlement in the agreed-upon manner and if the agreement of the parties does not preclude any further extent. It is important to determine whether the dispute is a law of the sea dispute, a climate change dispute, or both (Doelle, 2006). If a plaintiff agrees to settle a dispute over climate change mitigation under the UNFCCC dispute settlement procedure, individual states are not bound by the UNFCCC to take action to prevent harm to the marine environment from greenhouse gas emissions originating in their territory. Similarly, the Kyoto Protocol does not require parties to prevent harm to the marine environment, but rather obliges certain parties to reduce greenhouse gas emissions by 2012, using the same dispute settlement procedures as UNFCCC. Therefore, if the dispute were to be considered a climate change dispute, it would not be resolved. However, a defendant seeking to challenge jurisdiction may argue that a climate change dispute is only marginally, if at all, within UNCLOS (Freestone and McCreath, 2020). They may contend that climate change disputes are essentially related to the UNFCCC, which provides for a different dispute resolution mechanism that precludes

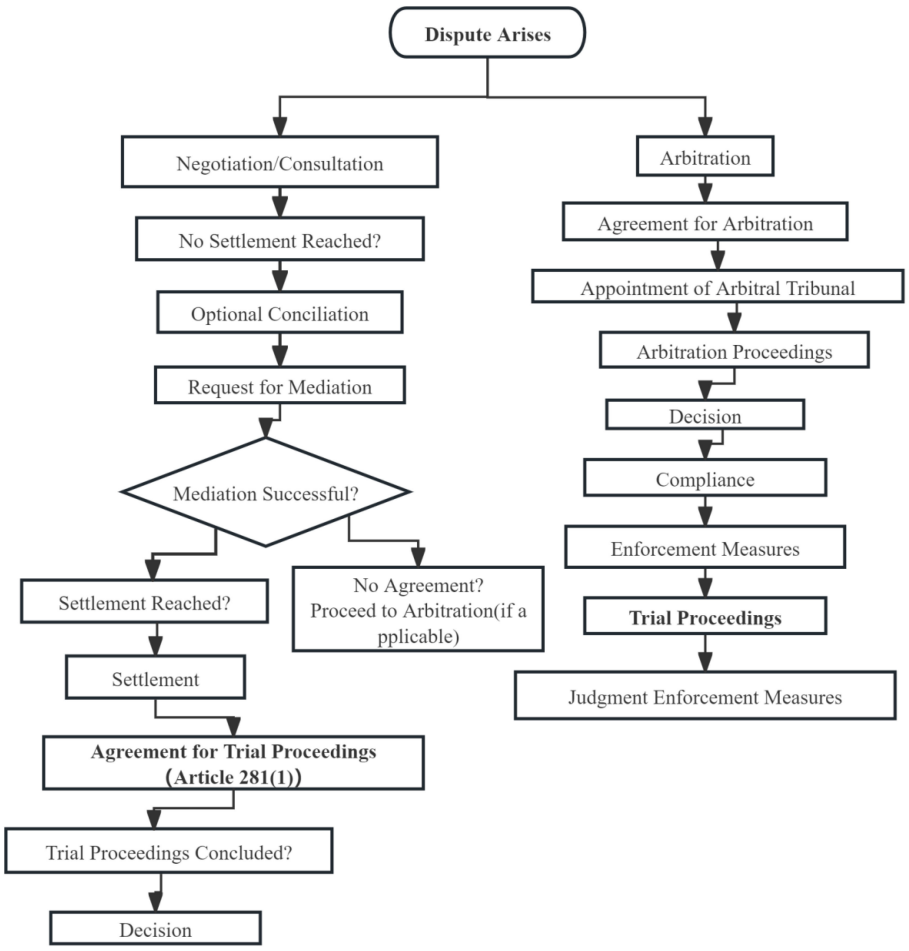


FIGURE 3
Dispute settlement mechanisms in the UNCLOS.

recourse to mandatory awards under Part XV. If the dispute concerns climate change and the UNFCCC, Part XV may be superseded by the UNFCCC's dispute settlement mechanism, resulting in the same outcome as previously mentioned, and the issue remains unresolved. After determining jurisdiction, the next consideration is the choice of dispute settlement procedure. It must be decided whether climate-related disputes should be subject to compulsory procedures or if Parties should have the option to exclude them (Iwatsuki, 2022).

3.4.2 Collective causation in climate change litigation

Climate change is a global phenomenon caused by the actions of many countries. The harms of climate change are caused by the actions and omissions of many actors, and it is generally not possible to attribute specific climate impacts to individual emitters, making it difficult to trace the contribution of individual states to climate change (Lloyd and Shepherd, 2021). Arguments based on collective causation take various forms and may leave the victims of climate change with nothing. This can marginalize the courts as the relevant institution for climate change governance, leaving individual defendants immune from liability. The issue of collective causation may lead courts to hold that a claim is inadmissible if the defendant State's conduct did not directly affect the plaintiff. It may also be argued that the defendant State has not breached its obligations because nothing the State could have done would have been sufficient to prevent the climate change-related harm (Nedeski and Nollkaemper, 2022). Additionally, it may be argued that the defendant State cannot be ordered to provide reparations because the court is unable to ascertain what portion of the harm was caused by the defendant. Climate change litigation typically involves establishing a causal link between specific activities and their impact on climate change (Verheyen and Franke, 2023). Damages caused by climate change arise from slow-onset events, such as sea level rise or glacial retreat, or from extreme weather events, such as droughts, floods, heat waves, or compound events. These two types of impacts from human-induced climate change differ greatly in terms of time scales, which affects the immediacy and causality of the damage. This adds to the complexity of causality (Otto et al., 2022).

4 Pathways to climate change governance in the UNCLOS

Oceans play two important roles in the climate change story. On the one hand, they have a central role in regulating the extent and scale of climate change. On the other hand, they unfortunately suffer the consequences of climate change. Developing effective ocean policies will help manage the oceans in a way that both mitigates climate change and enables people and communities to adapt to future climate change. One of the "Ten Challenges of the Decade of the Ocean" is to discover ocean solutions to climate change (UNESCO, 2021a; UNESCO, 2021b). The United Nations Decade of Marine Science for Sustainable Development (2021–2030), also known as the Decade of the Oceans, provides a framework for stakeholders worldwide to engage and collaborate beyond their traditional communities (UNESCO, 2021a; UNESCO, 2021b). However, there is currently little international support for rewriting the UNCLOS convention or for making substantive reforms to it (House of Lords, 2022). Therefore, it is necessary to address the issue of climate change within the existing framework of UNCLOS by adapting and supplementing it.

4.1 Development of the agreement relating to the climate change and ocean governance

The UNCLOS has three implementing agreements: the Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea, the Agreement relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and the Agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (United Nations, 2023). Of these, the BBNJ Agreement is concerned with the impacts of climate change, but focuses primarily on the impacts of climate change on marine life. However, it should be noted that the impacts of climate change on the oceans are diverse and far-reaching, affecting not only marine life but also oceanic processes, coastal communities, and global weather patterns. The BBNJ Agreement can be utilized as a model for the development of the fourth implementing agreement of the UNCLOS, the Agreement on Climate Change and Oceans Governance, which provides insights into the process of developing the Agreement. Primarily, the BBNJ Agreement explicitly requires that existing legal instruments, frameworks, and institutions not be weakened during the negotiation process (Berry, 2021). This principle is similarly crucial for the development of the Climate Change and Oceans Governance Implementing Agreement. It underscores that the new agreement should be compatible with the existing international legal system, rather than a complete replacement or conflict with it. This contributes to the achievement of a more stable and coherent international legal order. Second, the BBNJ Agreement anticipates the adoption of dispute settlement mechanisms, which may include more specialized judicial bodies, such as the international tribunals (Jiménez Pineda, 2021). The establishment of such a dispute settlement mechanism serves as a valuable reference for the implementation of the agreement on climate change and ocean governance. In the context of complex international disputes, it is evident that a clear and efficient dispute settlement mechanism is essential to safeguard the rights and interests of all parties. Finally, the negotiation process of the BBNJ agreement underscored the significance of interdisciplinary collaboration, necessitating the collective involvement of experts from a multitude of disciplines, including the environment, law, and science (Morgera et al., 2023).

This approach was employed to ensure that the agreement could comprehensively address the pertinent topics. This model of interdisciplinary cooperation is also applicable to the development of an implementing agreement on climate change and ocean governance. Indeed, the issue of climate change itself involves a number of disciplines, including meteorology, ecology, and economics.

In conclusion, the experience and framework provided by the BBNJ Agreement for the conservation and sustainable use of international marine biodiversity can be appropriately adapted and innovated. If there should be a new agreement focusing on climate change and ocean governance that covers the entire oceans, including the areas addressed by the BBNJ, it would need to carefully consider its relationship with the existing BBNJ Agreement. This new agreement should not override the relevant climate change provisions of the BBNJ but rather build upon them, ensuring a cohesive and comprehensive approach to ocean governance.

To effectively adapt and integrate the new agreement into the existing framework, several innovations and adjustments can be considered:

a. Integrated Climate-Ocean Governance: Develop a unified framework that seamlessly integrates climate change mitigation and adaptation measures with ocean governance (Borg, 2023). This would involve aligning the objectives and provisions of the new agreement with those of the BBNJ, ensuring that both climate and marine biodiversity goals are met without conflict.

b. Enhanced Legal Mechanisms: Strengthen legal mechanisms to address emerging climate-related challenges in ocean governance. This could involve incorporating more robust enforcement provisions, dispute resolution mechanisms, and compliance monitoring systems, drawing from the successful aspects of the BBNJ Agreement.

c. Adaptive Management Strategies: Implement adaptive management strategies that allow for flexibility and responsiveness to new scientific information and changing environmental conditions (Morgera et al., 2023). This could be achieved by incorporating regular review processes and feedback loops that enable continuous improvement and adjustment of policies and measures.

d. Capacity Building and Technology Transfer: Prioritize capacity building and technology transfer to support developing countries in implementing the new agreement. This could involve providing technical assistance, financial resources, and access to advanced technologies, ensuring that all countries can effectively contribute to and benefit from improved ocean governance (Young, 2023).

By incorporating these innovations and adjustments, the new agreement can enhance and complement the existing BBNJ framework, contributing to the improvement and development of the global ocean governance system in a manner that addresses the pressing challenges of climate change.

4.2 Interpreting UNCLOS in light of the Paris Agreement

UNCLOS is a dynamic document with many of its key provisions being subject to interpretation. Two compatibility clauses, Articles 237 and 311, determine its relationship with other documents. Article 237 of UNCLOS establishes the interrelationship between the obligations set out in Part XII and those set out in the more specialized agreements. In this way, those more specialized obligations will continue to exist as long as they are not in conflict with the Convention. This function of Article 237 of UNCLOS is further reinforced by Article 311, which sets out the relationship of the other agreements relevant to the Convention as a whole.

The fact that the Paris Agreements, although not agreements concluded exclusively for the protection and preservation of the marine environment, the principle of the protection and preservation of the marine environment as a general principle of UNCLOS implies that the general applicability of article 237 of UNCLOS is not limited to agreements concluded exclusively for the purpose of protecting the environment, and that it is subject to an extended interpretation (Stephens, 2020). Furthermore, UNCLOS is not a self-contained regime; its obligations can be concretized by the development of more specific rules in other instruments. It is therefore proposed that this explicitly recognizes that UNCLOS can be interpreted by way of its external rules, which include the Paris Agreement. Ultimately, compatibility between the United Nations Convention on the Law of the Sea and the Paris Agreement was ensured. Although the Paris Agreement does not specifically address the protection and preservation of the marine environment, its obligations are relevant to it. Anthropogenic greenhouse gas emissions have a significant impact on the marine environment, leading to ocean acidification, sea level rise, and a decline in biodiversity (European Environment Agency, 2023). One of the objectives of the Paris Agreement is to mitigate greenhouse gas emissions, which is relevant to the protection of the marine environment. UNCLOS Parties are required to fulfill their obligations under the Paris Agreement in a manner consistent with the general principles and objectives of UNCLOS (Klerk, 2023). This provision ensures a uniform standard for safeguarding the marine environment. The fundamental premise of the Paris Agreement is the submission of emission reduction targets by states, commonly referred to as nationally determined contributions. If incorporated into the obligations for marine environmental protection under UNCLOS, these targets would not only quantify the obligations of states but also motivate them to strive to achieve their emission reduction targets. Nations with a vested interest in both marine environmental protection and climate change mitigation, such as island nations and coastal states, are likely to support the inclusion of emission reduction targets within UNCLOS. For instance, countries like the Maldives, Fiji, and other members of the Alliance of Small Island States (AOSIS) have been vocal advocates for stronger climate action due to their vulnerability to sea level rise and environmental degradation. Additionally, the European Union has demonstrated

a commitment to integrating climate action across various policy areas, including marine governance.

Furthermore, UNCLOS Part XII includes provisions for protecting and preserving the marine environment. These obligations fall under the category of "due diligence" from both a case law and specific provision perspective (Nguyen, 2021). For example, article 194 requires States to take all necessary measures, individually or jointly, in accordance with the Convention to prevent, reduce, and control pollution of the marine environment from any source. Although UNCLOS does not use the term "due diligence", the provisions of Part XII are closely related to it. Part XII emphasizes that the protection and preservation of the marine environment can only be achieved through the control of activities in the oceans and relies on the "duty of care". This duty requires States to adopt laws and regulations, use their best endeavors, and take measures, as addressed in articles 207, 208, and 212. These provisions reflect the duty of due diligence to protect and preserve the marine environment from the harmful effects of greenhouse gases from all sources.

4.3 Reinterpretation of the relevant provisions on sea-level rise and maritime boundaries

During the negotiation of UNCLOS, sea level rise and its impacts were not recognized as issues to be addressed in the Convention. Article 312 of UNCLOS stipulates that the provisions of UNCLOS can be amended. This implies that existing provisions can be modified to better adapt to new circumstances arising from sea level rise. One potential avenue for adaptation is the specification of new types of baselines in UNCLOS. These could include "dynamic baselines" or "fixed baselines," which would enable the impact of sea level change to be reflected. Dynamic baselines should be able to reflect current geographic and environmental conditions while providing some flexibility to adapt to possible future changes. For example, a set of flexible adjustment mechanisms could be added to UNCLOS to cope with changes in maritime boundaries due to sea-level rise. These mechanisms could include the need for periodic review and reassessment of maritime boundaries, as well as allowing States to apply for adjustments to their maritime boundaries under certain conditions. A "fixed baseline" would stabilize and define maritime boundaries. Article 7(2) "in cases where the coastline is highly unstable due to natural conditions such as deltas, it is permissible to extend the coastline to the maximum level of the sea along the low-tide line. In situations where the coastline is highly unstable due to deltas and other natural conditions, suitable points may be chosen as far seaward as possible along the low-tide line. The straight baseline will remain in effect despite any subsequent retreat of the low-tide line until it is changed by the coastal State in accordance with the present Convention". The article mentions "other natural conditions" and the "recession of the low-water line", which could be interpreted to include sea-level rise. Therefore, even if the coastline is highly unstable due to sea-level rise, the baseline may remain unchanged even if the low-tide line retreats in the future (Sefrioui, 2017). The maritime zones and their associated rights and entitlements will remain in force and will not be reduced, regardless of any physical changes caused by sea-level rise resulting from climate change. Furthermore, the adaptability of UNCLOS could be enhanced through an evolutionary interpretation approach, thereby enabling it to address the diverse legal concerns that arise in practice (Starita, 2022). For instance, when international judicial bodies employ evolutionary interpretation of UNCLOS provisions in specific contexts, they may refer to the practices and principles of the International Court of Justice and arbitration institutions in addressing analogous maritime boundary disputes (Anggadi, 2022). This could include the principle of equitable settlement exemplified in the Gris Pardana case, which could provide a legal basis and an operational framework for revising the Convention.

Currently, UNCLOS does not recognize dynamic baselines, and this discussion is indeed a hypothetical exploration of potential adaptations in response to climate change. The relevance of considering these scenarios lies in the proactive approach to future-proofing the Convention against evolving environmental challenges. By examining potential amendments and adaptations, we can better prepare for the impacts of sea level rise, ensuring that the legal framework remains robust and effective. The aforementioned steps can effectively resolve the problem of uncertainty in the fixing of existing maritime boundaries while simultaneously enhancing the adaptability and practicality of the UNCLOS. By addressing hypothetical scenarios and considering proactive measures, the international community can ensure that UNCLOS remains a relevant and dynamic instrument in the face of climate change.

4.4 Harmonizing regulatory rules for ocean fertilization activities

Ocean fertilization should be regulated in a specific instrument. According to UNCLOS, ocean fertilization is not considered dumping. The use of ocean fertilization as an instrument is consistent with the obligation embodied in Part XII of UNCLOS to protect and preserve the marine environment by limiting the emission of greenhouse gases and mitigating their negative impacts on the marine environment. However, the assumption that ocean fertilization is an environmentally friendly tool has been questioned due to the potential negative impacts of adding nutrients to the marine environment (Johansen, 2020a; Johansen, 2020b). If an activity is close to the threshold of harm, it may be considered a form of pollution.

To develop ocean fertilization technology as a tool for combating climate change, a coordinated framework for designing management structures to study ocean fertilization is necessary. This should include assessing the environmental impacts of geoengineering activities, which should be carried out in parallel with the environmental impact assessment process. Additionally, close monitoring and regulation of ocean fertilization activities is necessary. Ocean fertilization technology is still in its early stages and requires more scientific experimental data to support it. Such data is essential for tests, environmental or otherwise, that may have

damaging effects. Therefore, it is wise to act on the precautionary principle, which advocates caution and environmental protection rather than "miracle" solutions with unknown side effects. For activities such as ocean fertilization, it is necessary to take a precautionary approach when there is insufficient scientific evidence to determine whether the technology will sequester carbon or have widespread harmful effects on the environment.

4.5 Using framework agreements to regulate ocean acidification

UNCLOS is relevant to the governance of ocean acidification in two ways. Firstly, it includes obligations in Part XII that focus on the protection and preservation of the marine environment. Secondly, it includes obligations in the relevant regional parts of the Convention that focus on the conservation of living resources (Harrould-Kolieb, 2020). It is widely recognized that the introduction of carbon dioxide into the marine environment can cause harm to living marine resources and life due to changes in ocean chemistry and its effects (Schulz and Maher, 2023). Ocean acidification has the potential to harm human health by altering the quality and quantity of proteins and nutrients (Falkenberg, 2020). Additionally, it may reduce the coastal protection provided by coral reefs. Carbon dioxide in the marine environment, which is the upstream cause of ocean acidification, is considered a pollutant under UNCLOS due to its impacts (Bai, 2021). States must address all sources of marine pollution, including pollution from land-based sources (Article 207), dumping (Article 210), vessels (Article 211), and the atmosphere (Article 212). Taken together, these articles cover all sources of carbon dioxide to the marine environment. The reduction of these sources is an important way of mitigating ocean acidification on a global scale, as required by article 192. Article 61 of UNCLOS deals with the protection of living resources within the exclusive economic zones of States. "Within these zones, States must establish catch limits for living resources and consider the best scientific evidence available when conserving and managing living resources within their jurisdiction". UNCLOS requires that ocean acidification be taken into account in the development of conservation measures and allowable catch limits, considering its potential contribution to the decline in maximum sustainable yield of certain stocks. Therefore, control measures should consider the impacts of ocean acidification.

UNCLOS has a broad mandate to manage ocean acidification comprehensively, as revealed by the relevant provisions of Part XII and the conservation-related provisions in other parts of the treaty discussed above. States are obliged to address the harms caused by ocean acidification to the marine environment. However, UNCLOS does not provide a methodology or criteria for implementing this framework. The methodology and criteria are to be established through provisions in the framework agreement and other external agreements. One way to address ocean acidification is by regulating carbon dioxide emissions through an implementing agreement on land-based sources of marine pollution. This can establish detailed pollution standards that identify the risks of ocean acidification and require that it be addressed through pollution reduction. For example, the BBNJ negotiations provide a more positive way to address ocean acidification provisions in UNCLOS (Craig, 2017). This is because ocean acidification is recognized as one of the greatest emerging threats to marine biodiversity and could affect new species found in the oceans (NOAA Fisheries, 2019). Secondly, including ocean acidification in existing implementing agreements, such as the United Nations Fish Stocks Agreement, provides a way forward for addressing the impact of ocean acidification on straddling and highly migratory fish stocks. Third, regulation through international rules and standards is intended to fill the gaps left by general agreements, so that more details of ocean acidification can be negotiated as needed and rules can be developed for unforeseen circumstances. This is achieved through the cooperative development and refinement of international rules, standards, and recommendations for the governance of ocean acidification. States can address ocean acidification by taking measures domestically and supporting international initiatives aimed at mitigating the phenomenon (Turner et al., 2021). In addition, international efforts to address ocean acidification can be complemented by regional agreements between states sharing a common marine environment. Such agreements could include provisions for monitoring, research, mitigation measures, and capacity-building, tailored to the specific needs and challenges of a given region. By utilizing these mechanisms, states can translate their domestic laws and agreements to address ocean acidification into international law or incorporate them into the UNCLOS. This process requires cooperation, negotiation, and commitment among states to effectively address the global challenge of ocean acidification.

4.6 Remedying the causation proof gap through the scientific theory of attribution and the due diligence obligation

Barriers to proving causation in climate change litigation prevent courts from finding greenhouse gas emitters liable for climate damage. In recent years, judicial decisions have been crucial in addressing the issue of causation in climate litigation. According to a research project at the University of Oxford, the evidence presented and cited in climate change litigation cases lags considerably behind recent developments in climate science (Stuart-Smith, 2021). This hinders causation claims and argues for a greater understanding and use of existing methodologies in the science of attribution to address barriers to causation in climate litigation (Stuart-Smith, 2021). Currently, climate attribution research is primarily relevant to domestic climate litigation. However, with the trend towards global warming and an increase in extreme weather events, attribution is likely to become a crucial aspect of future international climate loss and damage discussions. Attribution studies typically involve selecting an event to study, identifying a trend in the observed historical climate record, simulating this trend through a trial-order climate model, comparing simulations using all natural and anthropogenic climate drivers with simulations using only natural drivers, and estimating statistical confidence (Otto, 2023). At the practical level, attribution studies can confirm the link between global greenhouse

gas emissions and climate change-related hazards, such as extreme weather events (heat waves, storms, or floods), as well as slow-onset impacts (such as sea-level rise or ocean acidification) (Cho, 2021). For instance, studies have found that human-induced climate change increased the probability of a heat wave in Argentina in 2013–2014 by 400% (Chesini et al., 2022). In addition, attribution studies have produced methods capable of quantifying the marginal contribution of individual emitters to extreme weather events and slow-onset changes (Stuart-Smith, 2021). This allows the Court to consider the extent to which individual country contributions increase the severity or probability of particular climate change-related events. For instance, emissions from EU member states were responsible for 37% of the total increase in the likelihood of a heat wave in Argentina during 2013–2014 (Wehner, 2022).

5 Conclusions

UNCLOS is often referred to as the "constitution of the oceans" as it provides a comprehensive legal framework for all activities in the oceans and seas (Pyć, 2016). However, the adaptability of UNCLOS is being tested with the emergence of uncertainties such as climate change. This study highlights the critical relationship between ocean governance and climate change governance. These two governance systems are grounded, respectively, in the UNCLOS and the UNFCCC. Despite their shared objective of environmental stewardship, a noticeable lack of interaction exists between these legal systems. This lack of interaction stems from distinct negotiation backgrounds, legal scopes, and objectives. The oceans, which play a pivotal role in regulating the Earth's climate system, are underrepresented within the UNFCCC. This study aims to bridge this gap by analyzing the effectiveness of UNCLOS in addressing climate change. Through a comprehensive examination, which includes an examination of climate change impacts and logical structuring, the study identifies UNCLOS's limitations, particularly in regulating sea level rise, ocean acidification, and ocean fertilization. The study proposes a governance pathway grounded in UNCLOS and advocates for the development of the Agreement relating to the climate change and ocean governance, and reinterpretation of UNCLOS in alignment with the Paris Agreement. This reinterpretation calls for greater flexibility in content to meet current climate challenges, reevaluation of provisions related to sea-level rise and maritime boundaries, and development of coordinated regulatory rules and framework agreements to address ocean fertilization and acidification. Furthermore, the study proposes the implementation of scientific theories and due diligence obligations to address gaps in proof of causation. By adopting these measures, states can pursue an effective ocean law governance pathway to confront the challenges of climate change, ensuring comprehensive protection of the marine environment and sustainable management of ocean resources.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

WZ: Writing – review & editing, Writing – original draft. GW: Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by the Key-Area Research and Development Program of Guangdong Province "Development and Application Demonstration of BeiDou Sea-Air Coupling Real-Time Monitoring Buoy in Deep Sea" (2020–2023), funded by the Key-Area Research and Development Program of Guangdong Province under Grant No. 2020B1111020001.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Anggadi, F. (2022). What states say and do about legal stability and maritime zones, and why it matters. *Int. Comp. Law Q.* 71, 767–798. doi: 10.1017/S002058932200032X

Arafeh-Dalmau, N., Munguia-Vega, A., Micheli, F., Vilalta-Navas, A., Villaseñor-Derbez, J. C., and Précoma-de la Mora, M. (2023). Integrating climate adaptation and transboundary management: Guidelines for designing climate-smart marine protected areas. *One Earth* 6, 1523–1541. doi: 10.1016/j.oneear.2023.10.002

Bai, J. (2021). "Ocean acidification and Chinas response," in *Research Handbook on Ocean Acidification Law and Policy* (UK: Edward Elgar Publishing), 238–259. 178990014X.

Berry, D. S. (2021). Unity or fragmentation in the deep blue: choices in institutional design for marine biological diversity in areas beyond national jurisdiction. *Front. Mar. Science October Issue 8* p, 761552. doi: 10.3389/fmars.2021.761552

Bigg, G. R., Jickells, T. D., Liss, P. S., and Osborn, T. J. (2003). The role of the oceans in climate." International Journal of Climatology. *A J. R. Meteorological Soc.* 23, 1127–1159. doi: 10.1002/joc.926

Bodansky, D. (2021). "The ocean and climate change law: exploring the relationships," in *Frontiers in International Environmental Law: Oceans and Climate Challenges* (The Netherlands: Brill Nijhoff), 316–336.

Borg, S. (2023). "Chapter 11: Ocean governance in an era of climate change". In *Research Handbook on Ocean Governance Law*. S. Borg, F. G. Attard and P. M. Vella de Fremeaux (Eds.) Cheltenham, UK: Edward Elgar Publishing., 179–204. doi: 10.4337/9781839107696.00025

Boyle, A. (2016). "Climate change and international law beyond the UNFCCC," in *The Oxford Handbook of International Climate Change Law* (Oxford: OXFORD university press), 26–53.

Broberg, M. (2020). Interpreting the UNFCCC's provisions on 'mitigation' and 'adaptation' in light of the Paris Agreement's provision on 'loss and damage'. *Climate Policy* 20, 527–533. doi: 10.1080/14693062.2020.1745744

Carolina, G., Said, B. D., Rudiyanto, R., Widodo, P., Risma Saragih, H. J., and Suwarno, P. (2023). UNCLOS 1982 Analysis Regarding Problems of State Jurisdiction and Law Enforcement on Foreign Flag Ships. *International Journal of Social Science Research and Review* 6(3), 275–281. doi: 10.47814/ijssrr.v6i3.936

Chesini, F., Herrera, N., Skansi, M. M., and Morinigo, C. G. (2022). Mortality risk during heat waves in the summer 2013-2014 in 18 provinces of Argentina: Ecological study. *Ciênc. Saúde Coletiva* 27, 5, 2071–2086. doi: 10.1590/1413-81232022275.07502021

Cho, R. (2021). *Attribution Science: Linking Climate Change to Extreme Weather*. Available online at: https://news.climate.columbia.edu/2021/10/04/attribution-science-linking-climate-change-to-extreme-weather/ (Accessed 10 10 2023).

Congressional Research Service (2022). *Geoengineering: Ocean Iron Fertilization*. Available online at: https://sgp.fas.org/crs/misc/R47172.pdf (Accessed 23 December 2023).

Craig, R. K. (2017). Climate change, ocean acidification, and marine living resources: A more nuanced approach to common but differentiated responsibilities for the ocean. *Carbon Climate Law (2018 Forthcoming)* 4, 17. doi: 10.21552/cclr/2017/4/8

Doelle, M. (2006). Climate Change and the use of the dispute settlement regime of the law of the sea Convention. *Ocean Dev. Int. Law* 37, 319–337. doi: 10.1080/00908320600800945

Dundua, N. (2006). *Delimitation of Maritime Boundaries between Adjacent States* (Princeton, New Jersey: NEC Research Institute).

European Environment Agency (2023). *How Climate Change Impacts Marine Life*. Available online at: https://www.eea.europa.eu/publications/how-climate-change-impacts (Accessed 10 January 2024).

Falkenberg, L. J. (2020). Ocean acidification and human health. *Int. J. Environ. Res. Public Health* 17, 4563. doi: 10.3390/ijerph17124563

Freestone, D. (2020). "Climate change, the Anthropocene and ocean law: mapping the issues," in *Research Handbook on Climate Change, Oceans and Coasts* (UK: Edward Elgar Publishing), 49–80.

Freestone, D., and McCreath, M. (2020). "Climate change, the Anthropocene and ocean law: mapping the issues," in *Research Handbook on Climate Change, Oceans and Coasts* (UK: Edward Elgar Publishing), 49–80. 1788112237.

Garuba, O. A., Lu, J., Liu, F., and Singh, H. A. (2018). The active role of the ocean in the temporal evolution of climate sensitivity. *Geophysical Res. Lett.* 45, 306–315. doi: 10.1002/2017GL075633

Gattuso, J.-P., et al. (2018). Ocean solutions to address climate change and its effects on marine ecosystems. *Front. Mar. Sci.* 5, 410554. doi: 10.3389/fmars.2018.00337

Geoengineering Monitor. (2021). *Ocean Fertilization*. Available online at: https://www.geoengineeringmonitor.org/wp-content/uploads/2021/04/ocean-fertilization.pdf (Accessed 29 May 2023).

Gillingham, P. K., et al. (2024). Climate change adaptation for biodiversity in protected areas: An overview of actions. *Biol. Conserv.* 298, 110375. doi: 10.1016/j.biocon.2023.110375

Harrison, J. (2017). *Saving the Oceans through Law: The International Legal Framework for the Protection of the Marine Environment* (Walton Street, Oxford: Oxford University Press). 0198707320.

Harrould-Kolieb, E. R. (2012). Ocean acidification and climate change: synergies and challenges of addressing both under the UNFCCC. *Climate Policy* 3, 378–389. doi: 10.1080/14693062.2012.620788

Harrould-Kolieb, E. R. (2020). The UN Convention on the Law of the Sea: A governing framework for ocean acidification? *Rev. European Comp. Int. Environ. Law* 29, 257–270. doi: 10.1111/reel.12321

Hassan, D., and Soininen, N. (2015). "United Nations Convention on the Law of the Sea as a framework for marine spatial planning," in *Transboundary Marine Spatial Planning and International Law* (UK: Routledge), 60–84.

Hayashi, M. (2020). "Sea-level rise and the law of the sea," in *Research Handbook on Climate Change, Oceans and Coasts* (UK: Edward Elgar Publishing), 81–93.

House of Lords (2022). *UNCLOS: The Law of the Sea in the 21st century*. Available online at: https://committees.parliament.uk/publications/9005/documents/159002/default/ (Accessed 20 November 2023).

International Law Commission (2023). *Analytical Guide to the Work of the International Law Commission*. Available online at: https://legal.un.org/ilc/guide/8_9.shtml (Accessed 29 December 2023).

IPCC (2023). *Uniter Nations Climate Change, Ocean and Climate Change*. Available online at: https://unfccc.int/ (Accessed 5 12 2923).

Iwatsuki, N. (2022). "Regime interaction between the law of the sea and climate change law," in *Peaceful Maritime Engagement in East Asia and the Pacific Region* (The Netherlands: Brill Nijhoff), 423–432.

Jankowska, E., Pelc, R., Alvarez, J., Mehra, M., and Frischmann, C. J. (2022). Climate benefits from establishing marine protected areas targeted at blue carbon solutions. *Proc. Natl. Acad. Sci.* 119, e2121705119. doi: 10.1073/pnas.2121705119

Jiménez Pineda, E. (2021). The dispute settlement system of the future third UNCLOS implementation agreement on biodiversity beyond national jurisdiction (BBNJ): a preliminary analysis. *Paix Sec. Int'l* 9, 1. doi: 10.25267/Paix_secur_int

Johansen, E. (2020a). "Ocean fertilization," in *The Law of the Sea and Climate Change: Solutions and Constraints*. Ed. E. Johansen (United Kingdom: Cambridge University Press, Cambridge), 184–205. S. B. a. I. J.

Johansen, E. (2020b). The Law of the Sea and Climate Change: Solutions and Constraints (Cambridge University Press).

Keating-Bitonti, C. (2022). *Geoengineering : Ocean Iron Fertilization*. Available online at: https://sgp.fas.org/crs/misc/R47172.pdf (Accessed 1 May 2024).

Kim, S. W. (2023). Synergizing climate change and ocean regimes: A comprehensive international legal approach for ocean acidification governance. *Ocean Polar Res.* 45, 185–199. doi: 10.4217/OPR.2023016

Klein, N. (2020). "Adapting UNCLOS dispute settlement to address climate change," in *Research Handbook on Climate Change, Oceans and Coasts* (UK: Edward Elgar Publishing), 94–113.

Klerk, B. E. (2023). Protecting the marine environment from the impacts of climate change: A regime interaction study. *Rev. European Comp. Int. Environ. Law* 32, 44–56. doi: 10.1111/reel.12487

Kordi, Z. M. (2023). Treaty regime of ocean fertilization: gaps and solutions. *Rev. Direito Internacional* 20, 562. doi: 10.5102/rdi.v20i2.9079

Lin, J. (2020). *Climate Change Litigation in the Asia Pacific* (United Kingdom: Cambridge University Press). 1108804918.

Lloyd, E. A., and Shepherd, T. G. (2021). Climate change attribution and legal contexts: evidence and the role of storylines. *Climatic Change* 3, 28. doi: 10.1007/s10584-021-03177-y

LSE (2023). *How the Law Might Be Supporting A Watershed Moment for the Oceans Within the Climate Movement*. Available online at: https://www.lse.ac.uk/granthaminstitute/news/how-the-law-might-be-supporting-a-watershed-moment-for-the-oceans-within-the-climate-movement/ (Accessed 5 June 2023).

Marciniak, K. J. (2017). New implementing agreement under UNCLOS: A threat or an opportunity for fisheries governance? *Mar. Policy* 84, 320–326. doi: 10.1016/j.marpol.2017.06.035

Millicent, M. (2019). Introduction: Climate change and the Law of the Sea: Adapting the law of the sea to address the challenges of climate change. *Int. J. Mar. Coast. Law* 34, 387–390. doi: 10.1163/15718085-13431110

Minas, S. (2019). "The ocean-climate nexus in the unfolding Anthropocene: addressing environmental challenges through international law and cooperation," in *Charting Environmental Law Futures in the Anthropocene* (New York City: Springer Publishing), 83–94. 9811390649.

Morgera, E., McQuaid, K., La Bianca, G., Niner, H., Shannon, L., Strand, M., et al. (2023). Addressing the ocean-climate nexus in the BBNJ agreement: strategic environmental assessments, human rights and equity in ocean science. *Int. J. Mar. Coast. Law* 38, 447–479. doi: 10.1163/15718085-bja10139

NASA (2023). *Sea Level*. Available online at: https://climate.nasa.gov/vital-signs/sea-level/?intent=121 (Accessed 28 December 2023).

Nedeski, N., and Nollkaemper, A. (2022). A guide to tackling the Collective Causation Problem in International Climate Change Litigation. Available online at: https://www.ejiltalk.org/a-guide-to-tackling-the-collective-causation-problem-in-international-climate-change-litigation/ (Accessed 2 11 2023).

Nguyen, L. N. (2021). Jurisdiction and Applicable Law in the Settlement of Marine Environmental Disputes under unclos. *Korean J. Int. Comp. Law* 9, 337–353. doi: 10.1163/22134484-12340161

NOAA Fisheries (2019). *Understanding Ocean Acidification*. Available online at: https://www.fisheries.noaa.gov/insight/understanding-ocean-acidification (Accessed 7 July 2023).

O'Donnell, S. (2021). Climate change and sea-level rise. *Int. Community Law Rev.* 23, 133–157. doi: 10.1163/18719732-12341466

Oliver, J. T. (2019). "Geoengineering at sea," in *Climate Change and Ocean Governance: Politics and Policy for Threatened Seas* (United Kingdom: Cambridge University Press), 424. 1108422489.

Oral, N. (2018). Ocean acidification: falling between the legal cracks of UNCLOS and the UNFCCC? *Ecol. Law Q.* 45, 9–30. doi: 10.2307/jj.7657707.10

ORG (2021). *Geoengineering Technology Briefing*. Available online at: https://www.geoengineeringmonitor.org/wp-content/uploads/2021/04/ocean-fertilization.pdf (Accessed 13 December 2023).

Østhagen, A. (2020). Maritime boundary disputes: What are they and why do they matter? *Mar. Policy* 120, 104118. doi: 10.1016/j.marpol.2020.104118

Otto, F. E. (2023). Attribution of extreme events to climate change. *Annu. Rev. Environ. Resour.* 48, 813–828. doi: 10.1146/annurev-environ-112621-083538

Otto, F. E. L., Minnerop, P., Raju, E., Harrington, L. J., Stuart-Smith, R. F., Boyd, E., et al. (2022). Causality and the fate of climate litigation: The role of the social superstructure narrative. *Global Policy* 13, 736–750. doi: 10.1111/1758-5899.13113

Pandey, U. C. (2021). *SDG14–Life Below Water: Towards Sustainable Management of Our Oceans* (United Kingdom: Emerald Publishing Limited).

Pyć, D. (2016). Global ocean governance. *TransNav: Int. J. Mar. Navigation Saf. Sea Transportation* 10, 159–162. doi: 10.12716/1001.10.01.18

Schulz, K. G., and Maher, D. T. (2023). "Atmospheric carbon dioxide and changing ocean chemistry," in *Marine Pollution–Monitoring, Management and Mitigation* (Springer Nature Switzerland, Cham), 247–225.

Scott, K. N. (2014). "Exploiting the oceans for climate change mitigation: case study on ocean fertilisation," in *The Limits of Maritime Jurisdiction* (The Netherlands: Brill Nijhoff), 655–677.

Scott, K. N. (2020). LOSC, Ocean acidification: A due diligence obligation under the. *Int. J. Mar. Coast. Law* 25, 382–408. doi: 10.1163/15718085-BJA10005

Sefrioui, S. (2017). "Adapting to sea level rise: A law of the sea perspective," in *The Future of the Law of the Sea: Bridging gaps between national, individual and common interests*. Ed. G. Andreone (London (global), Berlin (corporate) and New York City (sales): Springer Nature), 3–22. 978-3-319-51273-0.

Siegel, F. R. (2019). *Adaptations of coastal cities to global warming, sea level rise, climate change and endemic hazards* (New York City: Springer).

Silverman-Roati, K., Webb, R. M., and Gerrard, M. (2022). *Removing Carbon Dio ving Carbon Dioxide Thr xide Through Ocean F ough Ocean Fertilization: Legal tilization: Legal*. Available online at: https://scholarship.law.columbia.edu/cgi/viewcontent.cgi?article=4652&context=faculty_scholarship (Accessed 30 May 2023).

Starita, M. (2022). The impact of sea-level rise on baselines: A question of interpretation of the UNCLOS or evolution of customary law? *Questions Int. Law Zoom-out* 91, 5–21.

Stephens, T. (2020). "Ocean acidification at the Poles: regional responses to marine environmental change in the Anthropocene," in *Research Handbook on Polar Law*. Eds. K. N. Scott and D. L. VanderZwaag (Cheltenham and Camberley, UK and Massachusetts, USA: Edward Elgar publishing), 434–454. 9781788119580.

Stuart-Smith, R. F. (2021). Filling the evidentiary gap in climate litigation. *Nat. Climate Change* 11, 651–655. doi: 10.1038/s41558-021-01086-7

Treves, T. (2015). Coastal States' rights in the maritime areas under UNCLOS. *Braz. J. Int'l L.* 12, 40. doi: 10.5102/rdi.v12i1.3487

Turner, J., Gassett, P., Dohrn, C., Miller, H., Boylan, C., and Laschever, E. (2021). Opportunities for US State Governments and in-Region Partners to Address Ocean Acidification through Management and Policy Frameworks. *Coast. Manage.* 49, 436–457. doi: 10.1080/08920753.2021.1947126

UNESCO. (2021a). *10 CHALLENGES*. Available online at: https://oceandecade.org/challenges/ (Accessed 11 November 2023).

UNESCO. (2021b). *United Nations Decade of Ocean Science for Sustainable Development, (2021-2030)*. Available online at: https://www.unesco.org/en/decades/ocean-decade (Accessed 28 November 2023).

UNFCCC. (2023). *Subsidiary Body for Scientific and Technological Advice*. Available online at: https://unfccc.int/sites/default/files/resource/Ocean_Dialogue_2023_Information_Note.pdf (Accessed 26 April 2024).

Union of Concerned Scientists (2019). *CO2 and Ocean Acidification: Causes, Impacts, Solutions*. Available online at: https://www.ucsusa.org/resources/co2-and-ocean-acidification (Accessed 1 May 2024).

United Nations (2023). *Agreement under the United Nations Convention on the Law of the Sea on the Conservation*. Available online at: https://www.un.org/Depts/los/bbnj.htm (Accessed 20 April 2024).

Valckenaere, J. (2022). Ocean fertilisation: strengths and weaknesses of the international governance framework. *Perth ILJ* 6, 56.

Verheyen, R., and Franke, J. (2023). "Climate change litigation: A reference area for liability," in *Corporate Liability for Transboundary Environmental Harm* (Midtown Manhattan, New York City: Springer Publishing), 353.

Warner, R. M. (2004). Preserving a balanced ocean: regulating climate change mitigation activities in marine areas beyond national jurisdiction. *Austl. Int'l LJ* 14, 99.

Wehner, M. F. (2022). Operational extreme weather event attribution can quantify climate change loss and damages. *PloS Climate* 1, e0000013. doi: 10.1371/journal.pclm.0000013

Winton, M., Griffies, S. M., Samuels, B. L., and Sarmiento, J. L. (2013). Connecting changing ocean circulation with changing climate. *J. Climate* 26, 2268–2278. doi: 10.1175/JCLI-D-12-00296.1

Young, M. A. (2023). Strengthening Capacity in Ocean Governance. *Asia-Pac. J. Ocean Law Policy* 8(1), 5–24. doi: 10.1163/24519391-08010002

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 27 September 2024
DOI 10.3389/fmars.2024.1484285

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Qiuwen Wang,
East China University of Political Science and Law, China
Hu Zhang,
East China University of Political Science and Law, China

*CORRESPONDENCE
Limei Wang
limeiw@cupl.edu.cn

RECEIVED 21 August 2024
ACCEPTED 06 September 2024
PUBLISHED 27 September 2024

CITATION
Wang L (2024) The rule of law system for China's marine security.
Front. Mar. Sci. 11:1484285.
doi: 10.3389/fmars.2024.1484285

COPYRIGHT
© 2024 Wang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

The rule of law system for China's marine security

Limei Wang*

The Institute for Data Law, China University of Political Science and Law, Beijing, China

This paper examines the current status of China's legislation on safeguarding sovereignty and security, resource security, navigation security, ecological security, and regulating law enforcement and judicial activities, and summarizes the characteristics of existing marine security legislation. This paper utilizes literature analysis and comparative analysis methods, under China's Overall National Security Outlook, this paper proposes a path of improvement by consolidating marine-related norms, promoting the formulation of a basic law on the seas, refining the legal provisions on marine security, improving the marine data classification and grading system and safeguarding marine data security, and pushing forward the reform of the adjudication mechanism of the maritime courts to enhance the ability to actively safeguard the rights and interests of the oceans and seas through the use of the rule of law.

KEYWORDS

marine security, rule of law system, legislation, improvement, the Overall National Security Outlook

1 Introduction

Marine space used to be a "natural barrier" to national security. Along with technological progress, it has gradually evolved into a "new frontier" for human activities that naturally extends from the land, opening up new channels of transportation and resources and becoming a new object of the game and a new source of risk. It has historically assumed the critical strategic mission of safeguarding national security and space for survival and development.

Since the fifteenth and sixteenth centuries, there has been a gradual awakening of the global awareness of maritime rights (Huang, 2004), and in the whole process of overall civilization, a gradual shift away from the law of the jungle of the strongest and the weakest in the initial state of nature, and away from the logic of confrontation of strength to the logic of constraint by rules and regulations, and onto the track of the rule of law in modernization. Marine awareness and awareness of the rule of law are both landmark issues in the progress of modern civilization, and the maintenance of maritime rights and interests through the rule of law and the safeguarding of marine security has increasingly become a global consensus.

The EU, the UK, the US, and other countries are no longer satisfied with traditional marine security based on free navigation and innocent passage and have formulated their own marine security strategies. The EU formulated the *Maritime Security Strategy* in 2014 (EU, 2014), which, in addition to guaranteeing free navigation and safeguarding maritime economic interests, pays more attention to responding to marine security risks and threats, focusing on the security and risks of ports and port facilities, offshore installations, submarine pipelines, marine scientific research, and other fields. In 2023, the EU published an update of the 2014 *Maritime Security Strategy* and its *Action Plan*, pointing out that the scope of maritime security is gradually expanding, and that it needs to focus on some emerging areas of risk, such as marine pollution and climate change, geo-risks, cyber-attacks against maritime installations, and put forward a six-point action program in a targeted manner (EU, 2023). The UK government set up the Joint Maritime Security Center (UK, 2022a) and submitted the *National Maritime Security Strategy* to Parliament in 2022, which not only includes free navigation, port security, border security, illegal immigration, and other issues but also covers ship security, maritime crime, ship flag protection, environmental risks, illegal and overfishing, maritime network risks and other non-traditional maritime security (UK, 2022b). In the US, the Clinton Administration first proposed the Maritime Security Program in 1996 as part of the 1996 *Maritime Security Law*. It focuses on maritime transportation safety, maritime security, coast guard and other security, and enhancing their respective capabilities. With the ever-changing world situation, the Maritime Administration of the US Department of Transportation has added the Office of Maritime Security (US Department of Transportation, 1966), which is mainly responsible for matters such as anti-piracy and armed hijacking of ships, enhancing industry awareness, port security, regional threats, and maritime cyber risks. Recently, the Biden Administration released its latest ocean strategy document, the *National Strategy for a Sustainable Ocean Economy* (US, 2024), which is intended to demonstrate the US government's commitment to protecting nature and its well-being through a joint effort by all of society and intends to achieve sustainable, inclusive, and prosperous ocean by protecting healthy ocean ecosystems, strengthening community resiliency, and advancing the just economy.

Marine security has become an essential condition for China's peaceful development and is the center of gravity of national security. It is related to both external and internal security, homeland and national security, traditional and non-traditional security, development and security, and its own security and common security. It must be guaranteed by strengthening the rule of law on marine security. Using methods such as literature analysis and comparative research, the paper compiles and analyzes relevant studies on the rule of law for marine security at home and abroad and compares the legislation and strategies for marine security in different countries and regions, identifying commonalities and differences, and summarizing China's shortcomings and challenges with regard to the rule of law for marine security on this basis. The paper aims to provide theoretical support and practical guidance for the construction and improvement of China's marine security rule of law system, in order to promote the realization of the country's marine security and the strategy of a strong maritime nation. The paper has formed the following structure under the guidance of the research objectives: firstly, the current Chinese domestic literature on the construction of the rule of law on marine security is sorted out, then the current status of the current marine security legislative system is analyzed, and on the basis of exploring the problems faced by the construction of the rule of law on marine security, suggestions for the improvement of the system of the rule of law on marine security are put forward.

2 Literature review

In recent years, the study of marine security and the rule of law in marine security has become a significant issue of concern to scholars. Marine security has gradually evolved from a subset of transportation security to an essential aspect of international security and geopolitical relations (Liu X. Y., 2023). Understood in the former sense, the rule of law on marine security has become a fundamental justification for maritime activities to safeguard the sovereignty and freedom of activities such as maritime transportation, the exploration of marine resources, and the maintenance of international maritime public order.

There is no unified concept of marine security, and its scope is constantly changing with the development of society and changes in the international situation; any element that involves a country's marine security interests can constitute marine security in a broad sense (Klein, 2011, p. 8). Some scholars believe that marine security can be summarized as an objective state in which there is no danger to national maritime interests, including no threat from the sea, and maritime rights and interests, and maritime exploitation and utilization activities are not infringed upon or encountered in danger (Wu and Zhang, 2010), which can be precisely divided into two categories: traditional marine security and non-traditional marine security (Wu, 2021). The former includes maritime military security and sea defense security. In contrast, the latter includes emerging security issues such as maritime terrorism, illegal activities at sea, marine natural disasters, marine pollution, ocean acidification, and safety of sea lanes and routes (Jin, 2012; Wu and Zhang, 2015), which some scholars have also expressed as territorial and sovereignty security, security of maritime rights and interests, security of strategic maritime corridors, and security of strategic activities at sea (Xing, 2019), or summarized into four subconcepts, namely, maritime strength, marine security, blue economy and artificial activity capability (Bueger, 2015). Marine security has become an all-round, multi-level, and comprehensive concept (Li, 2019), which needs to be combined with specific sub-concepts in a particular context to achieve a clear ideology and designation (Wang, 2024). The ever-changing international situation has led to expanding the scope of marine security and increasing its strategic importance.

The rule of law in marine security is not controversial in the Chinese academic community. The scholar believes that the rule of law for marine security refers to a comprehensive system for safeguarding the maritime rights and interests of the State,

maintaining the order of the seas, and protecting the marine environment through legal means, and that the system of the rule of law for marine security comprises four aspects, namely, legislation, law enforcement, justice, and international cooperation, and that it should focus on systematization and coordination (Xue, 2005). Then, based on the concept of the rule of law in marine security, the scholar summarized the core of the rule of law in marine security, namely, the core of the rule of law in marine security is to safeguard the sovereignty and jurisdiction of the State in the maritime domain, while taking into account the basic principles of the international law of the sea. The State should actively participate in international maritime affairs and promote the improvement of the international legal system of the oceans and seas to safeguard the maritime interests of the State (Amirell, 2016). At this level, China's strategic approach of building a marine community of shared future provides a Chinese program for the sustainable development of marine resources and calls on all countries to improve the governance of marine security (Fu and Wang, 2023).

The role of the rule of law for marine security in social development and the need to build a rule of law system for marine security has gradually emerged. The scholar has pointed out that global trade relies on the transportation of large quantities of goods and raw materials around the world by sea, and that marine security has a bearing on the global economy, but that there are still several critical issues in the current rule of law system for marine security, such as piracy, terrorism, regulatory methods, and economic disputes resulting from marine security measures. The rule of law in marine security is a critical issue in the current marine security rule of law system (Marlow, 2010). Furthermore, countries around the world have begun to intensify their competition for economic benefits and marine resources (Shriram and Giri, 2023). In the face of the complex international situation, China needs to make corresponding adjustments in its strategic theories and policies, and to shape the regional cooperation structure on peripheral maritime issues (Yang, 2022). However, establishing the rule of law in marine security takes much work, and multiple factors must be considered. It has been noted that when States and regional organizations emphasize their need, willingness, or obligation to "ensure the freedom of the seas," "preserve the global commons," "promote good governance of the seas," or "ensure the management of the seas," it is the geopolitical forces and factors that come into play, and not just "good faith" intentions (Germond, 2015).

In this regard, many Chinese scholars have conducted valuable discussions on the rule of law in marine security in China. The scholar has analyzed the new challenges and shortcomings facing China's rule of law on marine security based on the background of the significant change that has not occurred in a century and explored the path to enhance the level of the rule of law on marine security (Zhang H. W., 2022). From the perspective of the Overall National Security Outlook, the scholar put forward legislative proposals and implementation paths to strengthen China's marine security by analyzing the historical changes and development paths of China's awareness of safeguarding marine security (Wang G., 2022). The scholar discusses the importance of accurately grasping the relevant policies for the rule of law in China's marine security from the perspective of China's foreign policy on boundary and ocean affairs with its own characteristics (Hai, 2022). In addition, some scholars study the rule of law on national marine security from the perspective of the law of the sea (Jin, 2010). As well as systematic theoretical research on the construction of the rule of law security system for China's marine security in the new era (Guo and Yan, 2024). Finally, the scholar suggests giving full play to the fundamental role of marine cultural exchanges and integration and promoting the realization of the framework of marine cultural cooperation by proposing concrete and feasible practical paths (Cody, 2022).

Although the academic community has begun to recognize the importance of the rule of law in maintaining and safeguarding China's national marine security interests, from the point of view of the existing research, the focus of the improvement of the rule of law system for marine security should no longer be limited to the development of the direction of the type of macro-direction of the research and judgment. It should be in-depth legislation of the specific measures, law enforcement of the specific means, the specific way of justice, and the particular development of international cooperation, and to put forward practical recommendations.

3 China's legislative system for marine security

Legislation is the foundation of the rule of law. Declaring the territorial sovereignty and maritime rights of one's country and regulating the conduct of one's subjects and the subjects of other countries in the relevant area through legally binding means is a concrete manifestation of State sovereignty and a requirement under international law for the proper acquisition and implementation of the rights of States (Blum, 1965, p. 114). After more than 70 years of legislative practice, China has formed a particular legal system in the field of marine security, which covers the areas of maritime territorial security, maritime resource security, maritime navigation security, and maritime ecological security, as well as law enforcement in the field of marine security and international cooperation in marine security.

3.1 Basic composition of China's legislative system for marine security

3.1.1 Sovereign security legislation

Sovereignty is one of the essential elements of a State, a sign of its independence and a fundamental realization and reliable guarantee of its interests. Article 2 of the *United Nations Charter* stipulates the principle of sovereign equality. Only when the boundaries of sovereignty are clearly defined can jurisdiction, exploitation rights, and other interests be formed based on derivation. In China's legislative system, there is no unified basic law on the seas or specialized law on marine security. However, two laws play the function of safeguarding the security of maritime sovereignty and fundamental rights and interests, namely the

Territorial Sea and the Contiguous Zone Law, which came into force in 1992, and the *Exclusive Economic Zone and the Continental Shelf Law*, which came into force in 1998. It extends the scope of application of China's laws from land territory (including internal waters) to the territorial sea, the contiguous zone, the exclusive economic zone, and the continental shelf. It clarifies the spatial scope of China's maritime legislation.

The *Territorial Sea and Contiguous Zone Law* establishes China's system of the territorial sea, and the contiguous zone based on the 1958 *Declaration on China's Territorial Sea* and its practice. Article 1 of the Law specifies the legislative purpose of "exercising the sovereignty over the territorial sea and its right to control the contiguous zone and safeguarding national security and maritime rights and interests", thus shaping a clear legal basis for sovereignty and the right to control. The Law also grants the relevant authorities the right of hot pursuit of foreign vessels that violate Chinese laws and regulations. It confirms the right of control exercised to prevent violations of laws and regulations relating to security, customs, finance, sanitation, and entry and exit control in China's land territory, internal waters, or territorial sea.

The *Exclusive Economic Zone and the Continental Shelf Law* extends China's sovereign rights further into the sea from the outer limits of the territorial sea, establishing China's sovereign rights over the exclusive economic zone and the continental shelf regarding natural resources and other economic exploitation and exploration activities. It also establishes China's jurisdiction over the construction and use of artificial islands, facilities, and structures in the exclusive economic zones and the continental shelf, marine scientific research and protecting and preserving the marine environment. It establishes the exclusive right to authorize and regulate drilling on the continental shelf for all purposes. In particular, reservations were made concerning the historical rights enjoyed by China.

In addition, based on the fundamental interests in maritime space, the legislative system has made some derivations accordingly. For example, the 2000 *General Flight Rules* divides a number of flight information zones over China's territory, the contiguous zone, the exclusive economic zone, and the adjoining high seas, and the *Law on the Administration of Sea Areas* establishes the rudimentary systems of maritime area use administration such as maritime functional zoning system, maritime area tenure management system, maritime area compensated use system, to strengthen the administration of maritime area use, safeguard the lawful interests and rights and benefits of the State's ownership of maritime areas and the owners of the right to use maritime areas, as well as promoting the rational development and sustainable utilization of maritime areas. Chinese provinces such as Fujian, Guangdong and Zhejiang have also issued special regulations on the *Regulations on the Administration of the Use of Sea Areas*.

3.1.2 Resource security legislation

The seas are an essential economic space, and the sustainable development and utilization of the mineral, biological, and deep-sea resources contained in the oceans are directly related to a country's economic growth and energy security (Li, 2024).

In terms of mineral resources, the *Regulation on the Exploitation of Offshore Petroleum Resources in Cooperation with Foreign Enterprises* was the first time that China explicitly declared, in legal form, its ownership of the continental shelf and other petroleum resources in the maritime areas under China's jurisdiction, and explicitly stipulated that the Chinese government protects the rights and interests of foreign enterprises participating in the cooperative exploitation of marine petroleum resources by the law. The *Mineral Resources Law* stipulates the State's ownership of mineral resources and regulates the exploration and exploitation of mineral resources in the territory and maritime areas under its jurisdiction.

In terms of biological resources, the *Fisheries Law* and the *Detailed Rules for the Implementation of the Fisheries Law* extended China's fisheries jurisdiction from internal waters and territorial sea to all other maritime areas under the jurisdiction.

In terms of deep-sea resources, the *Law on the Exploration and Development of Resources in Deep Seabed Areas* is the first Chinese law regulating the activities of Chinese citizens, legal persons, or other organizations engaged in the exploration and exploitation of resources in deep seabed areas in maritime areas beyond the limits of national jurisdiction. It is an essential embodiment of China's active fulfillment of the *United Nations Convention on the Law of the Sea* (*UNCLOS*) and other international obligations. It is significant to the sustained and healthy development of China's maritime industry and humanity's peaceful utilization of deep seabed resources.

3.1.3 Navigation security legislation

The safety of navigation has a bearing on a country's economic and trade activities and the transportation of strategic goods (Ma, 2016). The *Maritime Traffic Safety Law* is the most basic and essential law on the management of China's maritime traffic safety. It establishes the primary system for the management of China's maritime traffic safety by laying down explicit provisions on the strengthening of the management of maritime traffic and on safeguarding the safety of ships, installations and the lives and property of people.

In addition, as maritime activities involve issues such as the scope of maritime areas, ships, and ports, the *Law on the Administration of Sea Areas*, the *Maritime Law*, and the *Ports Law* also contain provisions relating to the safety of navigation on the sea. Together, these provisions constitute a system of legislative safeguards for the safety of navigation that regulates maritime traffic.

3.1.4 Ecological security legislation

The inviolability of the marine and island environments directly impacts the sustainable utilization of resources and the ecological balance of coastal areas (Li, 2022). The *Constitution* and the *Marine Environmental Protection Law* have both made general provisions on the marine environment, such as Article 26 of the *Constitution*, which requires that "the State protects and improves the living environment and the ecological environment and prevents and treats pollution and other public hazards", and that "ecological

civilization" has also been explicitly written into China's 2018 *Amendments to the Constitution*, specifically in various areas.

In terms of marine ecology, the *Marine Environmental Protection Law* explicitly includes safeguarding ecological security as one of its legislative objectives. Article 73 stipulates that the competent department of ecology and environment under the State Council must conform to the safety principle in selecting and designating marine dumping areas. Article 84 stipulates that for the loading and unloading oil and toxic and hazardous cargoes, both sides of the ship and the shore must comply with the safety and anti-fouling operation regulations. The Law is the earliest, most direct, and most important law on marine environmental protection in China and has played a crucial role in protecting the marine environment and building a marine ecological civilization. The amended *Marine Environmental Protection Law* in 2023 improves the legal system of marine environmental protection, strengthens the management of the marine environment and the relevant legal responsibilities, is more adaptable to the requirements of the development of international marine affairs, and is more closely connected with the relevant international treaties (Liu, 2024). In addition, the *Regulation on Control Overdumping of Wastes in the Ocean* and the *Regulation on the Prevention and Control of Marine Pollution from Ships* have been complemented by other documents.

In terms of island ecology, the *Island Protection Law*, in keeping with the legislative intent of protecting the ecosystems of sea islands, rationally exploiting and utilizing natural resources, maintaining the ecological balance of sea islands and their surrounding waters, and promoting sustainable economic and social development, establishes the island protection planning system, island ecology protection system, uninhabited island state ownership and paid use system, special protection of islands for particular purposes system, and island protection supervision and inspection system.

3.1.5 Legislation regulating law enforcement and judicial activities relating to marine security

Marine law enforcement is an essential part of safeguarding national maritime sovereignty, protecting the marine environment, and guaranteeing national security (Wang G., 2022). The *Coast Guard Law* was formally enacted in 2021, ensuring its purpose is to safeguard China's national sovereignty and marine security rights and interests, which regulates and guarantees the maritime police agencies to carry out maritime rights protection and law enforcement work (Liu and Hu, 2024). Article 5 of the Law stipulates that the maritime rights protection and law enforcement work of the marine police agencies is mainly to carry out maritime security and defense and to maintain law and order at sea. Under the authority of the *Coast Guard Law*, since 2023, the China Coast Guard has issued the *Provisions on the Procedures for Handling Criminal Cases by Marine Police Agencies*, the *Provisions on the Procedures for the Handling of Criminal Reconsideration and Review Cases by Coast Guard Agencies* and the *Provisions on the Procedures for the Administrative Law Enforcement by Marine Police Agencies*, which provide a more detailed and more explicit legal basis for safeguarding and supervising the performance of the duties of marine police agencies by the law.

Maritime justice is essential to national maritime sovereignty, security and maritime rights and interests (Jia, 2019). Judicial reforms such as the 1999 *Special Maritime Procedure Law*'s special provisions on the territorial jurisdiction of the maritime disputes concerned. A series of interpretations on maritime justice formulated by the Trial Committee of the Supreme People's Court since 2015[1], all of which are conducive to the strengthening of judicial control over marine security and order, have promoted the standardization of the exercise of jurisdiction by the maritime courts by the law, the performance of maritime adjudicative functions, the fair trial of various types of maritime cases, the protection of the legitimate rights and interests of Chinese and foreign parties by the law, and the effective upholding and manifestation of China's judicial sovereignty over its oceans and seas, as well as the safeguarding of the maritime rights and interests of the country have been safeguarded. China's current effective laws and regulations related to marine security are summarized in Table 1.

3.2 Characterization of existing legislative practice on marine security

First, a strategic plan for national marine security has been initially formed, but the legislative system still needs to be strengthened. To rule the sea by law, the first thing to do is to "have a law". The 18th and 19th CPC National Congresses planned to build maritime power, and the 20th CPC National Congress included "marine security" as a critical area of national security for the first time (Xi, 2022). The rule of law system is a top priority in improving the national security guarantee system, and the strategic path to safeguard China's marine security interests through the rule of law is becoming more apparent. At present, China's legal system for the seas has made remarkable achievements, with the promulgation of the *Marine Environmental Protection Law*, the *Territorial Sea and Contiguous Zone Law*, the *Exclusive Economic Zone and the Continental Shelf Law*, the *Maritime Traffic Safety Law*, the *Provisional Regulations on the Management of National Sea Area Use*, and the *Provisions on Administration of Foreign-related Marine Scientific Research*, among other laws and regulations relating to the seas. At the same time, coastal provinces and cities have also formulated many local marine laws and regulations, effectively promoting the development of China's marine economy. However, in order to fully meet the needs of marine management under the new situation, the system of legislation is still being further improved. On the one hand, maritime elements need to be reflected in the *Constitution*, and a

1 Such as *Provisions of the Supreme People's Court on the Scope of Cases Accepted by the Maritime Courts*, *Provisions of the Supreme People's Court on Jurisdictional Issues in Maritime Litigation*, *Provisions of the Supreme People's Court on Several Issues Concerning the Trial of Cases Occurring in the Waters under the Jurisdiction (I)*, and *Provisions of the Supreme People's Court on Several Issues concerning the Trial of Cases Occurring in the Waters under the Jurisdiction (II)*.

TABLE 1 Laws and Regulations Relating to marine security in Force in China.

Legislative field		Name of legal document	Time of enactment
Sovereign security legislation	National legislation	Territorial Sea and the Contiguous Zone Law	1992
		Exclusive Economic Zone and the Continental Shelf Law	1998
		General Flight Rules	2000
		Law on the Administration of Sea Areas	2001
	Local legislation	Regulations on the Administration of the Use of Sea Areas issued by provinces Shandong	2003 (2015 revision)
		Regulations on the Administration of the Use of Sea Areas issued by provinces Jiangsu	2005 (2020 revision)
		Regulations on the Administration of the Use of Sea Areas issued by provinces Fujian	2006 (2016 revision)
		Regulations on the Administration of the Use of Sea Areas issued by provinces Guangdong	2007 (2021 revision)
		Regulations on the Administration of the Use of Sea Areas issued by provinces Zhejiang	2012 (2017 revision)
Resource security legislation	Mineral resources	Regulation on the Exploitation of Offshore Petroleum Resources in Cooperation with Foreign Enterprises	1982 (2013 revision)
		Mineral Resources Law	1986 (2009 revision)
	Biological resources	Fisheries Law	1986 (2013 revision)
		Detailed Rules for the Implementation of the Fisheries Law	1987 (2020 revision)
	Deep-sea resources	Law on the Exploration and Development of Resources in Deep Seabed Areas	2016
Navigation security legislation	The basic law	Maritime Traffic Safety Law	1983 (2021 revision)
	Maritime activities involving sea areas, ships and ports	Law on the Administration of Sea Areas,	2001
		Maritime Law	1992
		Ports Law	2003 (2018 revision)
Ecological security legislation	Marine ecology	Marine Environmental Protection Law	1982 (2023 revision)
		Regulation on Control Overdumping of Wastes in the Ocean	1985 (2017 revision)
		Regulation on the Prevention and Control of Marine Pollution from Ships	2009 (2018 revision)
	Island ecology	Island Protection Law	2009
Legislation regulating law enforcement and judicial activities relating to marine security	Marine law enforcement	Coast Guard Law	2021
	Marine justice	Special Maritime Procedure Law	1999

ruling maritime basic law or a special marine security law should be enacted (Sheng, 2008). On the other hand, the existing legislative level of marine security is not high, and relevant provisions are scattered in the fields of sovereignty security, resource security, ecological security, navigation security, law enforcement and justice, and the legislative process in various fields needs to be narrowed.

Second, China has actively translated international rules, such as *UNCLOS*, into domestic law and gradually improve the operability of legislation (Yu, 2023). In China's practice of transforming *UNCLOS* into domestic law, it has more direct reference to principled provisions and oath provisions, and the detailed interpretation or matching system needs to be further improved. In addition, with the emergence of new challenges such as global climate change, biodiversity conservation, ocean acidification, and polar governance, combined with China's strategic concept of building a non-zero-sum "ocean community with a shared future", how to establish a global maritime order based on international maritime rule of law in the future international governance of marine security needs to improve the necessary issue setting capacity (Wu, 2023).

Third, some progress has been made in promoting the rule of law at the national level and the rule of law relating to foreign affairs in an integrated manner, and the means and methods are being further diversified. China has concluded 16,000 foreign-related maritime cases in 2023 (Supreme People's Court, 2024). Resolving disputes over maritime rights and interests through

various legal means has become one of the core connotations of China's efforts to build a strong maritime nation and safeguard marine security. On the whole, China's approaches and means to deal with maritime disputes and disputes over maritime rights and interests focus on traditional political diplomacy and maritime law enforcement (Zhang N., 2022), and it is gradually realizing the organic integration of civil activities, administrative management and law enforcement, judicial jurisdiction and trial, and introducing mechanisms such as public interest litigation (Wang and Duan, 2019).

Fourth, marine rule of law institutions are relatively complete, and marine rule of law education and awareness of marine security rule of law need to be further strengthened. At present, in addition to the national legislature, including the National People's Congress, there are marine law enforcement agencies such as marine surveillance, public security, fisheries administration, fisheries supervision and marine environment monitoring, and maritime judicial organs such as maritime prosecutors and courts. It should be said that the national marine legislation, law enforcement and judicial institutions are relatively complete. In addition, marine rule of law education is an important part of national cultural education, and the formation of national awareness of marine security rule of law mainly depends on education (Liu X. H., 2023). China needs to set up marine rule of law culture propaganda institutions (such as Marine radio, television), improve special marine education and its administrative institutions, and no courses related to marine security rule of law culture have been set up in middle and primary schools.

4 Problems facing marine security and their legislative response in China

The rule of law has become the preferred option for safeguarding China's marine security interests. Marine security interests refer to the sovereign unity and territorial integrity of the State, the well-being of the people, the sustainable economic and social development of the economy, and other primary maritime interests of the State in maritime space and the direction of the seas (State Oceanic Administration, 2017, p. 223).

4.1 Complexity and variability of disputes over maritime rights and interests

Neighboring countries have differences and disputes with China over the ownership of islands and reefs and the delimitation of maritime areas, such as the South China Sea (Zeng, 2021). The instability of the international situation and the intervention of certain countries have made it more challenging to resolve these disputes. Therefore, the construction of the rule of law for marine security in China should, first and foremost, clarify the boundaries of rights and interests, safeguard national sovereignty, and make a positive response in the application of international law and the improvement of domestic legislation.

4.2 Intense competition for marine resources

With the growth in global resource demand, competition for marine energy, fisheries, and other resources has intensified (Su, 2023). China is facing pressure to participate in formulating international rules and safeguarding its rights and interests in developing marine resources by the law. In terms of marine resources, the sea area to which China belongs is rich in resources, with a large number of marine biological resources and mineral resources such as oil and natural gas. However, due to heavy fishing and marine pollution over a long period, offshore marine resources are becoming increasingly depleted, biological diversity is being challenged, and marine biological disasters such as red tides caused by pollution are occasionally occur (Man, 2014).

The *Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction* (*BBNJ Agreement*) was adopted on 19 June 2023 by the Intergovernmental Conference on Marine Biodiversity of Areas Beyond National Jurisdiction convened under the auspices of the United Nations. The *BBNJ Agreement* becomes the third implementing agreement to *UNCLOS*. Under the overall objective of the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, for the present and in the long-term, through effective implementation of the relevant provisions of the Convention and further international cooperation and coordination, the *BBNJ* Agreement addresses four main issues: marine genetic resources, including the fair and equitable sharing of benefits; measures such as area-based management tools, including marine protected areas; environmental impact assessments; and capacity-building and the transfer of marine technology. However, China lacks mature legal norms for the development and utilization of emerging marine resources. China should establish and improve the rule of law safeguards for exploration and development in accordance with the *BBNJ Agreement* to cope with the legal risks that may arise.

4.3 Increased pressure on marine ecosystems

Global climate change has led to problems such as sea-level rise and ocean acidification, which threaten our marine ecological security (Feng, 2024). These risks are caused by both natural causes, such as the Indian Ocean tsunami that hit Thailand, Indonesia, and other countries in 2004; man-made causes, such as the oil pollution from ConocoPhillip's drilling platform that occurred in China's Bohai Bay in 2011; and also by a combination of natural and man-made causes, such as the Tohoku Earthquake and Tsunami in Japan in 2011, as well as the leakage and pollution from a nuclear power plant. The international community's response to the marine ecological problem has been positive. The international community's cooperation mechanism

for dealing with marine ecological issues is imperfect. China needs to strengthen the construction of the rule of law for domestical marine ecological protection, while striving for more discourse power and international cooperation opportunities (Huang and Xu, 2023).

Transboundary marine pollution incidents occur occasionally, and the related definition of responsibility and governance mechanisms are controversial at the international level. China must improve its domestic laws to strengthen its response and safeguard its rights and interests under the international legal framework (Yuan, 2022).

4.4 Legal gaps arising from developments in marine science and technology

Rapid marine science and technology development, such as deep-sea exploration and marine biotechnology, has brought new security and legal issues. Existing laws are inadequate in regulating emerging marine science and technology activities, and China needs to formulate relevant laws and regulations promptly to ensure the safe and orderly development of marine science and technology.

The international rules for the protection and utilization of marine scientific and technological achievements have not yet been harmonized, and our country, while promoting marine scientific and technological innovation, should protect its intellectual property rights and technological advantages through the rule of law.

5 Overall improvement of the rule of law system for marine security in China

In order to maintain China's marine security and accelerate the building of a strong maritime country, the first and foremost meaning of the rule of law is to have a law to follow. With the development of science and technology and changes in the international situation, the connotation of the rule of law in marine security has gradually been enriched. It has evolved into a comprehensive system of the rule of law in marine security, covering legislation, law enforcement, justice and compliance (Bueger, 2015). The rule of law for marine security should safeguard the maritime rights and interests of States, maintain maritime order, protect the marine environment, and address issues arising from the development of marine science and technology. With globalization and the complexity of international relations, more attention should be paid to the systematic and coordinated nature of the rule of law for marine security, emphasizing coordination and cooperation among various sectors and levels to maximize overall effectiveness.

5.1 Consolidating sea-related norms and promoting the formulation of the basic law on the seas

The formulation of the basic law on the seas will lead to the construction of the rule of law for the sea and provide a fundamental legal basis for maintaining China's marine security. It will declare China's basic claims for the sea and establish the overall framework of China's legal system for the seas (Yang, 2021).

The world's central coastal States are actively defending their maritime claims and rights and interests in the form of laws, and the most common practice is to formulate a comprehensive and integrated basic law on the seas. For example, Canada enacted the *Oceans Act* in 1997, the UK promulgated the *Marine and Coastal Access Act* in 2009, and Japan and Vietnam have also adopted basic laws on the seas to provide comprehensive rule of law guarantees for the development of their ocean endeavors. Japan updates its ocean action plan every five years by its basic law to ensure the implementation of the various regimes in the *Basic Act on Ocean Policy*.

Accelerating the building of a strong maritime country is a national strategy and an essential manifestation of the national governance system and governance capacity in the maritime domain (Lin, 2021). In the field of marine strategy, China has long used policy documents instead of legislation, and has formulated and implemented planning documents such as the *China Ocean Agenda 21*, the *National Ocean Development Plan*, the *State Council on Functional Divisions of the Sea*, and the *Outline of the National Plan for the Development of the Marine Economy*, but these policy documents have not been able to fundamentally serve as guidance for the operation of the rule of law on the oceans of China, which is required at the level of a national strategy. Therefore, China urgently needs to promulgate the basic law on the seas to fundamentally resolve the situation in which there is no basis for implementing marine strategies. At the same time, it should cover the legal system of marine security, refine the conceptual formulation of laws and regulations, standardize the paradigm of expression, and improve the transparency, scientificity, and operability of the law, so as to cope with the increasingly complex situation of marine security.

5.2 Refining the legal provisions on marine security

The concept of the Overall National Security Outlook and the introduction of the *National Security Law* highlight the great importance that the State attaches to national security and the importance of national security to the development of China. The Overall National Security Outlook emphasizes people's security as the tenet, political security as the fundamental, economic security as the basis, military, cultural, and social security as the safeguard, and the promotion of international security as its backbone.[2] From an overall perspective, it coordinates all aspects of national security in the new era, incorporates the rule of law throughout the entire process of safeguarding national security, effectively prevents and

2 Article 3 of the *National Security Law* (2015).

resolves security risks, and advocates the security concept and outlook of "common, comprehensive, cooperative and sustainable security" (Li, 2021).

Under the vision of a holistic approach to national security, marine security is not only an important element but also a basic manifestation of national security (Qin, 2015). In terms of marine security, the Overall National Security Outlook mentions deep-sea security, and the *National Security Law* mentions "non-traditional security", "protection of territorial sea security", "safeguarding national maritime rights and interests", and "maintaining China's security in the international seabed area", all of which fully demonstrate that marine security is an essential component of national security. However, these provisions do not explicitly specify what marine security in these areas encompasses, nor do they define the relevant elements of marine security. At a time when marine security is becoming increasingly important, there is an urgent practical need to refine the relevant provisions on marine security at the legal level.

In formulating the basic law on the seas, specific provisions on marine security can be perfected. Guided by the Overall National Security Outlook and the relevant provisions of the *National Security Law*, the specific contents of marine security can be refined, and specific provisions can be made on China's concept of marine security, the basic principle of protecting marine security, the primary connotation of marine security, the functional departments responsible for safeguarding marine security, and the mechanism for preventing and resolving risks to marine security, to cope with the maritime risks faced by China and safeguard its marine security.

5.3 Improving the classification and grading system of marine data to ensure the security of marine data

Marine data plays a vital role in marine security, and improving the classification and grading system of marine data and protecting marine data is of great practical significance for safeguarding marine security and promoting data circulation.

Concerning the classification and grading of marine data, based on safeguarding marine security, marine scientific and technological development and changes in the marine industry should be tracked, and marine data relating to national security, the lifeblood of the national economy, meaningful livelihoods and significant public interests should be recognized as core national data and subjected to a stricter management system, by the provisions of Article 21 of the *Data Security Law*. It has also determined a specific catalog of essential data in the marine field by the data classification and hierarchical protection system and has provided vital protection for data included in the catalog. At the same time, consideration can be given to the establishment of a corresponding marine data exchange platform to standardize the management of various types of maritime and ocean data at all levels and to enhance the protection of data to safeguard China's marine security better.

5.4 Promoting the reform of the trial mechanism of the Maritime Court and improving the ability to safeguard maritime rights and interests using the rule of law

The protection of national security interests has become an essential element in the construction of foreign-related rule of law (Zhang, 2022). In the foreign-related rule of law, China's maritime judicial trial system and mechanism have distinctive features, and the current Chinese maritime trial system has apparent localized and trans-regional features. At the same time, maritime judicial cases have an apparent specialization, most foreign-related. The Supreme People's Court pointed out in the *China Maritime Trial (2018-2021)* that since establishing the 11 maritime courts, China's maritime trial practice has been increasingly developed. China has built the Asia-Pacific Maritime Judicial Center and is moving towards building an international maritime justice center. In the context of the new era of integrating the rule of law at the national level and the rule of law relating to foreign affairs, the establishment of a sound "three-trial-in-one model" maritime trial mechanism will become a trend in the development of the rule of law relating to foreign maritime affairs (China International Commercial Court, 2022). For example, the Ningbo Maritime Court publicly pronounced judgment on China's first maritime criminal case involving a significant liability incident involving a ship, the case of the vessel Triumph Worker 999, which has led to the development of maritime criminal, maritime administration, marine environmental resources and other areas of innovation (Zhejiang Maritime Safety Administration, 2019).

Concerning disputes over islands and maritime rights and interests between China and its neighbors, China's sovereignty and jurisdiction in the disputed maritime areas should be strengthened in light of the realities of the situation through the adoption of comprehensive means, such as the strengthening of civil activities, administrative management and law enforcement, and judicial jurisdiction and trial (Bai and Wang, 2017). For individuals, enterprises, and organizations at home and abroad that seriously infringe upon China's marine security, in addition to administrative penalties by the law, it is necessary to introduce a litigation mechanism to increase public interest litigation in the field of the legal protection of marine security and to pursue the legal responsibility of units and individuals that harm the country's maritime rights and interests.

6 Conclusion

Marine security is a crucial area of national security in China, and the rule of law system is the first step in improving the national security system. The rule of law will become the priority choice for maintaining China's national marine security interests. As a country moving from a major maritime country to a strong maritime country, it is crucial to effectively safeguard national marine security interests as the strategy of maritime strengthening continues to advance. Strengthening the rule of law in China's marine security is an important initiative to respond positively to

the adherence to the rule of law comprehensively and promote the construction of China under the rule of law. How effective it is will affect the realization of China's strategic goal of becoming a strong maritime power and the effectiveness of China's efforts to maintain the world's marine security order. In addition, while promoting the strategy of constructing a strong maritime country, China should promote the construction of a marine security community and strengthen international or regional cooperation in the prevention of and response to marine security risks to safeguard its marine security better.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

LW: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Amirell, S. E. (2016). Global maritime security studies: The rise of a geopolitical area of policy and research. *Secur. J.* 29, 2. doi: 10.1057/sj.2013.26

Bai, J. Y., and Wang, C. X. (2017). Maintenance of maritime rights and interests in the judicial perspective: Legal basis and development of China's maritime jurisdiction and its significance under international law. *J. Yunnan Minzu Univ. (Philos. Soc Sci. Edi.)* 34, 5.

Blum, Y. Z. (1965). *Historic titles in international law* (The Hague: Martinus Nijhoff).

Bueger, C. (2015). What is maritime security. *Mar. Policy* 53, 159–164. doi: 10.1016/j.marpol.2014.12.005

China International Commercial Court (2022). *China maritime trial, (2018-2021).* Available online at: https://cicc.court.gov.cn/html/1/219/208/210/2324.html (Accessed June 10, 2024).

Cody, S. (2022). Dark law on the south China sea. *Chicago. J. Int. Law* 23, 62–78.

EU (2014). *Maritime security strategy*. Available online at: https://oceans-and-fisheries.ec.europa.eu/ocean/blue-economy/other-sectors/maritime-security-strategy_en (Accessed March 13, 2024).

EU (2023). *Joint communication on the update of the EU Maritime Security Strategy and its Action Plan: An enhanced EU Maritime Security Strategy for evolving maritime threats*. Available online at: https://oceans-and-fisheries.ec.europa.eu/publications/joint-communication-update-eu-maritime-security-strategy-and-its-action-plan-enhanced-eu-maritime_en (Accessed March 18, 2024).

Feng, S. B. (2024). Forty years of the United Nations Convention on the Law of the Sea: Old regimes and new challenges of climate change. *Hebei Law Sci.* 10, 130–135.

Fu, M. Z., and Wang, L. (2023). Maritime community of shared future: Principles, practice and prospect. *Contemp. China World* 1, 100–117.

Germond, B. (2015). The geopolitical dimension of maritime security. *Mar. Policy* 54, 137–142. doi: 10.1016/j.marpol.2014.12.013

Guo, P., and Yan, L. C. (2024). On the realistic dilemma and improvement path of the rule of law on maritime security in China. *Acad. Exch.* 1, 63–77.

Hai, M. (2022). China's foreign policy on boundary and ocean affairs with its own characteristics. *J. Bound. Ocean Stud.* 2, 17–38.

Huang, S. L. (2004). A thousand years of strange changes: Coastal defense education and the awakening of national awareness of maritime rights in the late Qing dynasty. *China's Natl. Cond. Natl. Strength.* 4, 52–55.

Huang, Y., and Xu, W. Q. (2023). The implementation of a maritime community with a shared future from the perspective of global rule of law for oceans. *Pac. J.* 31, 10.

Jia, Y. (2019). The development of China's rule of law in oceans in the past 40 years of reform and openning-up. *J. Bound. Ocean Stud.* 4, 14.

Jin, Y. M. (2010). On China's maritime security and maritime rule of law. *Orient. Law* 3, 33–43.

Jin, Y. M. (2012). Study on the strategy of the ocean security of China. *Glob. Rev.* 4, 1–12.

Klein, N. (2011). *Maritime security and the law of the sea* (New York: Oxford University Press).

Li, J. W. (2021). Explanation of the theoretical essentials of the Overall National Security Concept. *Polit. Law* 10, 68–78.

Li, R. D. (2024). Comment on Xi Jinping's important discourse on the development of marine economy. *J. Hainan Univ. (Humanities Soc Sci.)* 5, 12–20.

Li, W. J. (2019). An analysis of the relationship between marine protected area system and China's marine security interests. *J. Int. Secur. Stud.* 2, 45–67.

Li, X. L. (2022). Global marine environmental crisis governance: mechanism evolution, compound dilemma and optimization path. *Acad. Forum* 45, 2.

Lin, S. W. (2021). The core essence and contemporary value of Xi Jinping's strategic thought on ocean power. *Theor. Horizon* 4, 20–31.

Liu, R. Q. (2024). Revision of China's marine environmental protection law: History, background and improvement. *Front. Mar. Sci.* 11. doi: 10.3389/fmars.2024.1409772

Liu, R. Q., and Hu, Z. F. (2024). Controversies and amendment proposals on the China Coast Guard Law. *Mar. Policy* 163, 106115. doi: 10.1016/j.marpol.2024.106115

Liu, X. H. (2023). National marine strategic education: A new perspective for the Promotion of Marine Education Practice. *Zhejiang Soc Sci.* 2, 144–146.

Liu, X. Y. (2023). Strategic assessment and prospect of China's maritime security in the new era. *Pac. J.* 31, 1.

Ma, J. X. (2016). Conflict and coordination of national jurisdiction in the safety of navigation in the South China Sea. *Soc Sci. J.* 6, 46–48.

Man, H. J. (2014). On the construction of the rule of law for marine security in China. *Acad. Exch.* 9, 78.

Marlow, P. B. (2010). Maritime security: An update of key issues. *Marit. Policy Mang.* 37, 7. doi: 10.1080/03088839.2010.524734

Qin, Q. (2015). Maintaining maritime security is an inevitable requirement of the Overall National Security Concept. *People's Rule Law* 6, 35.

Sheng, Q. C. (2008). Developing the culture of ruling the oceans by law to offer marine economy intellectual support and systematic guarantee. *J. Zhejiang Ocean Univ. (Humanities Sci.)* 1, 33.

Shriram,, and Giri, U. K. (2023). Geopolitics of South China Sea, China's interest and India's strategic response. *Int. J. Law Mange. Hum.* 6, 3. doi: 10.10000/IJLMH.115142

State Oceanic Administration (2017). *China Ocean Development Report* (Beijing: Ocean Press).

Su, Y. (2023). Research on deep sea development and sustainable development of marine economy—A review of blue resources and economic development driven by transparent ocean. *Financ. Econ.* 4, 1.

Supreme People's Court (2024). *Report on the work of the Supreme People's Court*. Available online at: https://www.Chinanews.com.cn/gn/2024/03-08/10176866.shtml (Accessed June 11, 2024).

UK (2022a). *Joint maritime security centre*. Available online at: https://www.gov.uk/government/groups/joint-maritime-security-centre (Accessed March 16, 2024).

UK (2022b). *National maritime security strategy*. Available online at: https://www.gov.uk/government/publications/national-maritime-security-strategy (Accessed March 15, 2024).

US (2024). *National strategy for a sustainable ocean economy*. Available online at: https://www.whitehouse.gov/wp-content/uploads/2024/06/National-Stategy-for-a-Sustainable-Ocean-Economy_Final.pdf (Accessed August 30, 2024).

US Department of Transportation (1966). *Office of maritime security*. Available online at: https://www.maritime.dot.gov/ports/office-security/office-maritime-security (Accessed March 27, 2024).

Wang, G. (2022). Development history and intrinsic logic of China's marine governance system. *Front.* 17, 42–50.

Wang, H. R., and Duan, X. X. (2019). Research on marine environmental enforcement and environmental public interest litigation. *J. Zhejiang Ocean Univ. (Humanities Sci.)* 6, 20–23.

Wang, L. (2024). Maritime cyber risks and maritime security: Relationship, problems and chinese governance. *Acad. Exch.* 1, 78–80.

Wang, R. L. (2022). Study on the historical origin and path of China's improvement of rule of law system and maintenance of maritime security under the Overall National Security Outlook. *Shanghai Law Res. Collect.* 6, 19–20.

Wu, H., and Zhang, D. (2010). Current situation of China's maritime security and suggestions. *J. Int. Secur. Stud.* 5, 48–52.

Wu, W. (2021). The rule of law path to building a community of destiny for the oceans. *Int. Stud.* 2, 102–113.

Wu, H., and Zhang, D. (2015). Problems, situation and legislative suggestions for China's maritime security. *China Inform. Secur.* 3, 98–103.

Wu, S. C. (2023). The time implication and the mission of China in the concept of a maritime community with a shared future. *Asia-Pac. Secur. Marit. Aff.* 4, 20–31.

Xi, J. P. (2022). *Hold high the great banner of socialism with Chinese characteristics and strive in unity to build a modern socialist country in all respects—Report to the 20th National Congress of the Communist Party of China*. Available online at: https://www.gov.cn/xinwen/2022-10/25/content_5721685.htm (Accessed February 26, 2024).

Xing, G. M. (2019). China's maritime security under the strategic framework of marine power. *J. Ocean Univ. China (Soc. Sci.)* 3, 3–5.

Xue, G. F. (2005). Countermeasures and suggestions for safeguarding China's maritime rights and interests under the system of the United Nations Convention on the Law of the Sea. *J. Ocean Univ. China (Soc. Sci.)* 6, 159.

Yang, H. (2021). Legislative positioning and system structure of the basic law of the sea. *Orient. Law* 1, 114–127.

Yang, J. M. (2022). China's major country relationship and periphery maritime strategies: Dealing and shaping in the New Era. *J. Bound. Ocean Stud.* 2, 67–82.

Yu, C. X. (2023). Analysis on rule of reference in the United Nations Convention on the Law of the Sea. *J. Polit. Sci. Law* 5, 61–73.

Yuan, Q. (2022). International law issues raised by the discharge of nuclear sewage into the sea and its response. *Seeker* 4, 169–177.

Zeng, Y. (2021). Some considerations on safeguarding maritime rights in the South China Sea within the framework of a two-level compound game. *Southeast Asian Aff.* 2, 36–39.

Zhang, H. W. (2022). National maritime security and its rule of law response under the great change not seen in a hundred years. *Theor. Explor.* 1, 5–11.

Zhang, N. (2022). The concept and system of foreign-related rule of law. *China Legal Sci.* 2, 264–282.

Zhejiang Maritime Safety Administration (2019). *Investigation report on the self-sinking accident of the triumph worker 999 in Ningbo*. Available online at: https://www.zj.msa.gov.cn/ZJ/zwgk/gkml/xzqz/201912/t20191203_588534.html (Accessed June 15, 2024).

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 28 October 2024
DOI 10.3389/fmars.2024.1486230

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
M. Jahanzeb Butt,
Shandong University, China
Wen-Yan Chiau,
National Taiwan Ocean University, Taiwan

*CORRESPONDENCE
Yuting Wang
wangyuting@cupl.edu.cn

RECEIVED 25 August 2024
ACCEPTED 07 October 2024
PUBLISHED 28 October 2024

CITATION
Liu X, Liu S and Wang Y (2024) The improvement of judicial protection of marine environment in China: based on the analysis of 2,443 judicial cases.
Front. Mar. Sci. 11:1486230.
doi: 10.3389/fmars.2024.1486230

COPYRIGHT
© 2024 Liu, Liu and Wang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

The improvement of judicial protection of marine environment in China: based on the analysis of 2,443 judicial cases

Xi Liu, Sijie Liu and Yuting Wang*

Institute for Data Law, China University of Political Science and Law, Beijing, China

With the proliferation of human activities, a series of marine ecological and environmental problems have arisen. Judicial application is important to test legislative achievements, explore judicial difficulties, and examine the compliance with the law. There is no case law in China and the impact of judicial decisions on the protection of marine environment is therefore indirect. Judicial decisions can reflect the implementation of the Marine Environmental Protection Law and play a crucial role in improving the marine environmental protection. An analysis of 2,443 cases related to marine environmental protection heard by courts at all levels across China from 1 January 2019 to 31 December 2023 has been conducted. The findings indicate an overall downward trend in cases related to marine environmental protection, suggesting positive governance outcomes to some extent. However, certain problems remain in the judicial protection of marine environment. Therefore, legislative efficiency should be properly increased and an independent crime for marine environmental pollution should be introduced to further clarify the legal bases for marine environmental protection. The intelligent trial assistance technology should also be applied to shorten trial time, improve trial efficiency, and unify judicial rules. The People's Courts should play an active role in the provision of evidence and specific evidentiary burden provisions for different types of marine environmental pollutions should be proposed. The data sharing channels between various systems should be facilitated and the functionality for case referral should be developed for the coordination of administrative enforcement and criminal justice within a unified administrative enforcement platform.

KEYWORDS

judicial protection, marine environmental protection, marine environment, burden of proof, intelligent trial assistance technology, administrative enforcement

1 Introduction

The ocean is an important component of the global life support system, affecting multiple aspects of global climate, biodiversity, and human society. At present, the marine economy has become one of the most dynamic and promising areas for economic growth in coastal countries and regions. In 2023, China's marine economy continued to develop rapidly, with a gross marine product of 9909.7 billion yuan, an increase of 6.0% over the previous year, and a growth rate of 0.8% higher than the gross domestic product (GDP), which accounts for 7.9% of the GDP and increases 0.1% over the previous year (Ministry of Ecology and Environment, 2024a). With the proliferation of human activities, the environmental pressure on the ocean is increasing and exceeds its own natural capacity for purification and recovery. This gives rise to a series of marine ecological and environmental problems, which can be categorized into two main types: first, there are issues of marine ecological destruction, such as the ecosystem disorder, a sharp decline in biodiversity, and the extinction of certain species; second, there are issues of marine environmental pollution, such as land-based pollutants entering the sea, the deposition of atmospheric pollutants and intensified eutrophication in coastal areas (Feng, 2023). The Chinese government attaches great importance to the protection of marine ecological environment, integrating it into the national ecological environment protection system. To strengthen the prevention and control of marine environmental pollution, significant progress has been made to prioritize the legislation on marine environmental protection (Zhu, 2016, p. 15). Simultaneously, active efforts have been made to carry out marine ecological protection and restoration. According to the *Report on the State of the Ecology and Environment in China 2023* released by the Ministry of Ecology and Environment, the overall water quality in the maritime areas under China's jurisdiction is stable and improving (Ministry of Ecology and Environment, 2024b). However, there are still phenomena such as water quality degradation and excessive marine litter in some areas, and issues such as waste discharge and leakage, overfishing, and illegal mining cannot be ignored.

Judicial application is a key measure to test legislative achievements, explore judicial difficulties, and examine the current situation of compliance with the law (Nie and Zhang, 2022). In China, there is no case law and the impact of judicial decisions on the protection of marine environment is therefore indirect. However, judicial decisions can reflect the implementation of the *Marine Environmental Protection Law* (*MEPL*), for instance, whether there is an increase in the number of the cases related to marine environmental pollution, the main manifestations of marine environmental pollution, what difficulties exist in investigating marine environmental pollution, and whether the relevant legal regulations for marine environmental protection are effective. Marine environmental protection cases refer to cases that directly or indirectly cause legal disputes and resort to judicial procedures due to marine pollution and ecological destruction. Its scope is not limited to cases aiming at protecting the marine environment and redressing environmental public welfare, but also includes civil private interest disputes caused by marine environmental pollution or resource utilization, as well as administrative litigation cases brought against administrative actions taken by maritime administrative agencies concerning the development and utilization of the ocean, navigable waters, fisheries, environmental and ecological resource protection, and other activities (Mei and Yin, 2018). Cases involving marine environmental protection are characterized by professionalism, technicality and comprehensiveness. The study of cases involving marine environmental protection is conducive to discovering the problems existing in marine environmental governance, revealing the legal loopholes, management deficiencies and enforcement challenges within the governance framework, and then proposing corresponding improvement measures.

This paper conducts an analysis of 2,443 cases related to marine environmental protection, aiming at contributing to the formulation and implementation of relevant laws and policies for China's marine environmental governance. Regarding the scope of the cases concerned, criminal cases related to marine environmental protection were analyzed to examine the manifestations of marine environmental pollution. Relevant administrative cases were also searched and selected, which can reflect the enforcement situation of administrative organs. Furthermore, marine environmental pollution may lead to civil disputes, such as aquaculture disputes caused by marine environmental pollution. It is found that due to the multi-source and spillover characteristics of marine ecological environment issues, there are problems such as unclear boundaries of administrative enforcement powers, unclear regulatory responsibilities, and even conflicts in marine environmental governance (Liang, 2024). There are also obstacles in marine environmental supervision, such as scattered enforcement forces and difficulties in obtaining evidence (Zeng et al., 2018). In the field of marine environmental protection, the crime of polluting the environment needs to be further activated (Hao, 2023). However, the *Criminal Law* in China does not specifically establish an independent crime for marine pollution, which makes it difficult to convict certain behavior that brought about significant damage to the marine ecological environment and should constitute a crime (Zhang, 2021). Marine environmental governance mainly relies on the leading role of the government and the involvement of other social forces such as enterprises, the public, and non-profit organizations is not very active. They may adversely influence the full play of governance effectiveness (Sun and Zhou, 2021). Therefore, improvements should be made to the legal rules related to marine environmental protection and the professional level of judicial protection should also be enhanced. In addition, it is essential to further strengthen the effective coordination between the judicial and administrative enforcement, reinforce the legal oversight, and jointly maintain the security of the marine ecological environment.

This paper will be divided into five sections. Following the introduction, the overview of the judicial protection of marine environment in China will be described on the basis of the analysis of 2,443 judicial cases. Then, the challenges in the

judicial protection of marine environment in China will be examined. The fourth section will focus on how to improve the judicial protection of marine environment in China. Finally, a conclusion of this paper will be put forward.

2 The overview of the judicial protection of marine environment in China

The protection of the marine ecological environment plays a crucial role in safeguarding national ecological security and promoting the sustainable development of marine resources. To identify the challenges in marine ecological environment protection, promote efficient and rational exploitation of marine resources, and enhance China's marine ecological environment governance, this paper analyzed 2,443 cases related to marine environmental protection heard by courts at all levels across China from 1 January 2019 to 31 December 2023. The analysis covers aspects such as case types, annual trends, regional distribution, distribution by trial levels, cause of action, criminal penalties, trial periods, and the rate of administrative agency defeats. The findings indicate an overall downward trend in cases related to marine environmental protection, suggesting positive governance outcomes to some extent. However, certain problems remain in the governance of marine environment, such as the limited application of criminal charges which are insufficient to cover all marine environmental damage behavior, light penalties with inadequate deterrence, prolonged trial periods, and the lack of professionalism of the administrative enforcement by administrative agencies.

All of the cases analyzed in this paper were sourced from the unified publication of first-instance, second-instance, and retrial judgments from courts at all levels on the "China Judgments Online" platform established by the Supreme People's Court. By sorting out potential causes of action and keywords involved in the marine environmental protection, relevant cases were extracted. In this paper, criminal cases refer to the ones that involve crimes such as environmental pollution, smuggling of waste, illegal disposal of imported solid waste, unauthorized import of solid waste, illegal fishing of aquatic products, illegal hunting, illegal mining, destructive mining, illegal occupation of agricultural land, destruction of natural protected areas, endangering precious and endangered wildlife, and endangering key nationally protected plants, where one of the keywords "marine environment", "marine ecology", or "marine resources" is contained in the reasoning of the judgment. In this paper, civil cases refer to the ones that involve disputes related to water pollution liability, liability for ship pollution damage, public interest litigation, maritime and commercial disputes, environmental pollution liability, and ecological environment damage compensation disputes; as well as all disputes over marine and navigable water pollution damage and marine and navigable water aquaculture damage, where one of the keywords "marine environment", "marine ecology", or "marine resources" is contained in the reasoning of the judgment. In this paper, administrative cases are those where the court's reasoning includes one of the keywords "marine environment", "marine ecology", or "marine resources".

2.1 The analysis of general situation

From 2019 to 2023, the courts in China concluded a total of 2,443 cases related to marine environmental protection disputes, with 196 criminal cases, 1,973 civil cases, and 274 administrative cases. From the perspective of the annual distribution, there were 1,020 cases in 2019; there were 526 cases in 2020, a year-on-year decrease of 48.43%; there were 303 cases in 2021, a year-on-year decrease of 42.40%; there were 282 cases in 2022, a year-on-year decrease of 6.93%; and there were 312 cases in 2023, a year-on-year increase of 10.64%. The overall trend of marine environment protection cases concluded by courts nationwide shows a decline, with an average annual decrease of 25.63%. The annual trend of national marine environmental protection cases from 2019 to 2023 is shown in the figure below (See Figure 1).

From the perspective of regional distribution nationwide, Fujian, Shandong, Tianjin, Liaoning, and Guangxi ranked among the top in the number of cases, accounting for 25.30%, 23.74%, 14.12%, 8.27%, and 7.74% respectively. The detailed distribution of the top 5 regions in terms of the number of marine environmental protection cases nationwide from 2019 to 2023 is shown in the table below. (See Table 1) Fujian had 618 cases, with aquaculture damage disputes accounting for 93.51% of civil cases and illegal mining at 95.24% in criminal cases. Shandong had 580 cases, with marine development disputes making up 43.58% and administrative compulsory enforcement cases accounting for 53.33%. Tianjin had 345 cases, with marine development disputes making up 47.48% and all administrative cases resulting in penalties. Liaoning had 202 cases, with administrative licensing at 92.78% and aquaculture damage at 54.95%. Guangxi had 189 cases, with pollution damage accounting for 79.78% and aquaculture damage accounting for 13.11% in civil cases.

From the perspective of trial level distribution, there were 2,002 first-instance cases, accounting for 81.95% of the total concluded cases; there were 435 second-instance cases, accounting for 17.81% of the total concluded cases; and there were 6 retrial cases, accounting for 0.25% of the total concluded cases. In 2019, there were 932 first-instance cases, 85 second-instance cases, and 3 retrial cases, respectively accounting for 91.37%, 8.33% and 0.29% of the total cases concluded that year. In 2020, there were 361 first-instance cases, 165 second-instance cases, and no retrial cases, respectively accounting for 68.63%, 31.37% and 0.00% of the total cases concluded that year. In 2021, there were 221 first-instance cases, 81 second-instance cases, and 1 retrial case, respectively accounting for 72.94%, 26.73% and 0.33% of the total cases concluded that year. In 2022, there were 227 first-instance cases, 53 second-instance cases, and 2 retrial cases, respectively accounting for 80.50%, 18.79% and 0.71% of the total cases concluded that year. In 2023, there were 261 first-instance cases, 51 second-instance cases, and 0 retrial cases, respectively accounting for 83.65%, 16.35% and 0.00% of the total cases concluded that year. The annual distribution of trial levels in national marine environmental protection cases from 2019 to 2023 is shown in the figure below (See Figure 2).

From the annual trend of the main causes of action, in criminal cases, the crime of illegal fishing of aquatic products showed a

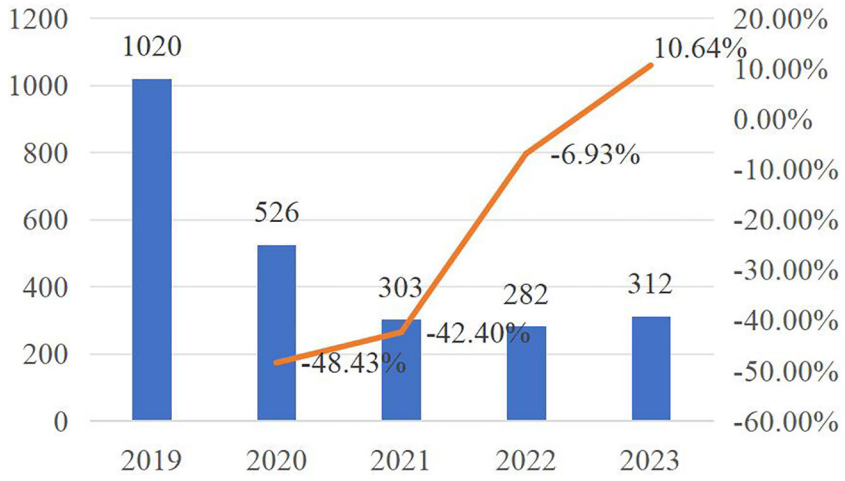


FIGURE 1
Annual Trend of National Marine Environmental Protection Cases from 2019 to 2023.

downward trend, and the crime of illegal mining showed a downward trend after an increase. In civil cases, disputes over liability for aquaculture damage and disputes over liability for pollution damage in offshore and sea-connected waters showed a downward trend, while disputes over marine development and utilization presented an up-and-down trend. The disputes over salvage contracts showed an upward trend followed by a downward trend. In administrative cases, both administrative licensing and administrative punishment cases were on the decline. The annual trend of the main causes of marine environmental protection in China from 2019 to 2023 is shown in the table below (See Table 2).

2.2 The analysis of criminal cases

2.2.1 Marine environmental crime rates have declined by 18.56% annually over the past five years

From 2019 to 2023, courts nationwide concluded a total of 196 marine environmental protection criminal cases. In terms of the annual distribution, there were 50 cases in 2019, 52 cases in 2020, which is an increase of 4.00% compared to the previous year; there were 35 cases in 2021, a year-on-year decrease of 32.69%; there were 37 cases in 2022, a year-on-year increase of 5.71%; and there were

TABLE 1 Distribution of the Top 5 Regions in National Marine Environmental Protection Cases from 2019 to 2023.

Number	Region	Type	Number of Cases		Proportion
1	Fujian Province	Crimial cases	42	618	25.30%
		Civil cases	570		
		Administrative cases	6		
2	Shandong Province	Crimial cases	8	580	23.74%
		Civil cases	537		
		Administrative cases	35		
3	Tianjin City	Crimial cases	0	345	14.12%
		Civil cases	337		
		Administrative cases	8		
4	Liaoning Province	Crimial cases	1	202	8.27%
		Civil cases	91		
		Administrative cases	110		
5	Guangxi Zhuang Autonomous Region	Crimial cases	2	189	7.74%
		Civil cases	183		
		Administrative cases	4		

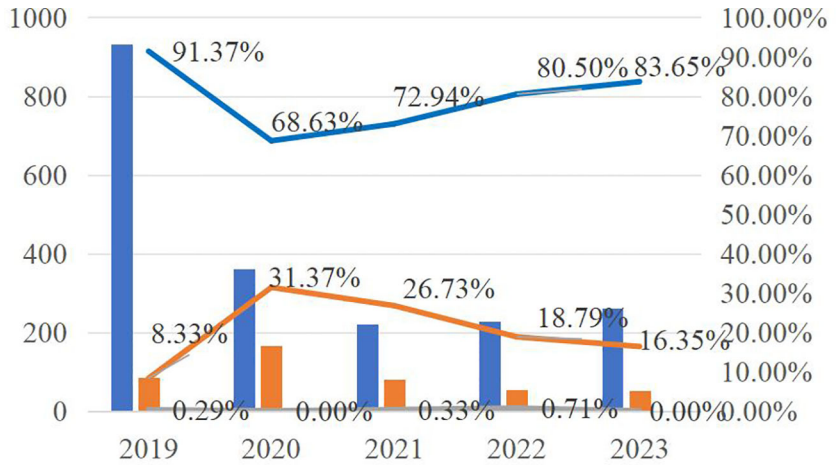


FIGURE 2
Annual Distribution of National Marine Environmental Protection Cases by Trial Level from 2019 to 2023.

22 cases in 2023, a year-on-year decrease of 40.54%. Overall, the number of criminal cases related to marine environmental protection nationwide shows a downward trend, with an average annual decrease of 18.56%. In terms of trial level distribution, there were 192 first-instance cases, accounting for 97.96% and 4 second-instance cases, accounting for 2.04%.

2.2.2 Over 60% of the cases involved illegal fishing, 30% were illegal mining, no environmental pollution crimes reported

Among the marine environmental protection criminal cases concluded by courts nationwide from 2019 to 2023, in terms of the distribution of charges, there were 134 cases of illegal fishing of aquatic products, accounting for 68.37%; 56 cases of illegal mining were concluded, accounting for 28.57%; and there were also 6 cases of crimes of endangering precious and endangered wildlife, accounting for 3.06%. No cases of environmental pollution crimes or other charges were found. The distribution of charges in national marine environmental protection criminal cases from 2019 to 2023 is shown in the table below (See Table 3).

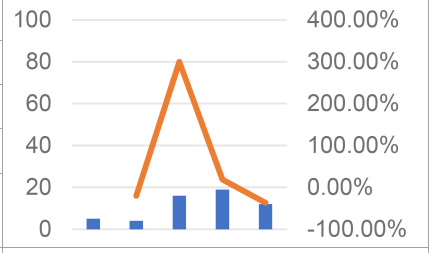
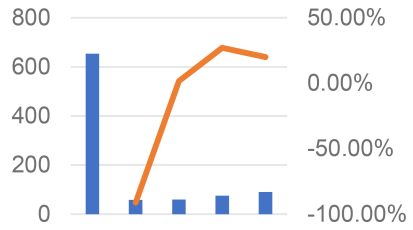
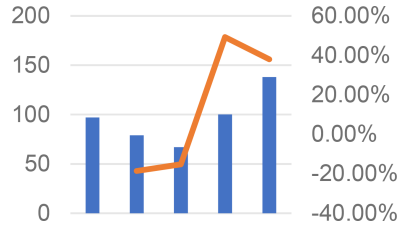
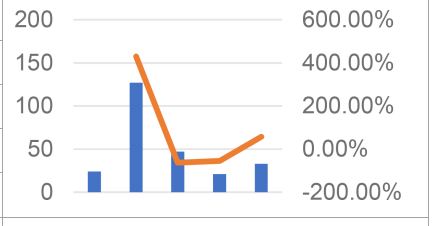
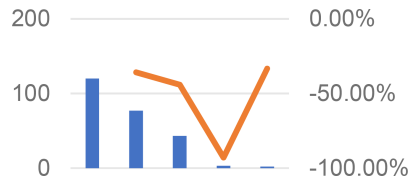
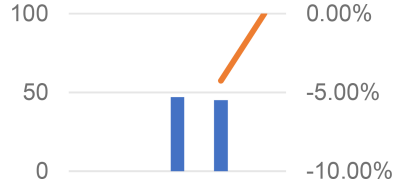
In criminal cases concerning marine environmental protection, there are actions of severe destruction of the marine ecological environment, which do not fall within in the scope of illegal fishing of aquatic products, illegal mining, and endangering precious and endangered wildlife. However, no cases of environmental pollution crimes were found among the marine environmental protection criminal cases concluded by courts nationwide from 2019 to 2023, indicating that this charge needs to be activated. For example, in the civil public interest litigation case of the *Haikou City People's Procuratorate* vs. *Hainan Zhonghui Dredging Engineering Co., Ltd. (hereinafter referred to as Zhonghui Company), Chen Si, and Haikou Liuyuan Earthwork Engineering Co., Ltd. (hereinafter referred to as Liuyuan Company)* regarding environmental pollution liability disputes, Liuyuan Company subcontracted part of the construction waste transportation work generated from its earthwork excavation project to Zhonghui Company. Zhonghui Company used ships to dump the construction waste into the sea. According to the appraisal and assessment opinion issued by the South China Institute of Environmental Sciences of the Ministry of Ecology and Environment, the construction waste dumped into the sea contained harmful and toxic substances such as cadmium, mercury, nickel, lead, arsenic, and copper. These substances entered the marine food chain, causing quantified ecological environmental damage amounting to 8.60064 million yuan.[1]

2.2.3 Over 50% faced up to one year in prison and just 10% received fines exceeding 100,000 yuan

From 2019 to 2023, among the marine environmental protection criminal cases concluded by courts nationwide, 53.65% of the defendants were sentenced to imprisonment of one year or less; 35.19% were sentenced to imprisonment of more than one year (excluding one year) and up to three years (including three years); 7.73% were sentenced to imprisonment of more than three years (excluding three years) and up to five years (including five years); 1.72% were sentenced to imprisonment of more than five years (excluding five years) and up to seven years (including seven years); and 0.86% were sentenced to imprisonment of more than seven years (excluding seven years). In terms of fines, 28.57% of the defendants were fined 10,000 yuan or less; 33.71% were fined more than 10,000 yuan (excluding 10,000 yuan) and up to 50,000 yuan (including 50,000 yuan); 23.43% were fined more than 50,000 yuan (excluding 50,000 yuan) and up to 100,000 yuan (including 100,000 yuan); and 14.29% were fined more than 100,000 yuan (excluding 100,000 yuan) and up to 500,000 yuan (including 500,000 yuan). Compared with the high profits generated from illegal fishing of aquatic products, illegal mining, and hunting and trading of precious and endangered wildlife, the amounts of the fine for marine environmental protection crimes are relatively low.

1 (2019) Qiong 72 Min Chu No. 227.

TABLE 2 Annual Trend of Main Causes of Action Related to Marine Environmental Protection in China from 2019 to 2023.

Number	Type	Cause of Action	Year	Number of Cases	Rate of Change	Annual Trend
1	Criminal cases	Illegal Fishing of Aquatic Products	2019	45		
			2020	48	6.67%	
			2021	14	-70.83%	
			2022	18	28.57%	
			2023	9	-50.00%	
		Illegal Mining	2019	5		
			2020	4	-20.00%	
			2021	16	300.00%	
			2022	19	18.75%	
			2023	12	-36.84%	
2	Civil cases	Liability disputes for damages caused by aquaculture in offshore or sea-connected waters	2019	654		
			2020	58	-91.13%	
			2021	59	1.72%	
			2022	75	27.12%	
			2023	90	20.00%	
		Disputes over marine development and utilization	2019	97		
			2020	79	-18.56%	
			2021	67	-15.19%	
			2022	100	49.25%	
			2023	138	38.00%	
		Disputes over salvage contracts	2019	24		
			2020	127	429.17%	
			2021	47	-62.99%	
			2022	21	-55.32%	
			2023	33	57.14%	
		Liability disputes for pollution damages in offshore or connected waters	2019	120		
			2020	77	-35.83%	
			2021	43	-44.16%	
			2022	3	-93.02%	
			2023	2	-33.33%	
3	Administrative cases	Administrative licensing	2019	47		
			2020	45	-4.26%	
		Administrative penalty	2019	12		
			2020	11	-8.33%	

(Continued)

TABLE 2 Continued

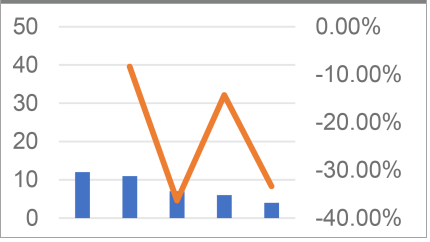
Number	Type	Cause of Action	Year	Number of Cases	Rate of Change	Annual Trend
			2021	7	-36.36%	
			2022	6	-14.29%	
			2023	4	-33.33%	

TABLE 3 Distribution of Charges in National Marine Environmental Protection Criminal Cases from 2019 to 2023.

Number	Region	Proportion
1	Illegal Fishing of Aquatic Products	68.37%
2	Illegal Mining	28.57%
3	Endangering Precious and Endangered Wildlife	3.06%

2.2.4 Criminal acts in 59.50% of cases happened at night or early morning

From 2019 to 2023, in China, 59.50% of marine environmental protection criminal cases with specified time by prosecutors occurred at night or in the early morning. Defendants also used methods like tampering with ship identifiers to conceal crimes. In a criminal case, the defendant painted over the ship's true identifier and disabled the Beidou and Automatic Identification System (AIS) to evade maritime enforcement.[2]

2.3 The analysis of civil cases

2.3.1 Civil marine environmental cases have dropped by 26.22% annually over the past five years

From 2019 to 2023, a total of 1,973 civil cases related to marine environmental protection were concluded by courts nationwide. With respect to the annual distribution, there were 901 cases in 2019, 358 cases in 2020 (a year-on-year decrease of 60.27%), 235 cases in 2021 (a year-on-year decrease of 34.36%), 212 cases in 2022 (a year-on-year decrease of 9.79%), and 267 cases in 2023 (a year-on-year increase of 25.94%). A downward trend has been shown on the civil cases related to marine environmental protection, with an average annual decrease of 26.22%. In terms of trial level distribution, there were 1,622 first-instance cases, accounting for 82.21%; there were 346 second-instance cases, accounting for 17.54%; and there were 5 retrial cases, accounting for 0.25%.

2.3.2 About half of marine environmental civil disputes were concerning aquaculture damage, and public interest cases were rare

From 2019 to 2023, among the civil disputes related to marine environmental protection concluded by courts nationwide, the disputes over liability for damage caused by aquaculture in offshore and sea-connected waters were the most prevalent, accounting for 47.42%, significantly higher than the number of cases for other causes. This was followed by disputes over marine development and utilization, which accounted for 24.37%; and disputes over maritime salvage contracts accounts for 12.82%. The distribution of the causes of action for civil disputes related to marine environmental protection from 2019 to 2023 is shown in the table below. Challenges such as investigation, evidence collection and scarcity of plaintiffs were among the issues (See Table 4).

From 2019 to 2023, courts nationwide concluded 28 civil public interest litigation cases related to marine environmental protection. For example, in the civil public interest litigation case of the *Haikou City People's Procuratorate* vs. *Hainan Zhonghui Dredging Engineering Co., Ltd. (hereinafter referred to as Zhonghui Company), Chen Si, and Haikou Liuyuan Earthwork Engineering Co., Ltd. (hereinafter referred to as Liuyuan Company)* regarding environmental pollution liability disputes, the clue of the case was sourced from public reports. During the investigation, drone footage was used and the maritime and fishery enforcement agencies collaborated with the procuratorate to jointly investigate and handle the case.[3] In the civil public interest litigation case of *the Second Branch of the Hainan Provincial People's Procuratorate* vs. *Xing Zengren and Ningbo xiandeyi trading co., ltd*, in response to the illegal sea sand mining activities of the defendants Xing Zengren and Ningbo xiandeyi trading co., ltd, the Second Branch of the Hainan Provincial People's Procuratorate had issued an announcement and sent a letter to the Dongfang City Natural Resources and Planning Bureau, urging the eligible social organizations and entities to file a lawsuit, however, no eligible parties filed a lawsuit.[4]

In public interest litigation, the court requires the plaintiff to show evidence of the defendant's polluting actions and their potential harm to the public. In a civil case about aquaculture

2 (2020) Su 0724 Xing Chu No. 459.

3 (2019) Qiong 72 Min Chu No. 227.

4 (2020) Qiong 72 Min Chu No. 25.

TABLE 4 Distribution of Causes of Action for Civil Disputes Related to Marine Environmental Protection from 2019 to 2023.

Number	Cause of Action	Proportion
1	Liability disputes for damages caused by aquaculture in offshore or sea-connected waters	47.42%
2	Disputes over marine development and utilization	24.37%
3	Disputes over salvage contracts	12.82%
4	Liability disputes for pollution damages in offshore or connected waters	12.41%
5	Public interest litigation	1.42%
6	Maritime and commercial disputes	0.96%
7	Liability disputes for ship pollution damages	0.35%
8	Environmental pollution liability disputes	0.25%

damage, the plaintiff, who bore the burden of proof, failed to establish the specific location of the aquaculture and the damage caused by a towrope.[5] Therefore, the plaintiff's claim was not supported.

2.3.3 Trials lasted over 200 days in 30% of the cases, and the appeal revision rate was 5.08%

From 2019 to 2023, among the civil disputes related to marine environmental protection concluded by courts nationwide, in terms of case closure methods, 57.35% of the cases were closed by adjudication, 35.76% by judgment, and 6.89% by mediation. Among the cases closed by adjudication, 74.91% of the cases were withdrawn. Among cases concluded by judgment, 30.58% of first-instance civil disputes involving marine environmental protection had a trial period exceeding 200 days, with an average trial period of 206.20 days for all these first-instance cases. And the appeal revision rate was 5.08% due to incomplete facts, causality issues, wrong damage basis, and responsibility misallocation (See Table 5).

From 2019 to 2023, among the second-instance cases of civil disputes related to marine environmental protection concluded by courts nationwide, 295 cases were closed by judgment, of which 15 cases were retried. The main reasons for such retrials included omissions in the determination of damage facts, unreasonable allocation of responsibility, insufficient determination of causal relationships, errors in the determination of the basis for damage compensation, and errors in the determination of the subject qualification of public interest litigation. In the civil public interest litigation case of the *Dongfang City Natural Resources and Planning Bureau* vs. *Mo Tuxiu*, due to the high costs of on-site investigation and assessment, which exceeded the amount claimed in the damage compensation lawsuit, the Dongfang Natural Resources Bureau proposed using the compensation standard recognized by the court in another case as the basis for

TABLE 5 Trial Periods for Nationwide First-Instance Civil Disputes Involving Marine Environmental Protection Concluded by Judgment from 2019 to 2023.

Number	Trial Period	Proportion
1	1 to 50 days	11.62%
2	51 to 100 days	18.96%
3	101 to 150 days	14.98%
4	151 to 200 days	23.85%
5	201 days and above	30.58%

compensation in this case.[6] The first-instance court did not support this claim, citing that China is not a case law country and that many specific factors that affect the quantification of compensation amounts, such as the time, place, method, and intensity of sand mining, influence the quantification of marine ecological environment damage. However, the second-instance court held that the sand mining behavior involved in the case was similar in location and method to those in another case, and the time periods were close, so it could be used as the basis for determining the compensation standard in this case.

2.4 The analysis of administrative cases

2.4.1 Fluctuating decline in administrative cases: 24.02% annual decrease

From 2019 to 2023, the courts in China concluded a total of 274 administrative cases related to marine environmental protection. The annual distribution is as follows: 69 cases in 2019; 116 cases in 2020, an increase of 68.12% year-on-year; 33 cases in 2021, a year-on-year decrease of 71.55%; 33 cases in 2022, remaining the same as the previous year; and 23 cases in 2023, a decrease of 30.30% year-on-year. Overall, the number of administrative cases related to marine environmental protection handled by courts nationwide shows a declining trend, with a decrease of 24.02%. In terms of the level of trials, 188 cases were first-instance trials, accounting for 68.61%; 85 cases were second-instance trials, accounting for 31.02%; and 1 case was a retrial, accounting for 0.36%.

2.4.2 Over 70% of the cases involve sea area rights and penalties for illegal activities like dumping, fishing and aquaculture

From 2019 to 2023, administrative disputes related to marine environmental protection concluded by courts across the country were predominantly administrative licensing cases, accounting for 50.83% of the total. The defendants in all these cases were the Zhuanghe Government, with plaintiffs alleging that the government delayed the processing of sea area usage rights certificates. This is followed by administrative penalties, making up 22.10%, primarily concerning the legality of administrative penalties imposed for illegal dumping, fishing, and aquaculture activities. Administrative enforcement cases accounted for 6.08%, with the main disputes concentrating on the legality of the seizure of vessels.

5 (2019) Su 03 Min Chu No. 232.

6 (2019) Qiong 72 Min Chu No. 227.

2.4.3 Administrative agencies lost 30% of the cases

From 2019 to 2023, the first-instance defeat rate of administrative agencies in marine environmental protection administrative cases concluded by courts nationwide was 30.19%. In terms of judgment methods, they included ordering the defendant to perform their legal duties within a certain period (44.00%), revoking administrative actions (40.00%), and confirming the illegality of administrative actions (16.00%).

Regarding the reasons for the loss, the main causes included failure to perform administrative duties (33.33%), procedural violations (31.37%), unclear fact-finding and insufficient evidence (29.41%), and incorrect application of the law (5.89%).

3 The challenges in the judicial protection of marine environment in China

The intensification of marine exploitation and utilization has led to a significant increase in the adverse effects of human activities on marine ecosystems (Chen et al., 2017). China is a major maritime power, with the ocean being a crucial resource and strategic domain for China's sustainable economic and social development. Despite the rapid growth of the marine economy, the pressure on the marine ecological environment remains significant, with an increasing number of cases involving damage to natural resources and ecological environments (Sun, 2022). However, the judicial protection in the area of marine environment has faced great challenges which failed to effectively fulfill its intended role. The issues of judicial "absence" and "hesitation" are particularly pronounced (Yang, 2012). In this section, the challenges in the judicial protection of marine environment in China will be examined, such as the lack of clarified legal bases, the lack of professionalism, the difficulties in evidence provision and allocation of burden of proof and the lack of effective coordination between judiciary and administrative enforcement.

3.1 Lack of clarified legal bases

With the development of marine environmental protection, China's marine environmental protection has formed a legal system with the *MEPL* as the core, and the various laws on the protection of marine eco-environment, which has provided an effective guarantee for marine pollution prevention and ecological protection in China. However, compared with the inland environmental protection law, China's research on marine environmental protection and marine ecology started relatively late. Considering the current status and needs of marine environmental protection in China, there are still deficiencies in the legal system, which may influence its implementation and the effectiveness of marine ecological environment protection (Miao and Liu, 2023). One of the most urgent issues that should be addressed is the lack of clarified legal bases.

First, the *MEPL* is the basic law for China's marine ecological protection and the first important law in China's environmental protection (Gao, 2024). Since its promulgation in 1982, it has undergone the first revision in 1999 and three amendments respectively in 2013, 2016 and 2017, and completed another revision in 2023 (*MEPL2023*) (Sun, 2023). The *MEPL2023* focuses on the main contradictions, special problems and prominent characteristics of marine environmental protection, providing legal protection for the significantly changing marine environment in China (Mei, 2023; Liu, 2024). However, marine environmental pollution is characterized by strong persistence, wide diffusion, irreversibility, and difficulty in prevention and control (Quan, 2022). Objectively, marine environmental legislation should be forward-looking and moderately advanced, or at least respond in a timely manner to changes in marine environmental risks. While, the proposal or update of related regulations is relatively lagging (Gao, 2024). For example, according to Article 72(2) of the *MEPL2023*, "the list of wastes that can be dumped into the sea shall be made by the ecological and environmental department of the State Council."[7] However, after the Ministry of Ecology and Environment publicly solicited comments on the relevant regulations in January 2022, the regulations have not yet been officially released. In addition, as the demand for marine environmental protection rapidly evolves and the *MEPL* has been revised, legal documents such as the *Regulation of the People's Republic of China on the Control of Marine Waste Dumping* are still lagging behind in terms of the pace of updating, even though revisions were made several years ago.

Second, many provisions of the *MEPL2023* need to be implemented with the support of other laws, rules and regulations. For example, according to Articles 114(1) and 119 of the *MEPL2023*, marine environment can also be protected within the laws like the *Civil Code* and the *Criminal Law*.[8] However, the imperfections of the relevant provisions pose obstacles to the judicial protection of the marine environment.

In aforementioned data analysis, no criminal cases related to marine environmental protection have been found concluded under the charge of "environmental pollution". In fact, this issue has existed for a long time. The reasons can be attributed to the unscientific setting of the crime itself, the unreasonable establishment of the elements of the crime, and the irrational setting of statutory penalties (Tian, 2019). In addition, the protection of legal interests is not clearly defined, and there is a lack of functionality. As a result, issues such as the "pocketing" of regulatory scope, "abstracting" of interpretation standards, and "blurring" of criminal boundaries have emerged in judicial protection (Li and Yuan, 2021; Pan, 2022). Due to the absence of a specific independent crime for marine pollution in China's *Criminal Law*, it is difficult to penalize certain behaviors that are

7 Article 1(4) of *MEPL2023*.

8 Articles 114(1) and 119 of *MEPL2023*.

sufficiently serious to constitute a crime and damage the marine ecological environment (Zhang, 2021). Moreover, international treaties cannot be directly applied as domestic law in China, which results in the reliance on civil compensation and administrative penalties to address some behaviors that pollute the marine environment (Zhao and Chen, 2019). In summary, it is still difficult to apply the provisions of the *Criminal Law* in China such as the crime of environmental pollution to acts that damage the marine ecological environment. This is also why this crime has not been activated in the field of marine environmental protection.

3.2 Lack of professionalism

Judicial protection of marine environment is a comprehensive institutional framework designed to protect and rehabilitate the marine environment through the application of legal mechanisms. It involves a multifaceted approach that includes legislation, law enforcement, and the judiciary. Judicial protection encompasses the essential function of transforming abstract legal principles into concrete operational guidelines (Su, 2000, p. 4). It enables the transition of legal statutes from static provisions to dynamic norms that guide and regulate the conduct of various entities in a structured and orderly manner (Chen, 2017). By converting legal doctrines into enforceable standards, judicial protection facilitates the consistent and effective implementation of the law, thereby fostering a legal environment that is both predictable and equitable for all stakeholders. Serving as the ultimate bulwark in the protection of marine environmental and the defense of the nation's maritime ecological rights and interests, the judicial protection of marine environment plays a critical role in preventing and reducing marine environmental pollution, preserving marine ecological balance, and promoting the sustainable use of marine resources. The efficacy of judicial protection is underpinned by two fundamental pillars, namely judicial efficiency and judicial fairness. To realize these two objectives, it requires a large number of highly qualified staff with a strong legal background and necessary knowledge in environmental science, as well as the utilization of intelligent technologies. However, in the cases concerning the marine environmental protection, the lack of professionalism problem has become a contentious issue.

In terms of judicial efficiency, the paramount value lies in the efficiency of time (Yao, 2006), which refers to the ability of the legal system to process cases in a timely and cost-effective manner. However, as analyzed above, the average trial period for first-instance civil disputes concerning the marine environmental protection exceeds 200 days and in fact nearly 31% of the cases took more than 200 days to be settled down. It is stated that the trial period for marine environmental protection cases significantly exceeds that of general maritime disputes (Song, 2021). Another empirical study also found that the average trial period for disputes concerning the protection of marine environment was much longer than that for other civil, criminal, and administrative disputes (Research Team of Shanghai High People's Court, 2022). From the above statistics on the judicial protection of marine environment, it can be seen that there is a notable gap of 441 cases between the total number of 2,443 cases and the total number of civil cases of the first instance, 2,002. This, to some extent, indicates that a considerable number of parties concerned did not agree with the corresponding judgment results, leading the cases to the second trial or retrial procedures, which accounts for 18.05% of the total sample cases. According to the main data of judicial trial work from January to September 2023 released by China's Supreme People's Court, the acceptance rate for civil and commercial first-instance cases is 89.22%, with an increase of 0.43% year-on-year (The Supreme People's Court, 2023). Nevertheless, the acceptance rate for marine environmental protection cases, at 81.95%, exhibits a discernible disparity. This disparity is a significant contributing factor to the long and extended trial periods for such cases. Judicial efficiency is of great importance to maintain the public trust and to mitigate the burden on the parties involved. Consequently, the lengthy trial period and the relatively low acceptance of the judgements may also be an indicator for the professionalism to be improved.

In terms of judicial fairness, it emphasizes the impartiality and equity of the legal process. Judicial efficiency is the basic component of justice, but judicial justice is the fundamental source of justice. On the premise of achieving judicial fairness, it is necessary to continuously enhance judicial efficiency in order to ultimately realize the value pursuit and objectives of judicial protection (Zhou et al., 2019). Judicial fairness demands that all parties receive equal treatment under the law, without bias or favoritism, and that decisions are made based solely on the merits of the case and the applicable legal standards. However, the benchmarks for the judicial protection of the marine ecological environment are not fully unified and there is an inconsistency in the judicial rules, which poses challenges to the professionalism of judicial marine environmental protection. When courts deal with cases related to the marine ecological environment, they are often required to exercise their discretion to issues where the law is either silent or unclear. Notwithstanding, such discretion is not always appropriately and consistently applied and need further enhancement. For instance, it is shown in the aforementioned statistics that the appellate court has modified the initial judgments in 5.08% of the cases upon second-instance review as a result of the lapses in the recognition of damage facts, inadequate assessment of causal relationships, misjudgments in the criteria for damage compensation, and the unjustifiable distribution of liabilities. Furthermore, according to the *Notice on the Establishment of Maritime Courts*, maritime courts are positioned at the intermediate level within the judicial hierarchy, appeals from which should be handled by the high people's courts located at the same region. As a consequence, marine environmental cases are initially under the jurisdiction of specialized courts, while the appellate process is conducted by general high courts. Such a dichotomy may undermine the pursuit of specialized judicial proceedings and the realization of a cohesive judicial protection for marine environmental cases. In addition, cases of marine environmental protection are entangled with intricate marine environmental science, necessitating a substantial reliance on specialized technical knowledge for monitoring and assessing the

ecology. Environmental litigation is generally multifaceted, especially marine environmental disputes, frequently encompassing a complex interplay of environmental civil, administrative, and criminal legal relationships, in which the judgment of a case of a certain nature at times needs to be based on the determination of related cases of another nature (Yang, 2016). When it comes to the administrative cases, the situation seems to be more serious. Given the intricacies of environmental cases, the utilization of specialized knowledge in the examination of environmental administrative actions may prompt judges to exercise a prudent approach that defers to administrative decisions. This could result in insufficient substantive review, thereby affecting the quality of the judicial determination (The Supreme People's Court, 2022). Therefore, inconsistencies in the judicial criteria for safeguarding marine environment pose a significant threat to the professionalism of the judicial protection and may impair the integrity of justice.

3.3 Difficulties in evidence provision and allocation of burden of proof

It can be seen from the data analysis above that in the past five years, some civil cases involving marine environmental protection in China have faced difficulties such as challenging investigations and evidence collection. In fact, whether in civil or criminal cases, clues in marine ecological environmental pollution cases are usually difficult to be discovered. To some extent, this leads to problems such as difficulties in obtaining evidence in judicial proceedings (Liu et al., 2023). The main reason is the unique circumstances surrounding the destruction of the marine ecological environment, which complicates the process of providing evidence.

One aspect that must be taken into account is that marine pollution often occurs in areas far from the inland, across different geographical boundaries, and the causes are complicated. Compared with the pollution of terrestrial rivers, more resources are needed to discover the clues of marine pollution. However, in the less developed coastal areas, due to the limitations in human resources, materials and financial resources, it is difficult for administrative agencies and judicial organs to organize special forces for long-term and large-scale investigations, which also pose great challenges to discover clues (Zhan and Xu, 2020). Given the vastness of the ocean, some marine ecological environment cases have transnational characteristics, such as involving certain sensitive sea areas or multinational enterprises (Chen and Bai, 2018), which increases the difficulties in obtaining and fixing evidence (Research Team of Shanghai High People's Court, 2022). As mentioned in the case analysis in section 2.2.4 of this paper, in marine environmental protection cases, the timing of criminal acts and the hidden methods of crime make it difficult to detect the criminal behavior, increasing the difficulty of discovering clues related to polluting the marine environment.

Another aspect that should also be considered is that the harm or damages brought about by marine environmental pollution is relatively concealed. This may make it not only difficult to discover clues but also increases the difficulty of investigation and evidence collection. Taking oil pollution damage as an example, it is one of the main forms of marine ecological environment destruction and the consequences of such damage are quite serious. However, oil pollution damage has the characteristics of potential existence, continuous presence and slow emergence. Typically, after a certain period, the damage only gradually appears due to the combined effects and accumulation of various factors. Therefore, it is challenging to prove the causal relationship between the occurrence of damage and the manifestation of its consequences. Additionally, due to the strong fluidity of marine environment, some evidence of water pollution disappears or becomes concealed. Aquatic products as evidence are not easy to be preserved for a long time, which also brings great difficulties to the collection and fixing of relevant evidence (Wang and Du, 2017). In addition to the inherent characteristics of marine environmental cases, the lack of relevant specialized knowledge of marine environmental protection on the part of the investigators and the lack of necessary and appropriate facilities for evidence collection, may lead to the permanent loss of evidence. In the public interest litigation, the difficulty of investigation and evidence collection is particularly evident. Plaintiffs in such cases cannot legally use force like the police to gather evidence and violators may refuse to cooperate, making it impossible for the plaintiffs to obtain the necessary evidence. The method to collect evidence confirms such difficulty. It is found in a public interest case that the drone was used to capture the photos and videos, which were crucial evidence.[9]

The difficulty in collecting, fixing and identifying evidence in cases involving marine environment also influences the burden of proof of the relevant parties. For example, in the criminal cases, the *Criminal Procedure Law of China* articulates, if the People's Procuratorate finds that the evidence is insufficient and does not meet the conditions for prosecution, a decision not to prosecute shall be made for cases that have undergone two supplementary investigations. If the difficulty in evidence collection results in the difficulty in evidence providing and there is a consequence of insufficient evidence, it may impede to the People's Procuratorate from providing evidence, thereby hindering the investigation of criminal acts (Tang, 2021).

What is more, the allocation of burden of proof in marine environmental civil cases is another challenge that must be considered. China's marine environmental public interest litigation has made remarkable achievements in protecting marine natural resources, protecting the marine ecosystem, as well as preventing marine pollution and ecological destruction (Yang, 2023). At present, although there are relevant judicial provisions for public interest litigation cases concerning marine natural and ecological environment (Zhai, 2024), relevant provisions on the burden of proof for marine environmental civil public interest

9 (2019) Qiong 72 Min Chu No. 227.

10 Article 12 of the *Provisions of the Supreme People's Court on Several Issues concerning the Trial of Cases Involving Disputes over Compensation for Damage to Marine Natural Resources, Ecology and Environment.*

11 (2019) Jin 72 Min Chu No. 57.

litigation have not been issued yet. Therefore, the *Civil Code*, the *Civil Procedure Law* of China and the relevant rules of environmental civil public interest litigation will be applied in such cases. In civil litigation, there are both general rules of proof and special rules for reversed burden of proof, which needs to be further clarified by legislation (Wang, 2019). According to the judicial interpretations issued by the Supreme People's Court, the rule of reversed the burden of proof in private interest litigation is applicable to civil environmental public interest litigation cases.[10] Compared with general environmental public interest litigation, marine environmental public interest litigation has the characteristics of concealment, indirectness, complexity and extensiveness (Li et al., 2015). There are still some problems to be resolved, though the rule of reversed burden of proof can alleviate the burden of proof of the plaintiff and to some extent satisfy the high evidentiary capacity requirements brought by the strong professionalism of marine environmental public interest litigation (Song, 2021). For example, some culturists lacked legal awareness and failed to keep receipts when purchasing aquaculture species seedlings and feeding materials, which led to a lack of clear evidence when filing claims for damages. This is actually a relatively common situation in cases involving marine environmental protection.[11] Besides, in China, cases of natural resource damage have been considered as ordinary torts and are not subject to the rule of reversed burden of proof rule. However, judicial interpretations have regarded damage compensation disputes over marine natural resources and the ecological environment as a special form of environmental civil public interest litigation and allowed the application of the reversed burden of proof rule, which seems to be inappropriate. In addition, the defendants in the marine environmental public interest litigation are often enterprises or units with strong economic power and professional knowledge, which may have easier access to the key evidence such as pollution data and technical information. However, it should not be assumed that all defendants have better evidence to assess the extent and impact of the pollution. It is also difficult for defendants to prove that there is no causal relationship between their conduct and the consequence of the harm, which could put them at a disadvantage in litigation. Therefore, there is still a lack of specific and clear provisions regarding the allocation of the burden of proof in China's marine environmental public interest litigation.

3.4 Lack of effective coordination between judiciary and administrative enforcement

In the modern national governance system, the administration and the judiciary are two vital branches, each bearing different responsibilities and missions, and jointly safeguarding the stability of the country and social justice. The administration branch serves as the representative of national interests, while the judiciary acts as the protector of the rights of the people (Mi and Zhu, 1997). The judiciary can not only provide a supplement to administrative enforcement but also supervise the exercise of administrative power, complementing each other effectively to enhance the governance capacity for the marine ecological environment (Mei, 2020). As a result, the effective coordination and collaboration between judiciary and administrative enforcement plays a key role in the marine environmental protection. However, it is stated that judicial collaboration is still confined to the scope of point-to-point or case-to-case interactions between specific judicial authorities and administrative agencies (Qin, 2021). In light of the increasing severity and complexity of current maritime issues, the effective integration and collaboration between the judiciary and administrative enforcement need to be further strengthened.

In particular, as stipulated in the *Notice of the Ministry of Environmental Protection, the Ministry of Public Security and the Supreme People's Procuratorate on Issuing the Measures for Coordination Work between Administrative Law Enforcement and Criminal Justice in Environmental Protection*, and the *Notice on Issuing the Provisions of the Supreme People's Procuratorate on Promoting the Coordination between Administrative Law Enforcement and Criminal Justice*, when administrative enforcement agencies are investigating marine environmental violations, they shall refer the case to the public security organ, if, based on the evidence collected and the facts of the case ascertained, there is a reasonable suspicion of a crime, and it is necessary for the public security organ to take measures to further obtain evidence to judge whether it meets the thresholds for filing and prosecuting criminal cases. Once receiving a case of suspected crime referred by an administrative enforcement agency, the public security organ shall examine it in accordance with the law. When the People's Procuratorate is performing its legal duties, it should pay attention to check whether there are cases of suspected crimes that administrative enforcement agencies should refer to the public security organs for filing and investigation but have not done. It should be noted that, in most marine environmental violations, the Coast Guard Agency plays the role of the Public Security. However, neither at the national level nor at the local level do the relevant legal regulations explicitly define the timing and manner at which the procuratorate should involve in the coordination of administrative enforcement with criminal justice. In addition, administrative enforcement agencies, coast guard agencies, procuratorates and other departments all established their own information systems but the data sharing among them is still relatively limited. Business flow and data flow between administrative enforcement agencies have not yet been able to interact with or be compatible with the information system of coast guard agencies, procuratorates and courts, and the functions of the relevant system do not work well. This may to some extent results in the phenomenon of "information silos". In practice, the case files and structured data records related to administrative penalties on marine environmental violations are in a "discrete state", scattered across various departments or agencies with marine environmental supervision or management power. This makes them difficult to share (Sun and Kong, 2021). Cases related to marine environmental protection can be attributed into many different categories and the legal rules applied are from various sources, which gives rise to difficulties to automatically identify and find case clues. Plus, there is a lack of uniformity in the criteria to apply substantive law and procedural matters require further refinement, which hinders the efficiency of case referral across

different departments. There may also be prominent issues such as the failure of administrative enforcement agencies for marine environmental protection to refer the cases that should be referred to the coast guard agencies for further investigation and prosecuting pursuant to relevant legal rules, or substituting administrative penalties for criminal punishment (Liu, 2012).

Given the complexities and diversity of the administrative enforcement agencies for marine environmental protection, the situation of coordination between judiciary and administrative enforcement seems to be more serious. On 17 March 2018, the 13th National People's Congress adopted the *Institutional Reform Plan of the State Council* (The Chinese Government, 2018). One important part of this *Institutional Reform Plan* is that the State Oceanic Administration is no longer in existence. To further enhance the governance of marine ecological environment and promote the sustainable development of economy and society in China, the Ministry of Natural Resources was established and the Ministry of Ecology and Environment was restructured. The responsibilities of the former State Oceanic Administration were integrated into the aforementioned two major departments, making their roles and responsibilities more clearly defined (Zhang and Chang, 2022). Moreover, the *MEPL* was revised again in 2023, which further clarifies and strengthen the distinct responsibilities of relevant departments at national and local levels (Liu, 2024). However, there are over a dozen departments or agencies involved in marine environment protection at the central level, including the Ministry of Ecology and Environment, Ministry of Natural Resources, Ministry of Transport, Ministry of Water Resources, the Coast Guard Agency etc. and many branches of these departments at local level. Although there is a relatively clear boundary among their respective responsibilities, given the complexity and difficulty of marine environmental protection cases, this inevitably leads to overlapping powers and gives rise to frictions. There is a possibility that the overlapping jurisdiction may lead to institution rivalry over important and influential cases and to non-action over trivial cases. These frictions may also result in the ineffectiveness and inefficiency of the administrative enforcement and, simultaneously, cause confusion and uncertainties to the parties under investigation. Among the judicial administrative cases in the sample, a very important focus of dispute is whether the administrative enforcement agencies have the specific responsibilities. For example, in a first-instance administrative trial, the plaintiff challenged the defendant, the Qionghai Enforcement Bureau, on whether it possesses the authority to issue the *Administrative Penalty Decision No. 002*.[12] In another second-instance administrative trial, one of the central issues in dispute is whether the appellee, the Maritime Police Qidong Station, has the jurisdiction to investigate the matters pertaining to the sea area in question.[13] As a consequence, the overlapping and unclear responsibilities among so many administrative enforcement agencies for marine environmental protection may aggravate the difficulty of coordinating judiciary and administrative enforcement.

4 Measures to improve the judicial protection of marine environment in China

4.1 The improvement of legal bases to protect the marine environment in China

The oceans are a treasure trove of resources and a strategic space for future development, and marine ecological protection is a systematic project (The Chinese Government, 2024). Marine environmental protection requires the construction of the rule of law for marine, and the improvement of laws and regulations for the protection of the marine ecological environment. Stringent legal systems should be used to consolidate the foundation of marine ecological protection, in order to achieve important goals such as building a strong maritime nation (Gao and Liu, 2024).

On the one hand, the legislative efficiency should be enhanced and the introduction and updating of the complementary provisions to the *MEPL2023* should be accelerated. First, marine environmental pollution and ecological damage are irreversible. To effectively improve marine environmental law enforcement and judiciary, relevant departments should expedite the revision of a series of supporting regulations and standards related to the *MEPL2023*. Provisions that are not in line with the current status of marine environmental protection and current management requirements should also be improved. Second, for regulations that are still in the draft stage for soliciting public opinions, they should be reviewed and formally promulgated as soon as possible to ensure that the entire chain of marine environmental protection can proceed in accordance with the law (Zhang et al., 2024). Third, the judicial system of marine environmental protection is marked by the complexity and variability of environmental situations, the diverse and peculiar nature of environmental violations, and the ever-increasing public demands for environmental quality. It is necessary to establish a dynamic mechanism for the continuous improvement of complementary legal rules to the *MEPL2023*, and evaluate relevant documents regularly. Based on this, these legal documents can be kept continuously adapted to the latest needs of marine environmental protection and possess clear operability (Cao, 2016). Fourth, the marine environment has a broad impact and involves many stakeholders. In the process of formulating and updating the aforementioned supporting regulations, it is important to further strengthen the cooperation among various departments, take into full account all aspects of marine environmental protection and ensure the scientific and comprehensive nature of the regulations.

On the other hand, other marine related laws and regulations such as the criminal legal system should be improved. For example, in response to the dilemma mentioned earlier that the "crime of environmental pollution" has not yet been activated, there is opposition to the establishment of a specific crime for marine

12 (2021) Qiong 72 Xing Chu No. 57.

13 (2022) Su Xing Zhong No. 930.

pollution based on considerations of legislative costs. It is proposed that the relationship between this crime and others should be clarified from the perspective of interpretative theory (The Chinese Government, 2024). However, the existing theories do not agree with the interpretative theory, with more emphasis on advocating for the establishment of a separate crime. As far as judicial practice is concerned, its primary task is to interpret and apply the law (Che, 2023). Even with the relevant judicial interpretations, it is difficult in judicial practice to find an effective breakthrough within the legal provisions of environmental pollution crimes. On this basis, it is suggested that a separate crime be established for behaviors that pollute the marine environment. This would resolve the problem of criminal behavior being left unchecked due to the lack of specific criminal charges and can provide strong judicial protection for the conservation of the marine ecological environment.

4.2 The application of the intelligent trial assistance technology for marine environmental protection cases based on artificial intelligence

As the foundational values in judicial practice, fairness and efficiency have always been of paramount significance. To ensure the efficacy of judicial protection of marine environment, judicial efficiency and judicial fairness should be promoted, which requires a high level of professionalism. One of the effective ways to improve the professionalism of judicial protection will be the application of the intelligent trial assistance technology to shorten trial time, improve trial efficiency, and unify judicial rules.

In 1970, a pivotal publication in the field of law and technology was unveiled by American academics Buchanan and Headrick, "Some Speculation about Artificial Intelligence and Legal Reasoning (Buchanan and Headrick, 1970)" This work served as the progenitor of a new era, heralding a profound inquiry into the synergies between artificial intelligence and the intricate processes of legal reasoning. In China, the wide application of artificial intelligent technologies in court trials has made China's judicial system stand out in the world (Xinhua, 2023). The establishment and refinement of "intelligent courts" in China perfectly reflect the technological approaches to realizing the values of intelligent justice (Liu, 2019). As a cutting-edge analytical instrument in the realm of judicial trial, intelligent justice stands as a formidable aid in the trial. It embodies a series of advanced functionalities designed to augment the efficiency and efficacy of legal proceedings. In the field of judicial protection of marine environment protection, Chinese maritime courts play a crucial role. Modern technological means can be used by maritime courts to improve the informatization level of maritime trials, enhancing trial efficiency and quality. By building information technology infrastructure, the transparency and efficiency of trial work can also be improved and the specialization can be reinforced. The construction of intelligent maritime courts in China has yielded certain accomplishments. For example, the Shanghai Maritime Court, as the "Practice Base for the Construction of An Intelligent Maritime Court (Shanghai) under the Supreme People's Court", released "the Maritime Chain Full-Factor Intelligent Analysis System" in 2023, which integrated maritime judicial and shipping big data analysis for the first time in China, providing new technical means for finding out the facts of a case (Shanghai Maritime Court, 2023). However, the application of intelligent trial assistance technology in the judicial protection of the marine environment is still in its nascent stage and confronts a myriad of challenges, such as the inadequate practical application and issues related to the seamless integration of systems (Liu, 2022). In particular, existing intelligent support tools and technologies cannot adapt to the complexities and unique demands of marine environmental protection cases during the intelligent trial process, such as clarification of liabilities, ascertainment of evidence, evaluation of damages, and the presumption of causal relationships. Therefore, it is imperative to conduct more profound and extensive research into the development of intelligent trial assistance technologies tailored for cases involving marine environmental protection.

To develop and apply intelligent trial assistance technologies for cases pertaining to marine environmental protection, legal benchmarks and logical frameworks for intelligent trial in this domain should be constructed, as well as a knowledge base and knowledge system for such cases. At the same time, it is necessary to integrate advanced technological approaches, including deep learning, natural language processing, and rule-based inference, to digitally model evidence criteria in the case database and build a model for evaluating the credibility of case evidence. The automated generation and verification of document frameworks and content should also be carried out. The theoretical research on the reasoning of intelligent justice is the core to realize the auxiliary function of artificial intelligence in judicial practice. Throughout this endeavor, the research on intelligent trial assistance technology for marine environmental protection cases should focus on addressing the challenges of intelligent verification and assistance in trials involving similar facts, identical legal elements, or legal rules and judicial interpretations. The application of advanced information technologies, such as artificial intelligence and big data analytics, should be maximized, adhering to the guiding principles in the knowledge system of the marine environmental protection cases. This adherence is vital for the exploration and creation of an intelligent trial assistance system that integrates a suite of intelligent methods comprising knowledge extraction, semantic analysis, inferential rules, and risk identification, specifically tailored for the marine environmental protection disputes.

Intelligent trial assistance technologies should be based on sufficient data to guarantee the fairness of the judicial results through scientific algorithms. In the context of artificial intelligence, the realization of uniform judgments for analogous cases is fundamentally predicated on the selective aggregation and integration of data from prior judgments, followed by preprocessing, statistical analysis, and further in-depth mining of the data. The essence of this approach is to refer to precedent cases to guide and constrain subsequent judicial actions, thereby ensuring the legal certainty and consistency even when there is not a perfect alignment between the facts and legal norms. Since 1984, a total of more than 5,000 civil disputes over marine environment have been

settled. Since 2015, the maritime courts have concluded more than 1,000 administrative litigation cases concerning the marine environment, exploring and exercising jurisdiction over criminal cases involving pollution of the marine environment, illegal sand mining at sea, and illegal harvesting of precious and endangered aquatic wildlife (The Chinese Government, 2024). These precedents provide valuable experience and robust data foundation that can guide future endeavors to leverage artificial intelligence technology for the judicial protection of the marine environment. The insights obtained from the precedents will be instrumental in enhancing the efficacy of the intelligent trail assistance technologies, ensuring that they are aligned with the complex realities of environmental litigation and the specific needs of marine protection efforts.

The application of the intelligent trial assistance technology for marine environmental protection cases based on artificial intelligence can facilitate retrieving analogous cases, effectively mitigate unreasonable differences in judicial trial standards of different judicial hierarchy and different geographical jurisdictions, and reasonably constrain discretionary power. Therefore, the professionalism of the judicial protection of marine environment can be considerably improved and the efficacy of judicial protection can also be realized. While, it should be noted that the role of the artificial intelligence technologies is only an assistant to facilitate the judicial trials and it should the human judges that make the final decisions.

4.3 The improvement of the legal rules on evidence and burden of proof

The reasonable allocation of the burden of proof and the provision of evidence are keys to judicial adjudication.

First, given the challenges encountered in the discovery and collection of evidence in marine environmental protection cases, Article 14 of the *Interpretations of the Supreme People's Court on Several Issues concerning the Application of Law in the Conduct of Environmental Civil Public Interest Litigations* stipulates that the People's Court shall investigate and collect the evidence required for the trial of environmental civil public interest litigation cases, if necessary. Therefore, for the public interest litigation with the fundamental purpose of safeguarding social public interests, the facts involved in the litigation are those that may harm the social public interests. The People's Court should take the initiative to investigate and collect such evidence, which may to some extent address the difficulties faced by other parties in investigating and collecting evidence in marine environmental protection cases. That is to say, when necessary, the People's Courts should not simply delegate the task of evidence collection and investigation to the parties involved, while it is obliged to actively ascertain the facts of cases involving public interest. However, it should be noted that although the defendants in such cases are usually large enterprises such as shipping companies that cause marine environmental pollution, it should not be assumed that a party has strong evidentiary capabilities in cases where the parties involved are diverse. The court should aim to uphold the public interest as the ultimate goal, make objective judgments on the evidence provided, and achieve the determination of facts.

In order to facilitate the collection of evidence, technical means can be used, such as drones. When collecting evidence with drones, compliance with relevant legal provisions is necessary. However, the regulations on evidence collection by drones still need to be improved. Article 59 of the *Interim Regulation on the Administration of the Flight of Unmanned Aircraft* stipulates that the relevant departments of the State Council shall separately formulate measures for the administration of airworthiness, registration, operators, and other matters concerning the unmanned aircraft of the police, customs, and emergency management departments. While, no such provisions have been found. In terms of application, the drones should only be used for investigation when other investigation means are relatively exhausted and the objectives are still not achieved or effective evidence cannot be obtained. Simultaneously, the appropriateness of drone investigations should be ensured. The information collected by these devices should be limited solely to content related to law enforcement. Strict procedures and supervision should be provided regarding the storage and browsing rights of videos taken by drones. For example, the captured videos should not be leaked, and only professional enforcers should have access to them. Therefore, relevant laws and regulations should explicitly state that the abuses of the information collected by drones or the improper use for illegal purposes should be severely punished. In addition, a sound complaint and supervision mechanism should be established to enable the public to have convenient and effective channels for appeal when they find privacy infringements.

Second, it is recommended to initiate and improve the social supervision mechanism for marine environmental protection. Through this mechanism, the public can be mobilized to actively discover marine pollutions, which can not only broaden the ways to obtain case clues but also deepen the exploration of case clues (Zhan and Xu, 2020). At the same time, public participation is an important driving force in promoting the implementation of laws in China. Within this mechanism, the public cannot only directly participate in the process of pollution protection of the marine environment but also more clearly understand the status and the degree of the marine environment pollution. This further enhances the awareness of marine environmental protection, making them strong defenders and supervisors of the marine environment (Li, 2019).

Third, while the application of the reversed burden of proof rule in environmental public interest tort litigation does not absolutely increase responsibilities of the defendant to provide evidence, it is a process in which both the plaintiff and the defendant continuously present and refute evidence (Zhang, 2024). The allocation of burden of proof in existing cases related to marine environmental protection remains to be solved. Hainan Province has issued the *Hainan High People's Court on the Trial of Marine Ecological Environment and Natural Resources Dispute Judgment Guidelines (For Trial Implementation) and Typical Cases*. It is pointed out that in marine environmental resources tort cases, the collection, extraction, and fixing of evidence are relatively difficult, and the

recognition of facts is challenging. Where the plaintiff and the public interest litigant provide preliminary evidence to prove that the actor has committed an environmental tort and caused damage, the actor shall bear the burden of proof for the circumstances under which the law stipulates that the actor is not responsible or is mitigated in responsibility, and where there is no causal relationship between the act and the damage. This provision is a specific reflection of the of the reversal of the burden of proof in marine environmental protection cases and provides guidance for clarifying the allocation of the burden of proof. On this basis, the relevant legal provisions should be further clarified, especially taking into full consideration the needs of marine environmental protection and the characteristics of marine environmental public interest litigation. In addition, the principles and specific rules for the allocation of the burden of proof should be detailed, and specific interpretations on the burden of proof can be provided for different types of marine environmental pollutions.

4.4 The improvement of the coordination between judiciary and administrative enforcement

To improve the coordination between judiciary and administrative enforcement in the field of marine environmental protection, effective communication and contact, between judiciary, procuratorates, coast guard agencies and administrative enforcement agencies for marine environment protection, should be actively promoted (Quan and Sheng, 2020). The essence of the coordination between administrative enforcement and criminal justice lies in the following: when the administrative agencies, in the course of investigating illegal activities, identify the amounts, circumstances, or consequences that potentially indicate a criminal offense, they are mandated by law to refer the case to the public security agencies. This will initiate the criminal justice process, which is then carried forward through the "public security organs-people's procuratorate-people's court" sequence, ensuring that potential criminal acts are properly addressed within the judicial system. On this basis, one of the most effective approaches to improve the coordination between judiciary and administrative enforcement is to make full use of modern information technologies to establish seamless data sharing channels among different departments, which should be accompanied by efforts to advance the development and utilization of data, as well as the research and development of intelligent system functionalities.

To address the current issue of limited interoperability and compatibility among cross-departmental information systems, it is essential to further facilitate data sharing channels between various systems. For instance, the functionality for case referral should be developed for the coordination of administrative enforcement and criminal justice within a unified administrative enforcement platform, which can be regarded as a strategic step. This would empower multiple departments, such as administrative enforcement agencies, coast guard agencies, and procuratorates by providing them with a centralized platform for case sharing. First and foremost, it is essential to prioritize and address the issues of low efficiency in offline circulation of case materials, the lack of clarity in the case referral process, and the prolonged delays in responses from relevant authorities. By ensuring that the entire process of case referral is documented and traceable, the efficiency with which various departments handle the referral of criminal cases between administrative and judicial proceedings can be enhanced. Second, in terms of data exploitation and application, the provincial integrated administrative enforcement platform, beyond merely collecting and storing data on administrative enforcement cases, should advance the development of intelligent case management capabilities, such as statistical analysis, trend identification, and predictive alert systems. These tools would enable administrative enforcement agencies to more effectively utilize accumulated case data, discern patterns, detect issues, and preemptively signal potential risks. As a result, the accuracy and efficiency of decision-making by administrative enforcement agencies in dealing with cases can be increased, thereby elevating the collective efficacy of administrative enforcement and the collaborative capacity. Third, the supervision platform for the coordination of administrative enforcement and criminal justice requires the support of intelligent scrutiny and alert mechanisms. These measures can to a great extent facilitate procuratorates to find clues of problematic cases more quickly and intervene at the right time.

Additionally, the improvement of coordination between judiciary and administrative enforcement should be based on strengthening the legal oversight. It is of great importance to optimize the use of the complementary advantages and resources sharing between administrative enforcement and criminal justice and to integrate the enforcement resources. At the same time, it is suggested that the power of oversight of procuratorates should be extended from the judicial phase to each stage of the lifecycle of administrative enforcement cases. This extension is crucial for forming a more effective joint effort to combat issues such as the failure of administrative enforcement agencies for marine environmental protection to refer the cases that should be referred to the coast guard agencies for further investigation and prosecuting pursuant to relevant legal rules, or substituting administrative penalties for criminal punishment. For cases referred by administrative enforcement agencies to coast guard agencies for filing and investigation, procuratorates can also promptly oversee the coast guard agencies to see whether the case is filed or has been delayed, which can improve the convenience and effectiveness of the legal oversight.

In this way, the efficiency of the case referral process can be considerably increased, leading to faster and more effective processing of cases with criminal elements across various departments.

5 Conclusion

The ocean holds significant importance for the survival and development of human society. Though the governance of marine environment in China has made some achievements, as the

proliferation of human activities and the rapid population growth near the coastal area in China, the marine environment is still under great press. Serving as the ultimate bulwark in the protection of marine environmental and the defense of the nation's maritime ecological rights and interests, the judicial protection of marine environment plays a critical role. From the analysis of 2,443 cases related to marine environmental protection, it can be seen that the judicial protection of marine environment has faced great challenges which may impose adverse effects on the efficacy. These challenges include the lack of clarified legal bases to prevent the marine environmental pollution, the lack of professionalism to realize the judicial efficiency and judicial fairness to protect the marine environment, the difficulties to provide evidence and to allocate the burden of proof, and the lack of effective coordination between judiciary and administrative enforcement. Therefore, it is submitted in this paper that the legislative efficiency should be properly increased and an independent crime for marine environmental pollution should be introduced. In addition, it is imperative to conduct more profound and extensive research into the development of intelligent trial assistance technologies tailored for cases involving marine environmental protection. When necessary, the People's Courts are obligated to actively ascertain the facts of cases that involve the public interest. It is also recommended to initiate and improve the social supervision mechanism for marine environmental protection, and to set out specific evidentiary burden provisions for different types of marine environmental pollutions. Finally, modern information technologies should be made full use to facilitate the data sharing channels between various systems of different administrative enforcement agencies for marine environment protection. The functionality for case referral should be developed for the coordination of administrative enforcement and criminal justice within a unified administrative enforcement platform. It is hoped that the proposals made in this paper can to some extent facilitate the judicial protection of the marine environment in China.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

XL: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. SL: Writing – original draft, Formal analysis. YW: Formal analysis, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Buchanan, B. G., and Headrick, T. E. (1970). Some speculation about artificial intelligence and legal reasoning. *Stan. L. Rev.* 23, 1. doi: 10.2307/1227753

Cao, H. (2016). On the straits and reflection of administrative enforcement in environmental protection. *Acad. Explor.* 11, 76–80.

Che, H. (2023). Disputes over the order of legislation and interpretation: Taking the crime of buying abducted women as an example. *Mod. Law Sci.* 45, 2. doi: 10.3969/j.issn.1001-2397.2023.02.13

Chen, H. Z., and Bai, J. H. (2018). The dilemma of determining the qualified plaintiff in the marine environmental civil litigation for public interests under the new situation and its solution. *J. South China Norm. Univ. (Soc. Sci. Edi.)* 2, 162–169.

Chen, S., Pearson, S., Wang, X. H., and Ma, Y. (2017). Public participation in coastal development applications: A comparison between Australia and China. *Ocean Coast. Manage.* 136, 19–28. doi: 10.1016/j.ocecoaman.2016.11.016

Chen, W. (2017). The Chinese experience of judicial system reform. *Chin. J. Law.* 39, 5. doi: 10.3969/j.issn.1008-6676.2017.21.036

Feng, S. (2023). Marine ecological environment governance from the perspective of international law: Model transformation and China's contributions. *Jinan J. (Philos. Soc Sci.).* 45, 12.

Gao, H. (2024). A review of the revision, improvement and application perspective of the Law of the People's Republic of China on the Protection of Marine Environment. *Asia-Pacific Secur. Marit. Aff.* 3, 73–90.

Gao, Z. G., and Liu, Z. H. (2024). Extraterritorial application of China's Marine Environmental Protection Laws: International practices, major issues, and feasible suggestions. *Chin. J. Marit. Law.* 35, 2. doi: 10.3969/j.issn.1003-7659.2024.02.004

Hao, Y. (2023). The doctrinal unfoldment of marine pollution wrongdoing: On the activation of environmental pollution crime. *Ocean Dev. Manage.* 40, 12.

Li, L. F. (2019). Forty years of rule of law in China's marine environment: Development history, practical dilemmas and legal improvements. *J. Zhejiang Ocean Univ. (Humanities Soc Sci. Edi.)* 36, 3.

Li, Y. S., and Yuan, H. X. (2021). Judicial dilemmas and solutions of the "crime of environmental pollution": Centering on the dual legal interests of ecology and humanity. *Hubei Soc Sci.* 1, 141–151.

Li, C., Zhao, Y. H., and Sun, P. Y. (2015). Study on the judicial authentication of marine environmental pollution damage and its evidentiary effect. *Mar. Environ. Sci.* 34, 1.

Liang, H. (2024). Administrative public interest litigation of marine ecology and environment: System generation and practical review. *Seeking Truth.* 51, 1.

Liu, F. (2012). Several problems in the convergence of administrative law enforcement and criminal justice. *J. Natl. Prosecutors Coll.* 20, 1.

Liu, Y. (2019). Theoretical basis and practical development of the modernization of trial system and trial ability in the era of big data. *J. Anhui Univ. (Philos. Soc. Sci. Edi.).* 43, 3.

Liu, Y. (2022). Practical application and prospects of AI technology in the construction of smart court. *J. Comp. Law.* 1, 1–11.

Liu, R. (2024). Revision of China's Marine Environmental Protection Law: History, background and improvement. *Front. Mar. Sci.* 11. doi: 10.3389/fmars.2024.1409772

Liu, Z. Y., Guo, S. H., and Bai, S. W. (2023). Strengthening judicial protection of marine ecological environment (Procuratorate Daily). Available online at: https://newspaper.jcrb.com/2023/20230305/20230305_007/news-zgjcb-10150-20230305-m-007-300.pdf (Accessed August 24, 2024).

Mei, H. (2020). The judicial protection subject of marine environment and its linkage mechanism. *J. Zhejiang Ocean Univ. (Humanities Sci.).* 37, 1.

Mei, H. (2023). The new revision of Marine Environmental Protection Law: Uphold fundamental principles and break new ground. *Environ. Prot.* 51, 21.

Mei, H., and Yin, Y. (2018). The status quo and strategies of trying marine-related environmental cases: A study based on the analysis of 418 cases in the past 18 years. *J. Poyang Lake.* 1, 90–98. doi: 10.3969/j.issn.1674-6848.2018.01.009

Mi, J., and Zhu, L. (1997). *An Introduction to Law* (Beijing: Encyclopedia of China Publishing House).

Miao, Z., and Liu, H. (2023). Review of the newly revised Marine Environmental Protection Law of the People's Republic of China. *Ocean Dev. Manage.* 40, 12.

Ministry of Ecology and Environment (2024a). In 2023, the gross marine product will increase by 6.0%, and the quantity and quality of China's marine economy will increase simultaneously. Available online at: https://www.gov.cn/yaowen/liebiao/202403/content_6940912.htm (Accessed August 23, 2024).

Ministry of Ecology and Environment (2024b). Report on the state of the ecology and environment in China 2023. Available online at: https://www.mee.gov.cn/hjzl/sthjzk/jagb/202405/P020240522601361012621.pdf (Accessed August 23, 2024).

Nie, L., and Zhang, Z. (2022). Empirical analysis of judicial application of Marine Environmental Protection Law. *J. Hebei Univ. Environ. Eng.* 32, 6. doi: 10.13358/j.issn.2096-9309.2022.0620.01

Pan, J. (2022). Rethinking on the legal interests of the "crime of environmental pollution. *Soc Sci. Xinjiang* 5, 103–110.

Qin, T. (2021). Transformation and reconstruction of judicial protection for river basins' environment. *Oriental Law.* 2, 158–167. doi: 10.3969/j.issn.1007-1466.2021.02.012

Quan, Y. (2022). Judicial coordination and relief of cross-regional marine environmental governance. *J. Univ. Chin. Acad. Soc Sci.* 42, 4.

Quan, Y., and Sheng, H. J. (2020). Construction of marine ecology and environment legal system from the perspective of Maritime Community with Shared Future. *Environ. Sustain. Dev.* 45, 2.

Research Team of Shanghai High People's Court (2022). An empirical study on judicial protection of marine ecological environment (I). *Mar. Law Policy* 1, 18–41.

Shanghai Maritime Court (2023). Intelligent shipping, empowered by technology. The full-factor intelligent analysis system for the shipping chain of the Shanghai Maritime Court is officially launched. Available online at: https://www.thepaper.cn/newsDetail_forward_21608206 (Accessed August 23, 2024).

Song, W. (2021). Study on the legal issues of judicial protection of marine environment in Bohai Sea-Taking Bohai Sea pollution cases from 2011 to 2019 as the analysis object. *Tianjin Legal Sci.* 37, 1. doi: 10.3969/j.issn.1674-828X.2021.01.008

Su, L. (2000). *Sending the Law to Countryside* (Beijing: China University of Political Science and Law Press).

Sun, H. (2022). Strengthening judicial protection of the Marine environment to serve the building of a maritime power (People's Court Daily). Available online at: http://society.people.com.cn/n1/2022/0512/c1008-32419914.html (Accessed August 23, 2024).

Sun, Y. H. (2023). Interpretation on the major changes and contents of the revised Marine Environmental Protection Law of 2023. *Environ. Prot.* 51, 21.

Sun, N., and Kong, F. (2021). Research on the early warning mechanism of marine environmental pollution incidents in China. *J. Shanghai Ocean Univ.* 30, 6. doi: 10.12024/jsou.20190602699

Sun, J., and Zhou, L. (2021). China's marine environmental governance in the new normal context. *J. Ocean Univ. China (Soc. Sci.).* 1, 32–39.

Tang, H. B. (2021). Research on legal issues of Marine ecological environment protection. *China Trial.* 17, 92–95.

The Chinese Government (2018). The institutional reform plan of the state council. Available online at: http://www.gov.cn/guowuyuan/2018-03/17/content_5275116.htm (Accessed August 23, 2024).

The Chinese Government (2024). Marine eco-environmental protection in China. Available online at: https://www.gov.cn/zhengce/202407/content_6962503.htm (Accessed August 23, 2024).

The Supreme People's Court (2022). Report on the development of environmental judiciary in China. Available online at: https://www.court.gov.cn/zixun/xiangqing/361301.html (Accessed August 23, 2024).

The Supreme People's Court (2023). The Supreme People's Court announced the main data of judicial trial work from January to September 2023. Available online at: https://www.court.gov.cn/zixun/xiangqing/415692.html (Accessed August 23, 2024).

Tian, G. B. (2019). Review of legislation on "crime of environmental pollution" in China. *Law Rev.* 37, 1.

Wang, X. W. (2019). Rethinking and reconstruction on the allocation of burden of proof in environmental civil public interest litigation in China. *Law Rev.* 37, 2.

Wang, Y. F., and Du, Y. X. (2017). On the issues of evidence in environmental criminal litigation in China. Available online at: https://mp.weixin.qq.com/s/BY3nmPlJ4O51rvj0aTluYA (Accessed August 24, 2024).

Xinhua (2023). "Intelligent courts" highlight of Chinese judiciary: SPC. Available online at: https://www.Chinadaily.com.cn/a/202303/07/WS6406f118a31057c47ebb2d7d.html (Accessed August 23, 2024).

Yang, J. (2012). After the stage fright of "rule of law" – taking the breakthrough of the predicament of environmental governance as the analysis object. *J. China Univ. Geosci. (Soc. Sci. Edi.).* 12, 60.

Yang, C. (2016). Two magic weapons of environmental justice: Specialization of environmental justice and the right of environmental resources. *J. CUPL.* 1, 81–96.

Yang, L. (2023). China's marine environmental public interest litigation: current situation, challenges, and improvement approach-analysis based on 339 cases. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1302190

Yao, L. (2006). Judicial efficiency: Theoretical analysis and system construction. *Stud. Law Business* 3, 94–101.

Zeng, R., Xu, Y., Yang, Y., Wang, X., and Qu, Y. (2018). Current situation and countermeasures of the utilization of marine dumping area in China. *Ocean Dev. Manage.* 35, 1. doi: 10.3969/j.issn.1005-9857.2018.01.007

Zhai, T. (2024). An empirical study of marine environmental civil public-interest litigation in China: Based on 216 cases from 2015 through 2022. *Ocean Coast. Manage.* 253, 107164. doi: 10.1016/j.ocecoaman.2024.107164

Zhan, Y. J., and Xu, Z. R. (2020). Guard the ocean blue with public interest litigation. *Outlook Weekly* 39, 48–49.

Zhang, L. (2021). Judicial construction and legislative improvement of the trial of maritime criminal cases by maritime courts–taking marine environmental crime as the break point. *Chin. J. Marit. Law* 32, 2. doi: 10.3969/j.issn.1003-7659.2021.02.007

Zhang, R. (2024). Burden of proof and allocation rules in environmental public interest tort litigation. *J. South-Central Minzu Univ. (Humanities Soc Sci.).* 44, 3.

Zhang, K., and Chang, Y. C. (2022). Daily penalty system under revision of the Marine Environment Protection Law in China: Review and prospect. *Sustainability* 14, 22. doi: 10.3390/su142214994

Zhang, H., Hu, Z., Shi, R., and Li, Y. (2024). Research on marine dumping management from the perspective of the newly revised Marine Environmental Protection Law of the People's Republic of China. *Environ. Prot.* 52, 59–62.

Zhao, W., and Chen, Y. (2019). Difficult position of criminal accusation of oil spilling in the ocean and its way out. *People's Procuratorial Semimonthly* 11, 37–40.

Zhou, Z., Xia, X., and Ran, R. (2019). Judicial protection, legal service and technology innovation. *Sci. Res. Manage.* 40, 2.

Zhu, J. G. (2016). *China's legal regime for marine environmental protection*. (Beijing: China University of Political Science and Law Press).

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 29 October 2024
DOI 10.3389/fmars.2024.1481635

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Sumedh Lokhande,
Auro University, India
Maruf M,
Dalian Maritime University, China

*CORRESPONDENCE
Shuqing Xu
137886906@qq.com

RECEIVED 16 August 2024
ACCEPTED 01 October 2024
PUBLISHED 29 October 2024

CITATION
Xu S (2024) Environmental legislation analysis improvement approach of global marine plastic pollution from the perspective of holistic system view.
Front. Mar. Sci. 11:1481635.
doi: 10.3389/fmars.2024.1481635

COPYRIGHT
© 2024 Xu. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Environmental legislation analysis improvement approach of global marine plastic pollution from the perspective of holistic system view

Shuqing Xu*

Law School, Hainan University, Hainan, China

Marine plastic pollution (MPP) has posed an unavoidable challenge to the conservation of marine ecosystems, escalating at an unprecedented rate. It extends beyond visible pollution, infiltrating the food chain and microcirculation, ultimately affecting the life and health of marine organisms. Of even greater concern is the fact that MPP has been found to penetrate human bloodstreams. The international community increasingly focuses on MPP, and has formulated a series of laws and regulations. This article analyses marine pollution prevention legislation within the context of international environmental resolutions and conventions, including those established by the United Nations, the European Union law and the domestic legislation of sovereign states. It is evident that the current legislation has played a pivotal role in the preventing MPP. However, global legislation on preventing MPP remains fragmented. The problems existing in the current legislation should be reviewed from the holistic systems perspective, and the integrity and systematicness of new plastics convention should be demonstrated. The proposed Marine Plastics Convention should emphasize environmental justice, protect the rights of vulnerable populations, lower the threshold for risk prevention, and focus on addressing residual risks. It must include clear provisions for regulating hydrosphere plastic pollution (HPP) to mitigate land-based pollution and scientifically define fundamental legal concepts to foster coordinated action among States. Moreover, the convention should establish standardized monitoring methodologies and assessment criteria to ensure accurate evaluation of the pollution status.

KEYWORDS

holistic system view, convention on marine plastics, environmental justice, residual risk, monitoring methodologies, evaluation criteria

1 Introduction

Plastic is a necessity for production and daily life, which highlights its positive attributes. However, plastic also lead to pollution, the general consensus is that plastic pollution should not be brought into the ecological environment that people rely on. On June 23rd, 2014, two reports, "UNEP Year Book 2014" and "Valuing Plastic", released at the first United Nations Environment Assembly, both point out that MPP has caused serious damage to marine ecosystems, such as marine biodiversity and offshore aquaculture (UNEP, 2014; UN, 2014a; UN, 2014b). According to conservative estimates, the economic losses caused by marine plastic waste will reach billions of dollars annually, which is shocking. Data from 24 oceanic expeditions suggested that the total amount of MPP was at a minimum of 5.25 trillion pieces weighing over 250,000 tons (Eriksen et al., 2014). However, more recent estimates based on the Great Pacific Garbage Patch suggest that the amount of plastic may be four to 16 times higher than previous estimates (Lebreton et al., 2018). The amount of plastic predicted to enter the ocean by 2025 is expected to increase by an order of magnitude, assuming a stable rate of pollution and accounting for population growth in coastal cities (Jambeck et al., 2015). Over the past 60 years, the global use of plastic products has shown a continuous upward trend, with plastic production soaring from 2 million tons in 1950 to 348 million tons in 2017, becoming a global industry worth $522.6 billion. It is expected that production capacity will double by 2040 (Wang and Li, 2022; Yang and Ding, 2022). In the three environmental crises that have catastrophic impacts on the Earth, namely pollution, climate change, and biodiversity, excessive production, overuse, and non-standard disposal of plastics have made significant contributions and have become important environmental crisis triggers that cannot be ignored.

The increasingly serious issue is the overproduction, overuse, and non-standard disposal of disposable plastic products. The use of disposable medical plastic products in medical protection facilities and equipment (such as masks, cotton swabs, test papers, protective clothing, etc.), especially since the global COVID-19 pandemic, has increased the production and use of disposable plastic products.

The environmental crisis caused by micro-plastics is more considered, but people's understanding of the pollution caused by plastics, especially micro-plastics, is not deep enough. It is a type of micro-plastic pollution with a diameter less than 5 millimeters, characterized by solidity, insolubility, and difficulty in degradation (Zheng and Chen, 2022). More than 70% of the surveyed subjects still hold a negative answer regarding whether they are concerned about the presence of plastic micro-beads in the skincare cosmetics they purchase, and whether they are aware of the harmful effects of plastic micro-beads on the environment (Zheng and Chen, 2022). Micro-plastics mainly come from two sources: primary and secondary. The first type is the original source represented by daily chemical products, such as shampoo, toothpaste, etc.; The second method is to use household garbage bags, beverage bottles, etc. (Conkle et al., 2018). Scientific research has confirmed that micro-plastics, based on ecological cycles, enter the bodies of animals and plants through the marine and terrestrial food chains and pose potential hazards to biological functions (Li J. et al., 2016). For example, if people consume seafood such as fish containing micro-plastics, they can also enter the human body through the food chain, posing potential threats to their health. Several media outlets (People's Daily, 2018), including CNN in the United States and The Guardian in the United Kingdom, reported that at the 2018 European Society of Gastroenterology Gastroenterology Academic Conference, Philipp Schwab and others from the Medical University of Vienna in Austria, reported the first discovery of micro-plastics in human fecal samples, which has attracted public attention. Therefore, "The presence and accumulation of plastic and micro-plastic debris in the natural environment is of increasing concern and has become the focus of attention for many researchers" (Karbalaeis et al., 2018).

It is commendable that most countries globally have recognized the severity of plastic pollution affecting the marine environment and have started to legislate both domestically and internationally to address it. For instance, in October 2015, the United Nations General Assembly adopted the 2030 Agenda for Sustainable Development, which addresses ocean plastics in Articles 6, 11, 12, and 14. The Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter has also played a pivotal role in combating MPP. The European Union, through the EU Waste Framework Directive, has established regulations regarding the sources, control measures, and waste management of plastic pollution. In December 2015, the United States passed the Microbead-Free Waters Act, becoming the first country to ban plastic microbeads in cosmetic products (Zhang et al., 2019). In China, specific legal guidance on managing household waste, including plastic waste, is provided through the Solid Waste Pollution Prevention and Control Law. Additionally, China's Marine Environmental Protection Law (2017 Amendment) emphasizes the strict prohibition of dumping any waste, including foreign waste, into Chinese waters (NPC Standing Committee, 2017).

While the aforementioned legislation has made significant contributions to preventing MPP, merely referencing it in a United Nations resolution or addressing it through specific laws represents a fragmented legislative approach that fails to fulfill the systemic function of comprehensive regulation. Therefore, this article seeks to emphasize the need for holistic prevention measures and systematic legal frameworks in the forthcoming global, legally binding instrument aimed at ending MPP. This growing demand for international legal instrument to combat global MPP underscores the urgency of coordinated global action.

Based on this background, the article underscores the importance of adopting a holistic systems approach to analyze the primary legislation aimed at preventing MPP. It provides a comprehensive review of the legislation addressing the three main types of MPP, aiming to enhance understanding of the current regulatory landscape. Additionally, from a systematic perspective, a detailed examination of the legislation for each type of MPP is essential to the overall analysis and ensure a more cohesive legal framework. The strength of the holistic systems approach lies in its comprehensive and systematic perspective. After examining three main types of legal texts, the article identifies four key practical

challenges. First, legislation must fully articulate the recognition of environmental risks. Currently, the understanding of these risks primarily derives from scientific research, which, despite its advancements, has inherent limitations. Second, fundamental legal concepts need to be reevaluated. The delineation of legal concepts directly influences legislative decisions regarding pollution control, including when and how to take action. Third, current enforcement mechanisms do not encompass the entire lifecycle of plastics. Effectively addressing plastic pollution, particularly micro-plastic pollution, necessitating improvements in enforcement mechanisms. Fourth, the lack of uniformity in monitoring methods and assessment standards is a significant issue. This discrepancy not only affects the thorough assessment of MPP but also influences international attitudes and actions toward prevention.

The article initially examines the impact of plastics on marine ecosystems, and then provides a brief review of legislative texts related to the three major categories of MPP prevention. It comprehensively discusses the current issues within the legislation and concludes with specific recommendations for the forthcoming global legally binding instrument aimed at ending MPP.

2 Materials, methods, and analytical frameworks

This paper categorizes the relevant legislation aimed at preventing MPP into three distinct types based on their geographical scope of application. The first category is international environmental resolutions and conventions under the framework of the United Nations. The second category is European Union law, which exhibits a supranational and complex nature, reflecting characteristics of both international and federal law. Thus, the paper classifies it as a unique form of regional international convention. Finally, The third category is the domestic legislation of sovereign states. From the adoption of the London Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Substances by IMO in December 1972 to UNEA-5.2 in February 2022—which aims at establish legally binding measures to combat plastic pollution, the United Nations has played a pivotal role in advancing MPP control over five decades. At the same time, significant contributions have emerged from domestic legislations in major countries such as the United States and China, addressing the regulatory management of land-based activities that contribute to marine pollution. Therefore, both international and domestic legal frameworks are crucial for this study's analysis. In addition to examining these legislative frameworks, this paper undertook a comprehensive review of relevant literature on "MPP" sourced from databases including CNKI, HeinOnline, and Science Direct; thereby laying a solid foundation for its literature review.

The primary methodology employed in this study is legal dogmatics, a normative science that assumes an unwavering commitment to the prevailing legal order as its foundational premise, from which it engages in systematic and interpretative endeavors. Its core activities include the description of existing laws, exploration of the conceptual legal framework underpinning these statutes, and formulation of recommendations to address complex issues (normative practice). MPP distinguishes itself from conventional environmental pollution by impacting not only coastal nations but also non-coastal states through ecological processes such as ocean currents and food chains. Therefore, a thorough examination of legislation related to MPP is crucial. The analysis of literature must be integrated with existing research findings; it should undergo topological analysis to sharpen the research focus and promote innovative developments.

The theoretical framework of this study is based on a novel approach known as the holistic system view. This comprehensive perspective incorporates the cultural concept of "unity of heaven and man" from Chinese classical thought, as well as the epistemological principles of holism found in Western classical philosophy (Qin, 2022a). The holistic system view underscores both integrity and systematicity (Qin, 2022b), calling for an approach that prioritizes wholeness and interconnectedness when analyzing phenomena. It reminds observers of the need to maintain a holistic and systematic viewpoint in order to mitigate potential biases that may arise from focusing on singular viewpoints. Wholeness refers to a comprehensive understanding that considers all dimensions of an entity, examining whether it consists of distinct components or exhibits characteristics of being a unified "whole". Systematicity, on the other hand, highlights the objective laws governing interactions among various elements within entities and delineates the hierarchical logical frameworks established by these components. It stresses whether the importance of each part functioning according to its intrinsic laws and whether their coordinated functioning yields synergistic outcomes where 1 + 1>2. In this context, wholeness represents an essential attribute demanded by the holistic system view, while systematicity emerges is the desired goal aimed at achieving synergies through interrelations between diverse elements.

This study adopts a whole system view analysis framework for two primary reasons. Firstly, extant global legislation aimed at preventing MPP is notably fragmented, with references to this issue often scattered across various resolutions and conventions, lacking a unified approach. Given the urgent need to address MPP comprehensively, it becomes challenging to capture the integrity of such legislation. Thus, examining current laws from a holistic perspective provides valuable insights into their coherence and overall effectiveness. Secondly, The article does not necessarily advocate for a specific legislative model, but the current global legislation to prevent MPP is fragmented, which has compromised the systematic function of the law and cannot achieve the desired synergistic effect of 1 + 1>2. The fundamental principle behind effective legislation lies its capacity to deter polluters through systemic social effects, as law functions as an organized mechanism of social control. Consequently, legislators should prioritize 'systematicness' when crafting laws. Therefore, this methodology is employed as a theoretical framework for analyzing extant legislation on global MPP. It suggests that future international legally binding documents should focus on enhancing both systematization and coherence while mitigating the fragmentation present in current legal frameworks.

3 Review: an overview of the current global legislative framework aimed at mitigating MPP

This paper conducts a legal doctrinal analysis of the international environmental resolutions and conventions under the framework of the United Nations, the law of the European Union and the domestic legislation of sovereign states. It is essential to note that while the subsequent investigations are conducted independently, they are not isolated; instead, they are interconnected. This interrelationship highlights the synergy between the application of international treaties and domestic law, which together from the legal foundation for combating MPP. As a result, an integrated systems perspective is necessary.

3.1 International environmental resolutions and international environmental conventions under the framework of the United Nations

3.1.1 International environmental resolutions

The prevention of MPP is primarily addressed through various governance measures established by relevant international conventions under the United Nations. This process is largely facilitated by the collaborative efforts of UN member states and international non-governmental organizations, alongside the gradual execution and enforcement of initiatives from United Nations bodies or specialized agencies.

A range of negative externalities resulting from the Industrial Revolution, including the rapid degradation of ecological systems, accelerated population growth, and the sudden depletion of resources, has compelled nations to reevaluate strategies for humanity's survival and development. It is within this context that the 2030 Agenda for Sustainable Development has been advanced. Indeed, since the 1990s, the United Nations has undertaken the formulation of a series of objectives and initiatives aimed at promoting global sustainable development (Pei, 2018). From Agenda 21 in 1992 to the Millennium Development Goals established in 2000, through multiple negotiation rounds held in Rio de Janeiro in 2012, culminating with the adoption of the 2030 Agenda for Sustainable Development during the 70th session of the United Nations General Assembly in 2015, the overarching objective remains sustainability. This document has been described as a robust framework for universal action aimed at eradicating poverty and protecting our planet (Carpentiera and Braun, 2020). In the pursuit of enhancing the ecological environment through scientific and technological advancements, the resolution adopted during the 71st session of the United Nations General Assembly in 2017 marked a significant milestone by addressing MPP for the first time. This resolution, titled "Our Oceans Our Future: A Call to Action," was highlighted by Fiji's representative, Mr. Daunivalu, who characterized it as a pivotal outcome of the United Nations High-Level Conference on Oceans (UNGA, 2017). From February 2014 to February 2022, the United Nations Environment Program adopted five distinct resolutions addressing marine litter and micro-plastics. Figure 1 lists keywords for the main issues that each resolution addresses. The adoption of these resolutions establishes a crucial policy framework and action plan for tackling issues related to marine plastic waste and micro-plastics. Resolution I/6 on Marine Plastic Debris and Micro-plastics (UNEP, 2016a) underscores the precautionary principle while concentrating on the sources, characteristics, and impacts of micro-plastics. II/11 Marine plastic litter, and micro-plastics (UNEP, 2016b) emphasizes effective management and waste prevention strategies, acknowledging that surface runoff, rivers, and sewage outfalls are significant pathways through which waste is transferred from land to sea. In Resolution III/7 on Marine Litter and Micro-plastics (UNEP, 2016c), priority is given to developing policies and measures at appropriate levels based on the best available knowledge; this includes specific initiatives such as

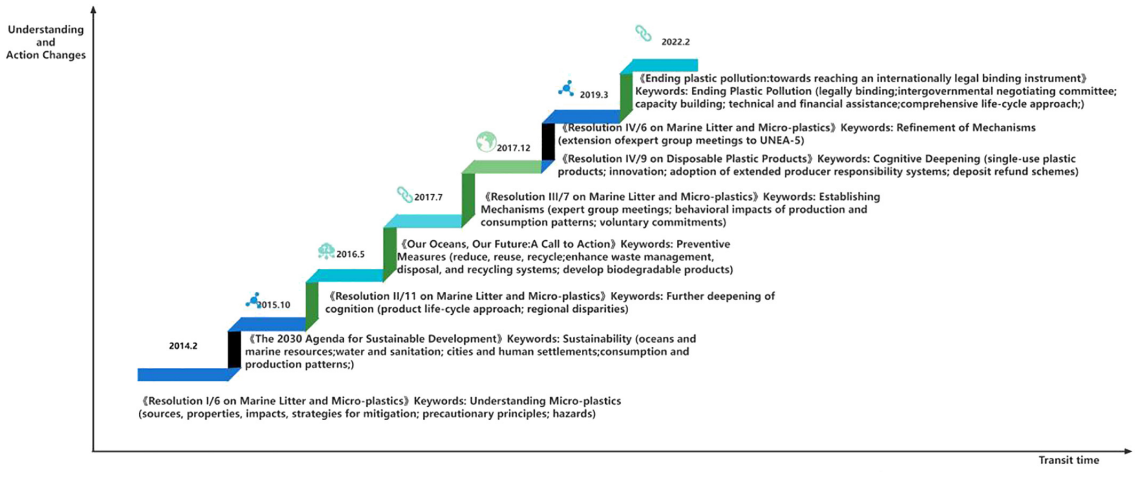


FIGURE 1
Legislative Development of Preventing Plastic Pollution within International Environmental Conventions under the United Nations Framework.

establishing harmonized definitions along with standardized monitoring protocols, as well as enhancing collection efficiency and recycling rates for plastic waste. It also calls for convening an *ad hoc* open-ended expert group meeting to examine barriers to managing marine plastic litter from all sources, particularly those originating from land-based activities. IV/6Marine plastic litter and micro-plastics (UNEP, 2016d) highlights the urgent need to strengthen collaboration between science and policy, promote global coordination in governance, and reiterates the importance of harmonizing testing methodologies and evaluation techniques while introducing life cycle considerations for the first time. Finally, IV/9Marine plastic litter and micro-plastics (UNEP, 2016e) focuses specifically on single-use plastic products by advocating restrictions or prohibitions on their production and sale while encouraging reductions in usage or exploring alternative biodegradable options. In February 2022, Section V of the United Nations Environment Assembly adopted the resolution titled "Ending Plastic Pollution: Towards an International Legally Binding Instrument". This resolution signifies a pivotal transition for nations from mere political declarations to a formal legal framework. It is therefore not surprising that Inger Anderson, Executive Director of the United Nations Environment Program, described the new plastics treaty as the most significant multilateral international agreement since the Paris Agreement (Wang, 2024).

Since the adoption of UNEA-5.2 on "Ending Plastic Pollution: Developing a Legally Binding International Instrument" in March 2022, the intergovernmental negotiating committee's consultations have been proceeding in an orderly manner. After two rounds of negotiations in November 2022 and May 2023, a document called Zero Draft Text of the international legally binding instrument on plastic pollution was formed, including in the marine environment (Zero Draft Text) (UNEP/PP/INC.3/4, 2023); In November 2023, the Zero Draft was revised at the third meeting of the intergovernmental negotiating committee, forming the Revised Draft Text of the international legally binding instrument on plastic pollution, including in the marine environment (Revised Draft Text) (UNEP/PP/INC.4/3, 2024). The Revised Zero Draft Text consists of six parts as a whole: Part One is covered with the Program, including the preamble, objectives, term definitions, principles and application scope; Part Two is the main body of the treaty, including the just transition route, the control method of plastic chemicals and other specific control measures; Party Three refers to financing, capacity building and technology transfer. Party Four deals with national action or implementation plans, implementation and compliance, progress reports and others. Part Five contains the governing bodies and subsidiary bodies of the future treaty and its secretariat; Part Six includes any possible annex to the document.

From the Revised Zero Draft Text, it can be seen that the Revised Zero Draft Text proposes four mechanisms to address the problem of MPP. First, the extended producer responsibility system. The second part of the draft uses 13 summaries for detailed regulations, with the aim of covering the entire lifecycle of plastic products. Second, a common but differentiated international cooperation mechanism. In the fourth part of the draft of the National Action Implementation Plans, it is particularly emphasized to increase the content of action plans based on the capabilities of each country, while also emphasizing that existing relevant data and legislation in each country are prerequisites for action plans, with the aim of taking into account the national conditions of developing countries. Thirdly, a regular reporting mechanism. The fourth part of the draft stipulates provisions on compliance and implementation, progress reporting, regular evaluation, information exchange, etc. Its purpose is to share relevant information and carry out international cooperation. Fourth, safeguard mechanism. The third part of the draft stipulates safeguard provisions such as financing, capacity building, and technology transfer, with the aim of ensuring the implementation of the new plastic convention.

The Revised Zero Draft Text also provides specific regulations for the implementation and compliance of the new Plastics Convention. The second section of Part Four of the Revised Zero Draft Text also states Implementation and compliance specially and offers three alternatives. The first option is to establish a review mechanism (including a committee) as a subsidiary body of the governing body to promote the implementation and compliance of the convention. The nature of this committee is facilitative non-punitive, non-adversarial,expert-based, It should not be used as a mechanism for enforcing or resolving disputes, nor should punishment or sanctions be imposed, and national sovereignty should be respected. The committee can also consider and provide flexibility to developing country contracting parties based on their capabilities. In addition, the plan also provides detailed regulations on the composition of the committee, election of new members, and rules of procedure. The second option is the Bracket entitlement provision. The third option is also to suggest establishing a review mechanism (including a committee). The committee is convenient in nature and operates in a transparent, non confrontational, and non punitive manner.

Figure 1 not only illustrates the keywords of each resolution, but also lists the time when the resolution was passed. Based on the specific content and time of the resolution, the author summarizes three points: First, in terms of timing, the 2030 Agenda for Sustainable Development, adopted at the 70th session of the United Nations General Assembly in 2015, addressed the sustainable development of oceans. However, this does not imply that nations were previously unaware of the dangers of MPP, particularly micro-plastics. As early as 2004, British scholar Richard Thompson introduced the concept of "Micro-plastics", noting that their levels in the ocean significantly increased from the 1960s to the 1990s, posing potential hazards when ingested by marine life. Secondly, awareness is continually evolving. This evolution is primarily manifested in: (1) progressing from conceptual understanding to practical actions and measures. As an example, the shift from individual and national-level scholarly awareness to the subsequent adoption of written resolutions by the United Nations General Assembly. (2) Preventive measures are continuously being refined. For instance, the 2017 United Nations General Assembly's "Our Oceans, Our Future: A Call to Action" emphasized a three-pronged approach of reduction, reuse, and recycling. This strategy includes market-based waste reduction strategies, enhancing eco-friendly waste management, disposal, and recycling systems, and developing substitutes like reusable or

recyclable products or naturally biodegradable items. In relation to disposable plastic products, there's an emphasis on continuous innovation, implementing extended producer responsibility systems, and establishing deposit refund schemes. (3) The focus has shift from plastic pollution to micro-plastic pollution, with a subsequent strong focus on micro-plastics. This shift began with the first United Nations Environment Assembly (UNEA-1) in 2014, Resolution I/6 addressed marine litter and micro-plastics, followed by subsequent resolutions at UNEA-2, UNEA-3, UNEA-4—II/11, III/7, IV/6, and IV/9 on marine litter and micro-plastics, respectively, and disposable plastic products. This underscores the global recognition of the severity of micro-plastic ocean pollution. (4) The development of internationally legally binding instruments. This marks a landmark acknowledgment of marine plastic and micro-plastic pollution. Clearly, governments worldwide now recognize not only the severe risks to water hygiene and the marine environment from MPP but also the potential for marine micro-plastic pollution to enter the human body via ecological cycles such as ocean currents and food chains, thereby presenting significant threats to human health. Consequently, we must resolve to establish an internationally legally binding instrument to bring an end to MPP. Thirdly, the international community has progressively developed a robust framework for implementation. To more effectively examine the barriers and alternatives for managing marine plastic and micro-plastic waste from all sources, especially from land-based ones, the Third United Nations Environment Assembly (UNEA-3) established an open-ended *ad hoc* expert group on marine litter and micro-plastics. In response to the expert group's valuable findings, particularly the need to bolster integration, coordination, and synergies among current mechanisms, the Resolution IV/6 on Marine Litter and Micro-plastics extends the expert group's mandate through UNEA-5 to strengthen cooperation and governance and more effectively tackle the challenges posed by marine litter and micro-plastics at local, national, regional, and global levels (Figure 1). Additionally, the resolution decided to establish a multi-stakeholder platform within the United Nations Environment Program to enhance coordination and cooperation, aiming to promptly implement a life-cycle approach to eradicate the long-term discharge of garbage and micro-plastics into the ocean.

3.1.2 International environmental conventions

The prevailing consensus is that, through years of practice, countries have come to recognize that concerted actions, the exercise of national jurisdictions, and engaging in normative institutional cooperation are essential for addressing the externality of environmental issues. The voluntary participation and equal consultation among nations, culminating in legally binding international multilateral treaties, positively contribute to preventing the rapid escalation and devastation of MPP. These efforts also serve as exemplary and guiding forces in global environmental protection.

The extant international environmental conventions pertinent to the prevention of MPP encompass the Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Substances, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, and the Stockholm Convention on Persistent Organic Pollutants.

3.1.2.1 Convention on the prevention of marine pollution by dumping wastes and other substances

As our understanding deepens, nations have increasingly recognized the significance of the marine environment for human survival and development, as well as the detrimental impact of waste discharging into the sea on marine ecosystems. In response, the Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Substances was established. This is one of the 21 international conventions and agreements established by the International Maritime Organization (IMO) aimed at addressing the intentional, negligent, or accidental release of hazardous substances from ships, as well as striving for the complete elimination of intentional pollution in the marine environment (IMO, 1973).The Convention encompasses the definition and scope of,the licensing and regulation of , a comprehensive list of substances prohibited from being dumped into, and the legal liabilities associated with. Consequently, many have regarded Annex V of the MARPOL Convention as a potential solution to the issue of MPP (Maheim and Bruce, 1988). In fact, it is also true that Article 4 (1) (a) and Article 5 (2) of the Convention, as well as the provisions on fishing nets and ropes in Annex I, have played an important role in preventing MPP (Figure 2). The MARPOL Convention and its annexes are applicable solely to pollution originating from vessels at sea. Consequently, the Convention is ill-equipped to address land-based sources of plastic debris, including plastics that enter the ocean via municipal sewage outfalls (Maheim and Bruce, 1988).

The criteria for evaluating wastes or other substances that may be eligible for dumping, as outlined in Annex II of the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Substances, are recognized to involve environmental risks that may surpass current scientific understanding. These criteria may be reassessed in the future if new uncertainties regarding these risks arise.

3.1.2.2 Basel convention on the control of transboundary movements of hazardous wastes and their disposal

In the 1980s, it became increasingly evident that industrialized nations were transferring hazardous waste to developing countries through various means. In March 1989, the United Nations Environment Program adopted the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal. This Convention aims to regulate transnational trade in plastic waste and promote environmentally sound disposal practices. It serves as a robust legal framework for the recovery or treatment of imported and exported hazardous wastes (Gonzalo, 1994). The Convention has significantly contributed to mitigating the ecological damage caused by hazardous wastes through their safe treatment and the regulation of transboundary movements (Iwona Rummel-Bulska, 1994). For example, the clear listing of "hazardous waste" in Article 1 (1) (a) and the definition of "waste" in Article 2 of the Convention provide a basic legal basis for identifying "hazardous waste" and

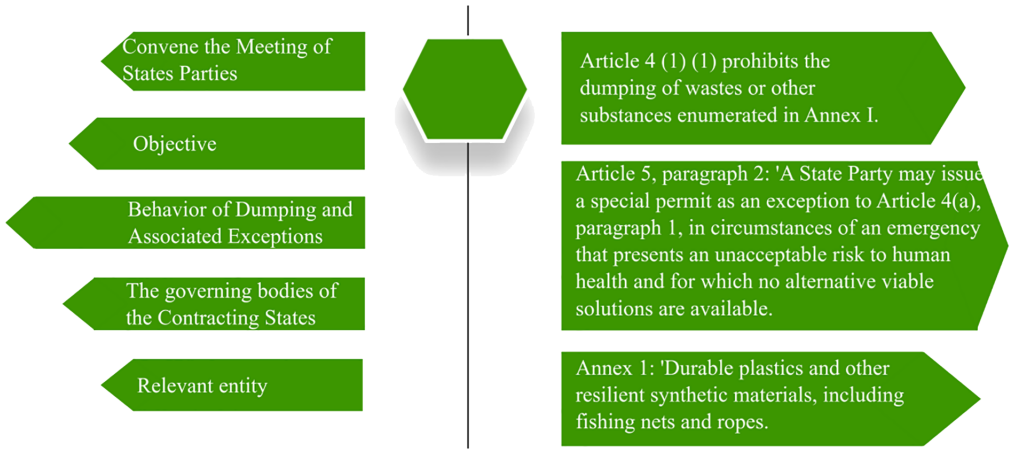


FIGURE 2
The primary stipulations of the Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Substances pertain specifically to plastics.

"waste" related to plastics (Figure 3). In addition, Annex I of the Convention lists many plastic related wastes, which are crucial for limiting the illegal transfer of plastic waste, reducing the degree of environmental injustice, and protecting the "right of everyone to be free from pollution" (Table 1). Nevertheless, the Convention exhibits certain limitations; for instance, the regulatory standards outlined in the amendment to the Basel Convention lack comprehensiveness, making it challenging to quantify indicators and targets aimed at reducing plastic waste production or trade (Liu, 2020). For instance, while the revised Convention delineates concepts such as 'waste', it fails to define the terms 'plastics' or 'micro-plastics', presenting a legal impediment for nations seeking to implement effective measures against MPP.

It is important to note that the Fourteenth Meeting of the Parties to the Basel Convention has revised Annexes II, VIII, and IX of the Convention. Specifically, Annex II introduces a new entry, Y48, related to plastic waste provisions. Annex VIII has added a new entry, A3210, addressing plastic waste, while Annex IX introduces a new entry, B3011, which explicitly specifies plastic raw material polymers such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), among others.

3.1.2.3 Stockholm convention on persistent organic pollutants

Adopted by the United Nations Environment Program in May 2001, the Stockholm Convention on Persistent Organic Pollutants aims to mitigate or eliminate emissions and releases of persistent organic pollutants, with a particular emphasis on micro-plastics and additives in plastics. The Convention strives to protect human

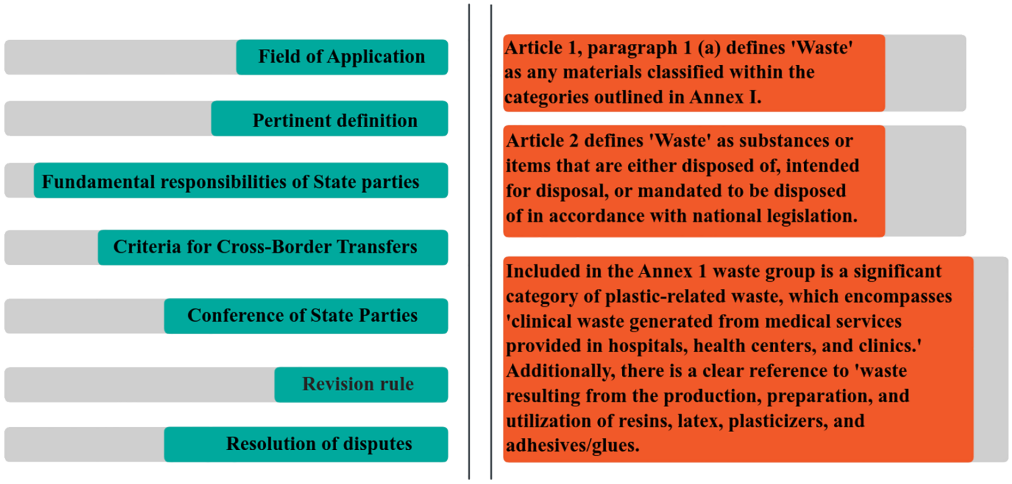


FIGURE 3
The principal stipulations of the Basel Convention concerning the regulation of transboundary movements of hazardous wastes and their disposal are pertinent to plastics.

TABLE 1 Environmental Justice Framework.

Terms	Basics
·Right to protection	Everyone has the right to be free from environmental pollution
·Prevention	Take measures to prevent pollution and eliminate environmental hazards in their early stages
·Inverted burden of proof	Allocate the burden of proof to the infringer, rather than following the traditional principle of who asserts and provides evidence
·Obviating proof of intention	Different data should be allowed to overturn the original qualitative analysis
·Correcting Injustice	From the perspective of pollution hazards, by coordinating resources and taking action to address the most severely polluted areas

health from the dangers associated with plastic products. Comprising 30 articles and two annexes, it marks a significant milestone in international law and has been played a crucial role in advancing global environmental protection efforts (Paul and Michael, 2005). It is also considered a significant milestone in the management of global chemical substances (Sellar and Abdel-Qader, 2021). Since its implementation over two decades ago, 23 chemicals have been added in its annexes. For example, in Annex A, Annex B, and Annex C of the Convention, there are many regulated polymer raw materials related to plastics (Figure 4), which can have adverse effects on the body's blood and respiratory systems. However, the Convention has faced several challenges, including a slow update process for the list of chemical substances (Blicke, 2002),and the ratification process remains notably complex (Mintz, 2001).

While the aforementioned three conventions have significantly contributed to mitigating MPP in recent years, their primary objective is not to directly address the global plastic pollution crisis. Furthermore, there remains a notable absence of international agreements aimed at systematically tackling this issue.

By organizing the texts of the three conventions mentioned above, the author examined them from the perspective of time dimension and content regulations (Table 2), and believes that there are three points worth affirming: firstly, the international environmental conventions mentioned above all have legal binding force. This indicates that the international community has recognized the necessity to establish legally binding international environmental conventions to combat MPP, emphasizing that mere publicity and appeals are insufficient. A convention can only be effectively enforced if it is legally binding among the contracting parties. Second, when examining changes over time, the author observes a tightening of international regulations concerning plastic hazardous waste. This is evident from the initial, more general prohibitions on the dumping of hazardous plastic waste, such as the 1972 London Convention's ban on the dumping of "durable plastics and other persistent synthetic materials" as waste or other substances, to the subsequent refinement of these prohibitions through specific listings. For example, Annex I of the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter imposes stricter regulations on substances allowed for dumping, explicitly outlining the permissible waste through a detailed list. Plastic boxes and microplastics are not included in this list, thus prohibiting their dumping. Third, an examination of the specificity in regulations regarding plastic pollution reveals that the international community's provisions on MPP are becoming progressively more detailed. This is evident in the Basel Convention, which broadens its controlled scope to encompass the vast majority of plastic waste, including non-recyclable and contaminated types, as outlined in Annexes II and VIII. The inclusion of a limited amount of pure plastic waste in Annex IX has heightened the requirement for environmentally responsible recycling. The annexes offer comprehensive specifications for plastic wastes, including mixtures such as PE, PP,

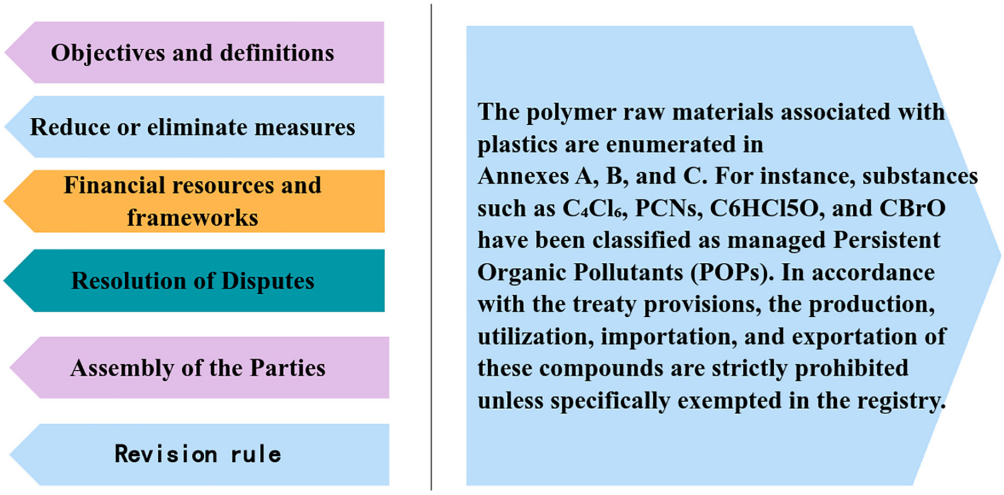


FIGURE 4
The primary stipulations of the Stockholm Convention on Persistent Organic Pollutants pertain to plastics.

TABLE 2 The legislative process in international environmental conventions on the prevention of MPP.

passing time	International Organization	Agreements	Focus
1972.12	International Maritime Organization	Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter (1972 London Convention)	Durable plastics and other durable synthetic materials are included in the list of waste or other substances that should be prohibited from dumping
1989.3	United Nations Environment Program	Basel Convention on the Control of Trans-boundary Movements of Hazardous Wastes and their Disposal	Waste generated from metal and plastic surfaces is a category of waste that should be controlled.
1996.11	International Maritime Organization	1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter Basel Convention	Annex I of the protocol specifies the types of waste that can be dumped in a specific manner, and plastic boxes and micro-plastics are not included in the list.
2019.5	United Nations Environment Program	Basel Convention on the Control of Trans-boundary Movements of Hazardous Wastes and their Disposal Amendments to Annex 2, Annex 8, and Annex 9	Annex 2 and Annex 9 provide detailed regulations on plastic waste.
2023.10	United Nations Environment Program	Stockholm Convention on Persistent Organic Pollutants	This marks the emergence of specialized control measures for plastic waste through the governance of international law.

or polyethylene terephthalate (PET) plastic waste. Likewise, the more significant Stockholm Convention on Persistent Organic Pollutants has introduced specific regulations for plastic waste through international legal mechanisms.

3.2 Legislative frameworks and policy initiatives within the European Union

In 2019, the EU produced generated an estimated 53 million metric tons of plastic waste. Over the coming decades, this amount is projected to grow, doubling by 2060 to exceed 100 million metric tons annually (Bruna, 2024). To tackle this global pollution issue, the EU has implemented various policies, directives, and laws to combat plastic pollution. The Eu's legislative approach to MPP is primarily divided into regulations targeting both land-based and water source pollution. The author lists the main legislation on preventing plastic pollution in EU law and will analyze it in the following sections (Table 3).

TABLE 3 The main legislation of the European Union on preventing plastic pollution.

passing time	Name of the Bill
2000.11	On port reception facilities for ship-generated waste and cargo residues(2000/59/EC)
2004.2	On packaging and packaging waste - Statement by the Council, the Commission and the European Parliament (2004/12/EC)
2006.12	Regarding the registration, evaluation, licensing, and restriction system for chemicals(REACH, 2006/1907EC)
2008.6	EU Marine Strategy Framework Directive
2008.12	EU Waste Framework Directive(2008/98/EC)
2009.5	Simplifying terms and conditions of transfers of defense-related products within the Community(2009/43/EC)
2009.11	Establishing a Community control system for ensuring compliance with the rules of the common fisheries policy(1224/2009)
2015.4	Amending Directive 94/62/EC as regards reducing the consumption of lightweight plastic carrier bags (2015/720)
2018.1	Plastic Strategy in the Circular Economy
2019.6	On the reduction of the impact of certain plastic products on the environment(2019/904)

The control of land-based pollution is primarily embodied in the regulations for solid plastic waste. In 2018, the EU initiated a revision of regional laws on solid waste, aiming to decrease ocean-bound plastic waste through recycling and reuse. For instance, the EU Waste Framework Directive mandates member states to identify the sources of plastic waste within their territories, establish effective measures to reduce it, and ensure its proper cleaning and collection. Regarding micro-plastic pollution, the EU issued Directive 2004/12/EC on packaging and packaging waste in 2004, setting specific recycling goals for plastic packaging waste. In 2015, the European Union revised the directive and substituted it with Directive 2015/720. The directive further details specific recycling targets for plastic packaging waste, ensuring that the annual consumption of plastic bags per person does not exceed 90 by 2019 and 40 by 2025, with a reduction of 50% by 2019 and 80% by 2025 compared to 2010. In 2015, the European Cosmetics and Personal Skincare Association recommended phasing out the use of plastic frosted micro-beads on cosmetics by 2020 (Cosmetics Europe, 2015). This directly prompted the revision of the six detergent product group standards in the EU echo-label, which incorporated the association's recommendation to ban plastic frosted micro-beads. Additionally, several EU member states have also addressed micro-plastic pollution through legislative measures. For instance, in 2014, five member states—Austria, Belgium, Sweden, the Netherlands, and Luxembourg, jointly declared a ban on the use of plastic micro-beads within the European Union. This

declaration inspired other countries to follow suit. Currently, the European Union is considering the use of the REACH directive to impose the intentional addition of micro-plastics in certain chemicals (European Commission, 2018). In 2018, the European Union released the "Plastic Strategy in the Circular Economy", adopting a holistic approach encompassing the life-cycle of plastics, integrating the design, use, recycling, and reuse of plastic materials. The objective is to ensure all plastic packaging in the EU market is reusable or recyclable by 2030, thereby reducing the consumption of single-use plastics and imposing stricter restrictions on micro-plastics (EU, DIRECTIVE 2019/904). The "Plastic Strategy in the Circular Economy" has yielded positive outcomes, leading scholars to opine that "The adoption of the Plastics Strategy is commendable. It is a farsighted plan for the transformation of economies and societies' relationship to a ubiquitous material that goes beyond just quick fixes" (Penca, 2018).

The control of water source pollution primarily involves the legal regulation of maritime activities. Marine activities that directly discharge plastic waste into the ocean include fishing, aquaculture, shipping, dumping at sea, and other maritime activities (Gilardi et al., 2020). In 2008, the European Union introduced the "Marine Strategy Framework Directive", the first legally binding instrument to tackle marine litter (EU, 2008). It mandates that by 2020, disposal standards for marine litter within the EU must ensure "a satisfactory environmental status", meaning the nature and quantity of marine litter must not harm coastal or broader marine environments. The EU has also established operational mechanisms, including decisions on disposal measures, monitoring, and implementation reporting. Additionally, a marine debris technical group has been created with the authority to provide effective guidance and recommendations to member states on the hazards, origins, and promotion of unified monitoring approaches for marine debris (EU, DIRECTIVE 2008/56/EC). Subsequently, the European Union has issued a series of policy documents, including Directives 2009/43, 2009/1224, 2019/904, and the Port Reception Facilities Directive. The first two directives impose legal obligations on fishing fleets regarding the disposal of plastic waste, the provision of appropriate equipment (Tickler et al., 2018), and notifying registered member states of unrecoverable fishing gear to prevent plastic pollution from lost fishing gear. The third directive further standardizes the management of discarded fishing gear, extending producer responsibility to cover fishing gear containing plastic and those used in aquaculture. This directive further standardizes the management of discarded fishing gear, extending the producer responsibility to cover fishing gear containing plastic and those used in aquaculture. It mandates fishing gear producers to cover the costs of collection, transportation, and disposal of discarded fishing gear, ensuring that discarded plastic fishing gear is fully integrated into the waste recycling system. Currently, the European Union is developing unified standards for the reuse of fishing gear to extend their lifespan (EU, 2019a). The Port Reception Facilities Directive, introduced by the European Union in 2019, broadly restricts the production of plastic waste at sea. This directive focuses especially on managing plastic waste in the shipping industry, encouraging, through economic incentives, the delivery of discarded plastic fishing gear and other plastics from passive fishing to appropriate onshore port facilities for proper treatment as specified in Annex 5 of the International Convention for the Prevention of Pollution from Ships (EU, 2019b).

3.3 Legislative frameworks and policies in China and the United States

3.3.1 Chinese policies and legislative frameworks

On December 31, 2007, the General Office of the State Council of China issued the "Regulations on Restrictions Notice on the Production, Sales, and Use of Plastic Shopping Bags", which requires that from June 1, 2008, the production, sale, and use of ultra-thin plastic bags be prohibited nationwide, and a paid use system for plastic bags be implemented (General Office of the State Council of PRC, 2007). Since then, China has become one of the sponsors in the world to ban plastic. In recent years, China has implemented initiatives such as urban waste sorting, pilot "waste-free cities" projects, and "beautiful countryside" initiatives. It has also launched targeted campaigns against environmental violations related to solid waste, which has played a positive role in reducing land-based solid waste pollution and curbing plastic waste from entering the sea. This has effectively reduced the amount of plastic waste reaching the ocean, contributing to the global effort to combat MPP. In January 2020, China's National Development and Reform Commission and Ministry of Ecology and Environment issued the "Opinions on Further Strengthening the Control of Plastic Pollution", aimed at "establishing a robust long-term management mechanism for plastic products" (National Development and Reform Commission, 2020). China previously imported plastic waste to make products out of recycled plastics, but as of 2017 has permanently banned non-industrial plastic waste from being imported (Brooks et al., 2018).The author has illustrated and listed the relevant legislation on preventing plastic pollution in China (Table 4), and categorized them into three groups based on their respective functions: firstly, regulation of plastic production; secondly, regulation of plastic waste disposal; thirdly, regulation of industry standards for plastic products. From the standpoint of legal logic and semantic interpretation, these laws and regulations can be expanded to address plastic pollution in the marine environment.

3.3.1.1 Plastic production regulations

The Clean Production Promotion Law's legislative intent is clearly stated in its Article 1, aiming to "reduce and prevent pollutant generation, protect and enhance the environment, and ensure human health" (NPC Standing Committee, 2012). Although the law does not directly mention "plastic" or "Micro-plastics", it focuses on the "residual risks" (Banse et al., 2012). Perhaps the most significant contribution of this law to addressing plastic pollution is outlined in Article 2, which established the fundamental principle of clean production: "to reduce pollution at its source, enhance resource efficiency, and minimize or prevent the generation and

TABLE 4 China's legislative measures aimed at mitigating plastic pollution.

passing time	Legal name	Pertinent provision
1984.5	Water Pollution Prevention and Control Law	Article 32
1995.10	Law of the Prevention and Control of Environment Pollution Caused by Solid Wastes	Article 56, Article 69, Article 93, Article 106
2002.6	Cleaner Production Promotion Law	Article 1, Article 2, Article 21
2011.5	Safety Technical Specifications for Washing Products (Under revision)	Article 5
2015.11	Safety and Technical Standards for Cosmetics	Section 3.1.1, Section 3.8.2
2018.8	Soil Pollution Prevention and Control Law	Article 20
2020.6	Regulation on the Supervision and Administration of Cosmetics	Article 55

discharge of pollutants throughout production, service, and product use". This serves as the fundamental legal basis for addressing the root causes of plastic pollution. Additionally, Article 20 sets up product design criteria for items to be "non-toxic, harmless, easily degradable, and recyclable". These regulations establish unyielding boundaries for the selection of materials and characteristics of plastic products, safeguarding against secondary micro-plastic pollution at its source. Furthermore, the "plastic restriction order" policy system provides detailed regulations concerning the pricing, materials, properties, and usage scope of plastic products (General Office of the State Council of PRC, 2007; Ministry of Commerce of PRC, 2008; National Development and Reform Commission et al., 2020).

3.3.1.2 Plastic waste disposal regulations

China has segmented its regulations on plastic waste disposal into two main areas: control of micro-plastic land-based pollution and control of micro-plastic water source pollution. Firstly, the management of micro-plastic land-based pollution primarily focuses on two aspects: preventing and controlling soil pollution as well as solid waste pollution. The Soil Pollution Prevention and Control Law of the People's Republic of China provides the fundamental legal framework for addressing soil pollution caused by micro-plastics. Article 20 of this law stipulates the screening and assessment of soil toxic and harmful substances, as well as the publication of a corresponding catalog. The benefit of establishing such regulations lies in the ability to include micro-plastics within the category of "soil harmful substances" by updating the catalog and expanding interpretations when necessary. This approach saves time on legislative amendments, enhances the efficiency of law enforcement, and enables timely regulation of emerging issues. The Solid Waste Pollution Prevention and Control Law of the People's Republic of China forms the basis for managing solid waste pollution caused by micro-plastics. In the realm of pollution disposal, the law mandates the real-time disclosure of pollution emission data (Article 56) and establishes a large-scale industrial model for pollution prevention and control (Article 93), thereby providing a framework for micro-plastic pollution stakeholders to take responsibility for, monitor, prevent, and manage secondary pollution from plastic waste, as well as implement large-scale remediation strategies. The term 'plastic' is mentioned 10 times in the law, specified in Articles 69 and 106. Article 69 outlines a comprehensive ban and restrictions on the production, sale, and use of disposable plastic items, including non-biodegradable plastic bags. It also sets up a system for the use and recycling of plastic bags by relevant entities, and promotes the use of alternative products. Article 106 mandates imposing fines ranging from 10,000 to 100,000 yuan for violations. Additionally, the management of micro-plastic pollution in water sources primarily encompasses freshwater and marine pollution control. Freshwater pollution control is grounded in the Water Pollution Prevention and Control Law, which, in Article 32, sets forth rules for updating the list of toxic and harmful water pollutants, risk management, and the assessment of environmental risks, as well as the disclosure of water pollutant information. In aquatic environments, micro-plastics have the potential to transform into toxic substances through dissolution and chemical bonding, providing a basis for their inclusion in the category of "toxic and harmful water pollutants". Marine pollution control is based on the Marine Environmental Protection Law, which establishes prohibitive regulations in three key areas: prevention of land-based pollutants, waste dumping, and engineering projects, thereby providing guidance for the prevention and control of micro-plastic pollution in marine environments.

3.3.1.3 Industry standards for plastic products

China regulates the production, use, and disposal of plastic micro-beads through a series of industry standards. From a temporal perspective, Article 5 of the "Technical Specification for Safety of Washing Products" issued in 2011, established the fundamental standard for washing product production: "The environmental impact should be within an acceptable range", This principle served as the basis for restricting the inclusion of plastic microbeads in daily chemical products at the national standard level in China. Currently, China is revising this technical specification by changing the original "General Provisions" to "General Requirements" in the published draft for comment. Under the "General Requirements", "substances in the persistent organic pollutant catalog shall not be used" in the formulation of washing products. Persistent organic pollutants are characterized by their toxicity, recalcitrant degradation, and capacity for bioaccumulation (UNEP, 2001). The "Technical Specification for Safety of Cosmetics," issued in 2015, incorporates in Section 3.1.1 the requirement for "cosmetic safety risk assessment" to ensure that its formulations do not compromise human health under "normal, reasonable, and foreseeable conditions". Additionally, Section 3.8.2 clarifies the dynamic regulation, mandating that the quality and safety of cosmetic raw materials must align with the "level achieved

by production processes and testing technologies". Article 55 of the "Regulations on the Supervision and Administration of Cosmetics", implemented on January 1, 2021, specifies the scenarios for dynamic regulation, namely "advancements in scientific research", "shifts in the understanding of cosmetic raw material safety" or "evidence of existing defects". Although the aforementioned standards and documents do not explicitly mention micro-plastics, those principles and contents of supervision, pollution prevention, and health protection they establish can be applied to the control of micro-plastic pollution. This provides potential solutions for managing new harmful substances such as micro-plastics.

3.3.2 U.S. policies and legislative frameworks

The United States is a major producer of plastics and corresponding waste. It is estimated that the country alone requires 12 million barrels of oil annually to meet the demand for plastic bag production (Clapp and Swanston, 2017). Due to low recycling rates, 100 billion plastic bags are discarded each year, all of which are treated as waste. Improper or inadequate disposal of these bags can lead to plastic pollution.

An overview of the legal regulatory framework for marine plastics in the United States reveals a parallel system of general and specific laws (Table 5). Regarding general law, it is primarily embodied in three legislative acts: the Clean Water Act and Clean Air Act, which address pollution after it occurs, and the Pollution Prevention Act, which focuses on source control. Although micro-plastic pollution was not a concern at the time these laws were enacted, they remain applicable to this type of pollution (Dixon et al., 2017). The CWA explicitly mandates that each state establish water quality standards for all state waters and define maximum allowable concentrations for various pollutants to ensure they do not interfere with designated uses. It also requires states to proactively identify water bodies damaged by pollutants, including household and plastic wastes, and implement appropriate remedial measures, thereby enhancing the environmental governance responsibilities of local authorities. The US Environmental Protection Agency or state governments should establish maximum daily load limits (TMDLs) for pollutants, including plastics, and require states to develop and update non-point source management plans in response to the characteristics of non-point source pollution caused by plastic waste in aquatic environments (National Academies of Sciences, 2022). The Pollution Prevention Act focuses on preventing and regulating pollution emissions from a three-dimensional perspective, enterprising government, enterprises and the public. In terms of special laws, they mainly refer to special provisions made for specific fields. It is mainly included in three laws, namely the Marine Debris Research, Prevention and Reduction Act, Microbead-Free Waters Act, and Save the Ocean Act (Table 5). The purpose of the Marine Debris Research, Prevention and Reduction Act is to identify, assess, prevent, reduce and eliminate marine debris, address the adverse effects of marine debris on the marine economy, environment and navigation safety, and establish the "Prevention and Removal of Marine Litter Plan" to clean up marine debris, including micro-plastics (EPA, 2006). The Micro-bead Free Waters Act was enacted in 2015 to address the issue of different state laws in the United States. Congress deemed it necessary to establish a single federal law applicable nationwide. The bill prohibits the sale or distribution of rinse off cosmetics containing plastic micro-beads, and also amends the Federal Food, Drug, and Cosmetic Act to prohibit interstate trade in cosmetics and toiletries containing intentionally added plastic micro-beads (Wood, 2018). According to the legislation, state and local laws that impose restrictions on the production or distribution of personal care products containing plastic micro-beads and differ from the new federal law shall not be enacted or enforced. The specific details must align with the provisions of the federal law. The enactment of federal legislation has further restricted the management of plastic micro-beads on a national scale (FDA, 2022). Currently, several states including Connecticut, Wisconsin, New Jersey, and Maryland have legislated to ban the sale of products containing micro-beads and have made corresponding changes to comply with federal law. The Save the Ocean Act enacted in 2018 fosters international cooperation in reducing marine debris, engages with other governments, and enhances solid waste management to more effectively address marine debris. In 2020, the legislation underwent further revision and was renamed the "Save the Oceans 2.0 Act", aiming to enhance the U.S. domestic plan for marine debris management, increase international involvement in marine debris control, and establish a national infrastructure for marine debris prevention (NOAA, 2022). Additionally, the legislation mandates and requires NOAA to partner with other federal agencies to develop additional outreach and educational strategies to tackle the sources of marine debris. Regarding emissions reduction, California has enacted a law that not only establishes source reduction goals for plastic and other packaging materials but also holds producers financially accountable for the infrastructure required to manage packaging and waste (Otum et al., 2023).

Beyond federal legislation, following Illinois' 2014 ban on micro-beads in personal care products, eight additional states have introduced similar measures. In its law, Illinois declares micro-beads "present a grave threat to the state's environment" and "concentrate existing harmful pollutants, harming fish and other aquatic species that form the foundation of the aquatic food chain" (Schroeck, 2016). As a result, the law mandates a ban on micro-plastics, and this rationale has been adopted by other states in their subsequent legislation.

TABLE 5 Major US laws aimed at preventing plastic pollution.

passing time	Name of the Bill	Explanation
1972.10	Clean Water Act (CWA)	These three laws possess universal applicability
1970.12	Clean Air Act (CAA)	
1990.10	Pollution Prevention Act (PPA)	
2015.12	Microbead-Free Waters Act (MFWA)	These three principles are applicable to particular domains
2018.10	Save the Ocean Act (SOA)	
2019.2	Marine Debris Research, Prevention, and Reduction Act (MDRPRA)	

4 Commentary: in light of the aforementioned three categories of legal texts

The author needs to make a simple comparison of international environmental resolutions and conventions under the United Nations framework, European Union law, and the domestic legislation of sovereign states (Table 6), in order to find out at a glance the advantages and disadvantages of the current legislation on the prevention of MPP, and to provide a clear direction for the future legislation on the prevention of MPP. This will facilitate a clear understanding of the strengths and weaknesses of current laws on plastic pollution control, thereby providing a definitive direction for future efforts to combat plastic pollution.

4.1 The comprehension of environmental risks must be continually enhanced in legislation

Plastic pollution, particularly the advent of micro-plastics, has significantly surpassed people's comprehension of environmental risks. In January 2018, researchers from China's 34th Antarctic Expedition discovered micro-plastics smaller than 0.3 millimeters in the Powell Basin of Antarctica (People's Daily, 2018). In October 2022, the Global Daily reported that micro-plastics were found in human breast milk for the first time in a study. It was reported that breast milk samples from 34 healthy mothers contained microplastics in 75% of the cases (Global Times, 2022). This finding surpasses traditional understanding of plastic pollution and highlights how emerging forms of environmental contamination are expanding the boundaries of your risk perception. Indeed, the emergence of various new types of environmental pollution is progressively pushing the boundaries of our risk perception. This necessitates a reevaluation of environmental risks from a holistic systems perspective. The advent of new environmental risks highlights two notable aspects: firstly, the occurrence of new environmental risks indicates a pervasive and systematic degradation of the ecological environment in a particular domain, impeding the ecosystem's ability to self-repair; secondly, the legal norms governing environmental infringements show gaps and inadequacies in the legal system's comprehensiveness. Consequently, it is imperative for the author to continuously deepen their understanding of environmental risks and to translate this understanding into legislative terms.

We have always lived in the polymer age. Humans are essentially polymeric, from the deoxyribo nucleic acid (DNA)that encodes our human traits to the protein that covers our body (skin)

TABLE 6 Overall comparison of three types of legislation.

Type Contend	Relevant legal concepts	Monitoring Techniques and Assessment Criteria	Implementation mechanism
International Environmental Resolutions and International Environmental Conventions under the framework of the United Nations	International environmental resolutions are not clearly defined; International environmental conventions have provided preliminary definitions of relevant concepts, but are not very clear about plastics and microplastics.	International environmental resolutions are not clearly defined; Some international environmental conventions exist, but they are inconsistent. For example, the provisions of the Stockholm Convention and the 1972 London Convention are inconsistent	Resolution III/7 concerning marine litter and micro-plastics has established an expert group meeting; Establish appropriate mechanisms, for example, the Stockholm Convention mandates that contracting parties establish registers for the emission and transfer of pollutants. The Basel Convention (1996 Protocol) requires contracting parties to establish action plans.
Law of European Union	The EU Chemicals regulation REACH defines the concept of microplastics.	The EU has adopted decisions on disposal measures, monitoring and implementation reporting within the Maritime Strategic Framework Directive.	The EU established a technical group on Marine litter in the Maritime Strategic Framework Directive
Domestic legislation of sovereign states	The Micro-bead-Free Waters Act in the US offers a definition of plastic micro-beads; China has not provided a specific definition, but has outlined basic characteristics. Waste plastics are defined in the "Technical Specifications for Pollution Control of Waste Plastics" (HJ 364—2022).	The United States advocates for a comprehensive life cycle management strategy in the report titled Mobilizing Federal Action on Plastic Pollution: Progress, Principles, and Priorities. The Chinese Clean Promotion Law mentions evaluation, but does not provide specific evaluation methods	China has established operational mechanisms for "screening and assessing toxic and hazardous substances in soil" as well as "publishing a directory of such substances" in the Soil Pollution Prevention and Control Law; The United States has created a Marine Waste Coordination Committee under the Marine Waste Research, Prevention, and Reduction Act, comprised of eight agencies, including the National Oceanic and Atmospheric Administration and the Environmental Protection Agency.

and our keratin-laden hair (Iroegbu et al., 2021). Therefore, ever since its invention, plastic has been an integral part of people's lives. However, pollution caused by plastics soon followed. One could argue that plastic pollution closely follows its introduction into people's lives. While the initial forms of pollution went unnoticed, visible pollution soon become apparent, such as the "white pollution" caused by white plastic bags discarded carelessly or suspended in the air during strong winds. Surprisingly, the discoveries do not end here. The ingestion of plastic pollution poses another critical threat to marine life. Plastic can break down into micro-plastics (less than 4.75 millimeters) and disappear from the ocean's surface (Eriksen et al., 2014). This not only makes them harder to quantify but also intensifies their infiltration of the marine food web. Ultimately, most micro-plastics settle into the deep sea, where their impact on the biota of deep-sea sediments remains uncertain (Woodall et al., 2014). Experts consider the ingestion of plastic utensils and bags discarded at sea by large marine animals such as seabirds, turtles, and marine mammals to be a significant risk (Wilcox et al., 2016). As it turns out, in the Northeast Atlantic, 74% of seabird species have been found to ingest plastic (Wilcox et al., 2016), and Marine mammals, turtles, seabirds, and invertebrates have been found to die from ingesting plastic (Rochman et al., 2016). After these microplastics are ingested, organisms will also be exposed to toxic, bioaccumulated, persistent organic pollutants that are concentrated in plastics (Li W. C et al., 2016).

The United States Environmental Protection Agency defines environmental risk as the likelihood that adverse effects resulting from an environmental factor will inflict harm on human beings or the ecosystem (EPA, 2024). In other words, the entities responsible for this damage probability are either human beings or the ecosystem itself. Article 4 of the General Provisions of the Estonian Environmental Code articulates the concept of environmental risk in terms of both the likelihood of its occurrence and the severity of potential adverse consequences. The realization of risk pertains to the probability that a specific environmental risk transitions from being classified as "risk" to resulting in "damage". The severity of an adverse outcome is determined by the extent to which an environmental risk can manifest and cause harm (Veinla, 2018). China has explicitly articulated the concept of environmental risk in the Technical Guidelines for Environmental Risk Assessment of Construction Projects. The definition of environmental risk in China has evolved through two distinct phases. In 2004, China promulgated the Technical Guidelines for Environmental Risk Assessment of Construction Projects (HJ/T169-2004), which not only established the notion of "environmental risk" but also delineated the fundamental formula for calculating the probability of environmental risk occurrence: R[hazard/unit time] = P[accident/unit time] × C[hazard/accident] (Ministry of Ecology and Environment of the PRC, 2004). However, this concept was revised in the Technical Guidelines for Environmental Risk Assessment of Construction Projects (HJ169-2018), released in 2019, to define environmental risk as the extent and possibility of environmental harm resulting from unforeseen accidents. A significant aspect of this revision is the removal of the formula previously used to calculate environmental risks. This change primarily reflects a shift away from assessing an acceptable level of risk represented by the R value, recognizing that risk evaluation is influenced by a multitude of factors. Simultaneously, the new guideline (HJ169-2018) has introduced the concept of "environmental risk potential", which denotes a generalized analytical expression of the degree of potential environmental harm associated with construction projects. This revision has progressively refined and enhanced the scientific and rational definition of this concept. The detrimental effects of MPP represent a significant environmental risk, particularly concerning the risks associated with micro-plastics.

As previously noted, plastic pollution has transitioned from visible "white pollution" to an insidious form that often goes unnoticed. Without advancements in scientific monitoring, it would be challenging to comprehend how micro-plastics infiltrate human blood and impact marine life. These observations underscore the urgent need for a paradigm shift in our understanding of environmental risks linked to MPP, especially within legislative frameworks; thus, enhanced regulatory measures are imperative.

4.2 The definition of fundamental concepts requires further elaboration

The enforcement power and regulation degree of the legal system depend on the general social understanding of a particular hazard. However, the current level of scientific and technological understanding is not the final of scientific inquiry (Ulrich, 2003), and its limitations are self-evident. The legal regulation of plastics or micro-plastics is not the final end of such pollution control, let alone the best choice.

The concept of plastic or micro-plastics is not clearly defined in the four types of legal texts mentioned above, making it challenging to legally categorize these materials as pollutants. For instance, the US Plastic Free Beads Act uses the scientific physical characteristic of "diameter less than 5 millimeters" to define micro-plastics. However, the bill lacks clarity in defining and standardizing plastic micro-beads, making it difficult to establish a comprehensive regulatory framework for their production and sale. In contrast to the Plastic Free Beads Act, California's legal definition of micro-plastics is more explicit. It characterizes micro-plastics in drinking water as solid polymer materials that may have been produced with chemical additives or other substances, and are defined as two-dimensional particles larger than 1 micrometer and smaller than 5000 micrometers (California State Water Resources Control Board, 2020). But whether this definition method conforms to legal logic and has operability remains to be discussed, at least this effort deserves recognition. The biggest potential loophole in many state bans in the United States is the definition of micro-plastic beads (Nicholas, 2016). China's domestic laws also do not define plastics or micro-plastics at the legal level. However, in the "Notice on Solidly Promoting Plastic Pollution Control Work" released in 2020, "intentionally adding solid plastic particles with a particle size less than 5 millimeters" was excluded from the addition materials of daily

chemical products. But the existing framework cannot explain whether micro-plastics are "legal pollutants" and lacks confirmation of environmental laws. According to Article 42 of China's Environmental Protection Law, which specifies the types of pollutants that should be prevented and controlled by law, micro-plastics cannot be included in the category of "statutory pollutants". In addition, the legal concept of plastic or micro-plastics is not clearly defined in international conventions, only the term plastic or micro-plastics is mentioned.

The definition of plastic pollution should be explicitly articulated in the forthcoming plastics convention. Neither the Zero Draft Text nor the Revised Draft Text explicitly specifies the terms of this definition. The third clause concerning definitions in Part I of the Zero Draft remains unfilled; it is noted in a footnote that specific term instructions may be provided as footnotes within particular clauses. In contrast, Article 3 of Part I in the Revised Draft suggests that a precise definition could either be established as an independent clause or integrated into the substantive provisions of the instrument.

However, as a globally binding convention on plastics, it is essential to uphold legislative uniformity. Legislation should incorporate standardized provisions addressing plastic pollution. This approach aims to avert the pitfalls of legislative fragmentation observed in existing relevant conventions.

4.3 Implementation mechanisms are inadequate to cover the complete life cycle of plastics

Addressing marine plastics necessitates assistance from various disciplines to gain a precise understanding of marine plastics. Once this foundational information is grasped, comprehensive regulation of the entire life cycle of plastic design, production, use, recycling, and disposal becomes essential, requiring effective legal enforcement mechanisms. Regrettably, existing international environmental resolutions and conventions have not yet established an implementation mechanism system that covers the entire lifecycle of plastic pollution control. While some implementation mechanisms exist within existing international conventions, they fail to cover the whole life cycle of plastics. The cornerstone of marine plastic waste management is to reduce waste at the source over the long term.

However, most current international regulations primarily focus on downstream control and waste management of plastics to prevent pollution. For instance, the Basel Convention addresses the trans-boundary movement of plastic waste, but it lacks jurisdiction over actions countries take within their own borders. While it is possible to develop an international regulatory system for both upstream and downstream plastics through amending existing conventions, this approach is hindered by challenges such as coordinating internal regulations, lengthy procedural time-frames, and regulations that inadequately address marine waste, as outlined in the amendment processes and practices of each convention. The US Plastic Free Micro-beads Act is similarly limited, as it only regulates the inclusion of plastic micro-beads in personal care products and the trade of related items, failing to adequately address the broad range of sources of micro-plastics. A literature review and analysis of convention provisions reveal that the enforcement mechanisms of current international agreements have only limited success in addressing marine litter concerns and are incapable of achieving comprehensive life cycle pollution management for plastics.

4.4 Monitoring methods and evaluation standards lack uniformity

Legal governance across various domains must leverage the intrinsic mechanisms of each field. Likewise, employing environmental laws to tackle MPP requires us to first clarify the quantity, types, hazards, and growth of marine plastic waste, a task that these environmental laws alone cannot fulfill. This necessitates the support of environmental science. Global scale data for plastic waste generation, collection, and disposal are often incomplete or unreliable due to inconsistencies in reporting among countries, differences in methodologies and units used in reporting, and omitted values (Kaza et al., 2018). Therefore, it is imperative to address the lack of standardization in monitoring methods and assessment criteria for marine plastics. Currently, there are no globally unified methods and standards for monitoring and assessing marine plastic waste. According to a review report by UNEP on current governance, the 37 reported monitoring activities cited more than 25 different monitoring protocols (Yang and Ding, 2022).

Despite the issuance of several research methodologies and analytical guides both domestically and internationally, the absence of uniform technical standards has rendered monitoring data collected in various locations and environments unusable for global comparative analyses, and has complicated accurate environmental and ecological risk assessments. Without knowing all the populations or species affected, it is hard to scale up even further to ecological effects. For instance, one review found no significant ecological effects from plastic ingestion studies, something they attributed to studies not using systematic data (Browne et al., 2015). Without knowing all the populations or species affected, it is hard to scale up even further to ecological effects. For instance, one review found no ecological effects from plastic ingestion studies, something they attributed to studies not using systematic data (Browne et al., 2015).Additionally, the absence of globally standardized statistical data within the plastic value chain hampers the ability to comprehensively represent and compare the situations of plastic production, trade, consumption, and disposal across different countries, thereby complicating the establishment of global objectives and whole life cycle management. Relevant UNEA resolutions consistently emphasize that enhancing scientific comprehension is essential for tackling the challenges of marine debris and micro-plastics, underscoring the pressing requirement to enhance the integration of science and policy, along with bolstering global coordination, cooperation, and governance (UNEP, 2016d, e).

5 Solution: the environmental law approach to a global agreement for ending plastic pollution

There is a consensus to develop a globally legally binding agreement that covers the entire life cycle of plastics. This study suggests that five environmental legal considerations need to be taken into account when formulating a global plastic agreement.

5.1 The new plastic convention should clearly outline the principles of environmental justice

Justice is an enduring theme, particularly in the realm of the environment. The concepts of environmental justice and marine environmental justice originated in the United States in the 1980s, deriving from concerns about the disproportionate pollution burden borne and experienced by black communities and socioeconomically disadvantaged populations (Cutter, 1995). Broadly, environmental justice encompasses the equal and effective participation of all in the distribution of environmental benefits and risks, as well as in environmental decision-making and legal frameworks. In its 2021 resolution, the United Nations Human Rights Council recognized that everyone has the right to live in a clean, healthy and sustainable environment (United Nations Human Rights Council, 2021).

It is worth noting that people need to analyze the meaning of "Global conventions" in order to facilitate the negotiation and formulation of "Global conventions". In this context, the term "global" here should not refer to the geographical level of the world, but rather to the global pollution caused by ecological cycles such as ocean currents and marine plastics, and the measures taken to protect the global ecological environment. Therefore, when formulating a global plastic agreement, not every country should be required to participate, and of course, only some countries should be determined to participate. The author aims to refute a viewpoint called "key action countries", which argues that these countries (China, Indonesia, Philippines, Vietnam, Sri Lanka, Thailand, Malaysia, Bangladesh, India, and Pakistan) have poor management of plastic waste and contribute 50% of the value of land-based plastic waste flowing into the ocean. Hence, they are required to take immediate action to establish consensus, demonstrate urgently needed commitment, political will, and support for the negotiation process of the new plastic treaty, in order to achieve the proposed treaty's goal of "ending plastic" as adopted in the resolution (Hussain et al., 2023). This viewpoint is disturbing, particularly because of the challenges in quantifying the aforementioned countries' contribution to plastic pollution. As highlighted above, there is currently no unified global monitoring method or evaluation standard. Assuming the "50%" figure is based on a specific monitoring method in a particular country, the validity of this data remains to be substantiated. It is also important to recognize that countries not part of the "key action nations" may have different models for prevention and control obligations, which clearly undermines the goal of establishing consistent monitoring and evaluation standards. As a result, this viewpoint fails to achieve logical consistency within the legal framework.

Plastic pollution is intricately linked to environmental justice. Plastic pollution frequently affects vulnerable populations disproportionately and varies across regions, necessitating tailored solutions that account for local conditions. Tens of thousands of individuals involved in the plastic waste recycling continue to face systemic environmental injustice (International Alliance of Waste Pickers, 2023).The majority of plastic pollution issues are disproportionately located in the Global South, especially in South and Southeast Asia (Jambeck et al., 2015; Lebreton et al., 2017), leading to environmental injustice and "slow violence" (Nixon, 2011). For example, the Philippines, a country in the Northern Hemisphere, generates 163 million plastic bags, 48 million shopping bags and 45 million film bags every day (GAIA, 2019). However, this plastic waste lacks proper disposal methods and is often discarded on the streets, eventually making its way through waterways to the oceans and impacting countries in the Southern Hemisphere (Conlon, 2020).In the United States, approximately 79 percent of municipal incinerators are situated in communities that possess the least economic and political influence (Baptista and Perovich, 2019).

Despite the global prevalence of plastic pollution, its negative externalities are specially severe in impoverished regions where plastic waste is not originally produced. These externalities manifest in issues such as clogged sewer systems, increased disease transmission, and reduced tourism (Giacovelli, 2018; Godfrey, 2019). A significant factor is the legal or illegal transport of plastic waste from developed nations to developing ones (Blettler and Wantzen, 2019; McCormick et al., 2019). On the surface, these countries seem to bear the brunt of plastic pollution, with the responsibility of managing the waste falling disproportionately on them However, it is precisely these nations that contribute the least to global plastic waste (Conlon, 2020).From this perspective, nations that generate lower levels of plastic waste have taken on the responsibilities typically borne by those countries that manage plastic waste disposal, exemplifying a prevalent form of environmental injustice. Hence, environmental justice considerations must be integrated into policy-making to ensure fairness, legitimacy, and efficacy of these policies.

Although the newly revised draft of the plastics convention identifies "the protection of vulnerable communities" as a fundamental principle, it lacks detailed specifications. Nevertheless, the need for environmental justice is unmistakable. This section outlines the framework for environmental justice and proposes specific measures to reinforce its role within the new plastics Convention. The imperative of environmental justice is undeniable. Yet, explicit frameworks for environmental justice are relatively scarce (Nathan et al., 2022). It is essential to explore how environmental justice can be incorporated into this new global agreement on plastics. For instance, from the standpoint of environmental benefits and responsibility, upstream producers, not downstream victims and local governments already suffering from pollution, should bear the primary responsibility for preventing plastic pollution. Additionally, the environmental justice framework

proposed by Bullard can be applied to assess whether the new global plastics agreement embodies environmental justice (Table 1).

The new plastic convention should reflect contents such as "Right to protection", "Prevention", and "Correcting Injustice". Equally important for the treaty's legitimacy and credibility is the recognition of environmental justice as a fundamental component of human rights within this ambitious international framework.

In the new plastic convention, distributive justice should be considered as the overall action plan to address environmental inequality, which is also a manifestation of the "Right to protection" concept in Bullard's theory of environmental justice(Table 1). Firstly, the stipulations of this convention should address the inequitable distribution of plastic waste impacting low-income and marginalized communities (Adeola, 2000; Bullard, 2021; Davies and Mah., 2020). Secondly, it should also highlight that individuals exposed to higher levels of plastic pollution tend to receive fewer benefits (Clapp and Swanston, 2009; Conlon, 2020). As previously stated, the widespread environmental injustice of illegal plastic waste disposal by developed nations in developing countries underscores the need for stricter regulations within the relevant provisions.

In addition, specific action plans should also be developed. For example, the principle of environmental justice must be integrated into financial and technical assistance initiatives. Such support is crucial for developing countries to effectively mitigate plastic pollution (Stoett, 2022; Environmental Investigation Agency, 2022). Environmental justice should not only be addressed in the preamble or introduction but must also be reflected through concrete countermeasures. The provisions of the new plastics convention should include financial mechanisms such as finance, taxation, and funding to assist developing countries with governance costs. Additionally, support for technology governance in these nations should be strengthened through measures like technology transfer and promotion. Furthermore, international or national compensation mechanisms can be established to address the needs of regions most adversely affected by plastic pollution (Orellana, 2021).

Emphasizing the elements of environmental justice within the new plastics convention is likely to yield a beneficial impact on societal development. Once implemented, this convention can further safeguard the legitimate rights of indigenous peoples, women, and marginalized communities, including their rights to clean water and a healthy environment (Orellana, 2021). It also strengthens and promotes the fundamental rights of children and adolescents (Children and Youth Major Group to UNEP, 2023), exemplifying the principle of intergenerational equity. Furthermore, it was recognized that adopting a human rights framework could effectively fulfill the objectives of the new plastics Convention, particularly concerning the health rights of vulnerable populations (The Government of Peru, 2022).From an economic perspective, the adoption of environmental justice principles may elevate the costs associated with plastic management; however, it is likely to yield significant long-term benefits for human health and the ecological environment. Furthermore, data from the United Nations Conference on Trade and Development (UNCTAD) indicate that global international trade in plastic waste amounts to approximately 3.3 billion US dollars, underscoring the necessity for collaborative efforts within the international community to address waste recycling challenges (Barrowclough et al., 2020).

5.2 The new plastic convention should lower the risk prevention threshold

The principle of risk prevention is the cornerstone of modern environmental protection. This status is dictated by the uncertainty inherent in risks and is intimately linked to environmental issues themselves. The continual emergence of new environmental risks necessitates a reevaluation of risk management. As discussed earlier, the emergence of environmental issues indicates irreparable harm to ecosystems and underscores the need to lower or raise the threshold for risk prevention. Accordingly, international legal instruments aiming to decisively tackle plastic pollution must embody the primacy of risk prevention principles, with a focus on the presence of "residual risks". Ulrich K. Preuss exhibits a forward-looking perspective on "residual risk" which can be considered a fundamental criterion for establishing the threshold of the risk prevention principle. He posits that the three distinct forms of danger, risk, and residual risk can be broadly delineated based on linear determinism: Danger is the belief that there is a "sufficient likelihood" between the current cause and future harmful effects, as perceived by the average person; risk is met when this "sufficient likelihood" is partially achieved; both can be regulated and adjusted once the respective criteria are met. As in the case of environmental pollution, legal regulation can be determined by general causal principles. However, the necessity for regulatory intervention in relation to potential risks, particularly "minimal possible dangers", presents a challenge in applying the precautionary principle. Although it is now possible to demonstrate that marine animals are poisoned and even killed by the ingestion of plastic, the danger of micro-plastics may be limited to this. Hence, the "residual risk" needs to be reconsidered in people's cognition. For example, while individual animals have died or been injured due to plastic pollution, it is unclear how this scales to population-level effects (Wilcox et al., 2016).

In fact, the regulation and adjustment of danger and risk encompass not only objective linear and deterministic factors but also include people's subjective judgments about these factors. In other words, judgments of danger and risk encompass both objective and subjective aspects, with residual risk representing a distinct scenario. UIrich K. Preuβ defines it as a threshold that indicates the possibility of a certain type of damage occurring. Below this threshold, considering resource lack, protective measures are no longer provided because the probability of this potential damage materializing is very low. As a consequence, while the existence of damage cannot be theoretically excluded, it is dismissed based on "the standard of practical rationality". In essence, this represents a trade-off among potential cognitive errors, regulatory adjustments, and technological advancements. However, people today can no longer afford to engage in such trade-offs and should aspire to the Eu's ambition in fulfilling its treaty obligations (Article 21 (2) (f) TEU (EU, 1991a) and Article 191 (1) of the EU Treaty (EU, 1991b), with the EU resolved to "lead by example" (EEAS, 2016). Individuals likewise require this courage and

spirit of inquiry to confront the "residual risks" beyond the known hazards of microplastics. With this cognitive foundation, it can achieve Goal 14 of the 2030 Agenda for Sustainable Development.

5.3 The new plastic convention should clearly address the regulatory issue of HPP

Although already mentioned in the revised draft, the goal is "to end plastic pollution, including in the Marine environment [and other aquatic and terrestrial ecosystems]" (UNEP/PP/INC.4/3, 2023). However, there is a lack of explicit reference to HPP. As a new comprehensive convention addressing plastic pollution, HPP should not be broadly categorized under other aquatic and terrestrial ecosystems. Clear provisions for HPP are necessary. Because, HPP has become an increasingly significant challenge in managing MPP.

Studies have shown that plastic waste on land accounts for about 80% of MPP (Jambeck et al., 2015), indicating that rivers are important carriers of MPP (Schmidt et al., 2017). Therefore, labeling plastic pollution as a marine issue has limited the full understanding of the problem (Hartley et al., 2018). People must re-examine the relationship between river plastic pollution and MPP.

For instance, a study on marine MPP in European waters suggests that limiting MPP requires considering the role of rivers and land-based activities in plastic accumulation in the marine environment (Black et al., 2019). This study on land-based plastic pollution provides favorable evidence for this result, with 10 rivers accounting for 88% to 95% of the world's marine plastic load (Schmidt et al., 2017). Another study estimates that approximately 1.15 million to 2.41 million tons of plastic waste flow from inland rivers to the marine environment worldwide each year (Lebreton et al., 2017). These rivers cover approximately 2.2% of the land area and 21% of the global population. However, the shocking data is that they account for about 67% of the total input of plastic waste into the world's oceans (Hussain et al., 2023).

Recent research suggests that approximately 3-19% of plastic emissions in coastal areas come from land-based river sources such as rivers (Lebreton et al., 2017). The production activities in coastal regions are directly linked to inadequate management of plastic waste [MMPH], while the role of rivers in this issue is often underemphasized (Small and Nicholls, 2003). Rivers create networks that enable the long-distance transport of plastic waste to the ocean, similar to the transport of terrestrial sediments (Ludwig et al., 1996). This indicates that the riverine transport of plastic waste has emerged as a significant pathway for marine ecological pollution. Although people believe that this matter is related to the direction of controlling MPP, their understanding of plastic pollution control in river systems lags behind their understanding of MPP control (Wagner and Scott, 2018). People must understand the environmental mechanism behind the qualitative transformation of river systems into carriers of plastic waste transportation, namely the natural flow principle of river networks, in order to develop a good and targeted legal framework for global response to MPP.

From this perspective, the natural flow principle of river networks should be given due attention, especially in the treatment of marine environmental pollution. Therefore, the focus of a legally binding international instrument to end MPP should not only be on the issue of marine plastic, but equally important should also be on plastic pollution in inland rivers. This kind of attention may seem to interfere with some domestic legislation on the surface, but the fact is that it is through data investigation of the source and through the phenomenon to see the essence. At the legislative level, how to avoid appearing as "interference" in domestic legislation can be achieved entirely through legislative techniques, such as the selection of legislative models. Research shows that the current fragmented freshwater legislation in Europe lacks a deep understanding of plastic sources and transportation carriers, which poses a significant challenge for the development and implementation of effective plastic laws and regulations (Black et al., 2019). Consequently, it is imperative to explicitly outline the regulations governing HPP within the forthcoming plastics convention.

5.4 The new plastic convention must elucidate fundamental legal concepts

Concepts are the logical foundation of law, and both domestic and international law need to be developed from these foundational concepts of the book. Bodenheimer once pointed out: "Concepts are necessary and essential tools for solving legal problems. Without strict and specialized concepts, people cannot think clearly and rationally about legal issues. If people completely reject concepts, the entire legal building will be reduced to ashes" (Bodenheimer, 1999). The definition of legal concepts will directly affect the application of law. To sum up, legal concepts are the foundation of the legal system and play an important role in regulating behavior, interpreting laws, constructing systems, safeguarding rights, and achieving fairness and justice. This is essential for a thorough understanding and grasp of legal concepts in order to correctly understand and apply the law.

Introducing certain concepts from other environmental fields into the legal domain can facilitate the regulation of social relations through legal means. This is interdisciplinary communication and necessary, but after all, there are still significant differences between the two and cannot be completely borrowed directly. Concepts in other environmental fields possess their unique physical and chemical characteristics. In law, the basic elements that define concepts are the basic points of legal concepts such as adjustment objects, adjustment scope, adjustment methods, and adjustment objectives.

Taking the concept of micro-plastics as an example, the current approach mainly adopts the viewpoint of Thompson et al. from Plymouth University in the UK in 2004, which refers to plastic fragments and particles smaller than 5 millimeters. But some scholars define micro-plastics as those with a diameter less than (<4.75 millimeters) and can disappear from the ocean surface (Eriksen et al., 2014). There are also scholars who believe that

"Micro-plastics are those plastics that are less than one millimeter in diameter" (National Geographic, 2024).

This illustrates the following two points: Firstly, people's understanding of "micro" is not unified; secondly, the scientific validity of defining plastic beads with a diameter less than 5 millimeters as micro-plastics needs further validation.

This discrepancy in definition gives rise to at least three negative implications.

(1) From a legal standpoint, differently characterized pollutants are subject to inconsistent regulatory measures and legal applications.

(2) In the context of environmental law, the categorization of pollutants essentially embodies the threshold of the precautionary principle and influences future pollution prevention efforts.

(3) In the realm of international law, it represents a form of disguised application or non-application of international treaties to the diverse interests of the international community (disguised application might arise from trade barriers; disguised non-application might stem from the significant economic costs of controlling microplastic sources domestically). This is also among the reasons why the international community is ambitiously working to establish an international agreement with universal binding force for contracting parties.

In the absence of a legal definition, substances that take decades or even centuries to degrade might still be considered biodegradable. Therefore, at this historic juncture, a universally binding international instrument must first address fundamental legal concepts. These concepts cannot be individually detailed in this text, but they must at least encompass the fundamental elements of degradability (basic scientific understanding), regulatory targets, scope, and environmental impact.

While the authors find it challenging to finalize the definition of plastic pollution within the new plastics convention, These concepts must include at least two fundamental elements. First, It must demonstrate certain typical characteristics of the environment and offer quantitative criteria for the formulation of specific legal measures. Second, there is a legal dimension; ultimately, plastic pollution is fundamentally a legal construct. Within this framework, it is crucial to emphasize its detrimental impact on social or ecological environments to underscore the necessity of legal regulation concerning plastic pollution.

5.5 The new plastics convention must delineate standardized monitoring methodologies and evaluation criteria

The development of unified plastic testing methods and evaluation standards is a formal justice for the unified application of the upcoming international treaty. On the basis of unified monitoring and evaluation, what measures should countries take to address domestic land-based plastic pollution is convincing. Various research methods and analytical techniques are currently available. For instance, surface monitoring is carried out through aerial imaging and remote sensing technology (such as satellites and drones), water column monitoring is carried out through autonomous underwater vehicles (AUVs) and remotely operated underwater vehicles (ROVs), seabed detection is carried out through bottom trawl and grab sampling and underwater imaging (ROVs, AUVs), biological monitoring is carried out by examining the intestinal contents and feces of marine organisms, biological accumulation in biological tissues, feeding and entanglement of marine organisms, and public science and community monitoring are conducted through beach cleaning surveys and data collection. Due to various reasons, the National Oceanic and Atmospheric Administration (NOAA) of the United States has been unable to take satellite photos of the garbage patch (Goldberg, 2012). Resolutions 20/86 and 274/00 of the Brazilian National Environmental Protection Commission have established criteria for saltwater used for recreational purposes, including floating materials, oil and grease, odorous or turbid substances, artificial dyes, and substances that form harmful sediments; Fecal coliforms, DBO-5 and other indicators. Despite various indicators, the "foamability" of Brazilian beaches (determining the parameters suitable for bathing) has always been determined by the number of bacteria (Escherichia coli and/or Enterococcus) in the water's coliform community (Diogenes et al., 2020). The description of the size of the ocean plastic problem varies greatly, as a clear scientific method for measuring debris has not yet been established (Goldberg, 2012). This is a very serious issue.

Consequently, it is urgent to develop unified monitoring methods and evaluation standards in the new global plastic agreement to determine more accurate data on current seabed plastic waste. Because this is a prerequisite for taking unified action. Regardless of the legislative model used for this monitoring method and evaluation criteria. Of course, the author tends to favor a specific convention model. Because it, firstly, can ensure the simplicity and clarity of the convention documents, which also meets the requirements of streamlining and seriousness in formulating laws; Secondly, the formulation and modification of annexes are more flexible compared to the main text of the convention. The variability of pollution forms and scientific uncertainties necessitate that the convention allows for flexible modifications; Thirdly, incorporating core obligations directly into the main text of the convention will further encourage contracting parties to accelerate their transformation efforts.

6 Conclusion

This paper adopts a holistic systems perspective. The strength of this framework lies in its ability to assess only the coherence and systematic nature of extant legislation but also to propose recommendations for a new plastics convention from an integrated viewpoint. In response to the fragmented legislative landscape addressing MPP, the paper presents targeted strategies to tackle legislative fragmentation. These strategies include emphasizing environmental justice within the new Marine

Plastics Convention, lowering the threshold for risk prevention, clearly defining legal regulations concerning HPP, scientifically elucidating fundamental legal concepts, and standardizing monitoring methodologies and evaluation criteria on a global scale.

The global issue of MPP is no longer just a matter of international environmental law. It also spills over issues such as environmental justice and provides a renewed understanding of environmental risks. As for the issue of environmental justice, it includes two aspects. On the one hand, countries or regions with high emissions of pollution make regions with low emissions bear more environmental externalities. On the other hand, when formulating a global plastic agreement, it is important not to overly criticize economically countries or regions. The recent discovery of micro-plastics in marine animals and human blood has renewed awareness of environmental risks. This phenomenon needs to be reminded that people should not only focus on causal relationships based on determinism in classical physics, but also pay attention to the existence of "residual risk". At a time when there is a strong global call for the development of a legally binding international document, including the above-mentioned spillover issues requires a holistic and systematic approach. In this agreement, a comprehensive approach to the global issue of plastic pollution should be adopted, along with systematic measures to address it. For example, determining the overall goals of governance, the main measures taken, and supporting measures.

Of course, the discussion in this paper is an analysis based on the existing legal situation and scientific knowledge. With the continuous improvement of international regulations and national laws for the prevention of MPP, as well as the interaction between the two, some of the views in this paper will also change and be subject to further review, but given the systemic nature of the ecological environment, the study of this issue from a holistic systemic perspective will continue to be of great practical importance in terms of methodology.

Author contributions

SX: Writing – original draft.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Adeola, F. O. (2000). Cross-national environmental injustice and human rights issues: a review of evidence in the developing world. *Am. Behav. Sci.* 43, 686–706. doi: 10.1177/00027640021955496

Banse, G., wolf, R., and Preuß, U. K. (2012). *Risk regulation: Theory and practice in Germany (Gang Liu & Xiao Chen, Trans.)* (China: Law Press).

Baptista, A. I., and Perovich, A. (2019). U.S. Municipal Solid Waste Incinerators: An Industry in Decline. Available online at: https://www.no-burn.org/zh-CN/u-s-municipal-solid-waste-incinerators-an-industry-in-decline/ (Accessed September 16, 2024).

Barrowclough, D., Birkbeck, C. D., and Christen, J. (2020). *Global Trade in Plastics: Insights from the First Life-Cycle Trade Database* (Geneva: United Nations Conference on Trade and Development).

Black, J. E., Kopke, K., and O'Mahony, C. (2019). A trip upstream to mitigate marine plastic pollution-a perspective focused on the MSFD and WFD. *Front. Mar. Sci.* 689, 1. doi: 10.3389/fmars.2019.00689

Blettler, M. C., and Wantzen, K. M. (2019). Threats underestimated in freshwater plastic pollution: mini-review. *Water Air. Soil pollut.* 230, 1–11. doi: 10.1007/s11270-019-4220-z

Blicke, C. V. (2002). "The Stockholm Convention on persistent organic pollutants, Review of European," in *Comparative and International Environmental Law* (New Jersey: Wiley-Blackwell), 328–342.

Bodenheimer, E. (1999). *Jurisprudence: Legal philosophy and legal method (Zhenglai Deng, Trans.)* (China: China University of Political Science and Law Press).

Brooks, A. L., Wang, S., and Jambeck, J. R. (2018). The Chinese import ban and its impact on global plastic waste trade. *Sci. Adv.* 4, eaat0131. doi: 10.1126/sciadv.aat0131

Browne, M. A., Underwood, A. J., Chapman, M. G., Williams, R., Thompson, R. C., and van Franeker, J. A. (2015). Linking effects of anthropogenic debris to ecological impacts. *Proc. R. Soc. B.* 282, 20142929. doi: 10.1098/rspb.2014.2929

Bruna, A. (2024). Plastic waste in Europe-statistics &facts. Available online at: https://www.statista.com/topics/5141/plastic-waste-in-europe/dossierKeyfigures (Accessed August 13, 2024).

Bullard, R. D. (2021). Environmental justice – Once a footnote, now a headline, Harv. *Environ. L. Rev.* 45 (2), 243–248.

California State Water Resources Control Board (2020). Public consultation on definition of microplastics in California. Available online at: https://www.clii.com.cn/cyaq/202003/t20200326_3943449.html (Accessed August 13, 2024).

Carpentiera, C. L., and Braun, H. (2020). Agenda 2030 for Sustainable Development: A powerful global framework. *J. Int. Council. Small. Business.* 1, 14–23. doi: 10.1080/26437015.2020.1714356

Children and Youth Major Group to UNEP (2023). Submission on the potential options for elements towards an international legally binding instrument on plastic, Second session of the Intergovernmental Negotiating Committee to develop an international legally binding instrument on plastic pollution, including in the marine environment, 29 May – 2 June 2023 (Paris, France). Available online at: https://apps1.unep.org/resolutions/uploads/230113_children_and_youth_major_group.Pdf (Accessed September 7, 2024).

Clapp, J., and Swanston, L. (2009). Doing away with plastic shopping bags: international patterns of norm emergence and policy implementation. *Environ. Polit.* 18, 315–332. doi: 10.1080/09644010902823717

Clapp, J., and Swanston, L. (2017). Doing away with plastic shopping bags: international patterns of norm emergence and policy implementation. *Environ. Politics.* 18, 315–332. doi: 10.1080/09644010902823717

Conkle, J. L., Báez Del Valle, C. D., and Turner, J. W. (2018). Are we underestimating microplastic contamination in aquatic environments? *Environ. Manage.* 61, 1–8. doi: 10.1007/500267-017-0947-8

Conlon, K. (2020). Adaptive injustice: responsibility to act in the plastics economy. *Resour. Conserv. Recycl.* 153, 104563. doi: 10.1016/j.resconrec.2019.104563

Cosmetics Europe (2015). Cosmetics Europe recommendation on solid plastic particles (plastic micro particles). Available online at: https://www.cosmeticseurope.eu/files/3714/7636/5652/Recommendation_on_Solid_Plastic_Particles.pdf (Accessed August 13, 2024).

Cutter, S. L. (1995). Race, class and environmental justice. *Prog. Hum. Geogr.* 19, 111–122. doi: 10.1177/030913259501900111

Davies, T., and Mah., A. (2020). *Toxic truths: Environmental Justice and Citizen Science in a Post-Truth Age* (Manchester: Manchester University Press).

Diogenes, B. N., Soares, M. d. O., and Mont'Alverne, T. C. F. (2020). Rethinking the environmental quality of Brazilian beaches: the incidence of microplastics as an indicator for sea water and sand quality. *Califomia. Western. Int. Law J.* 51, 133–182. Available online at: https://scholarlycommons.law.cwsl.edu/cwilj/vol51/iss1/5.

Dixon, S., Lees, Z., and Leshak, A. (2017). The big apple's tiny problem: a legal analysis of the microplastic problem in the N.Y./N. J. Harbor. *Roger. Williams. Univ. Law Rev.* 22 (2), 398. Available online at: http://docs.rwu.edu/rwu_LR/vol22/iss2/5.

EEAS (2016). *Shared Vision, Common Action: A Stronger Europe – A Global Strategy for the European Union's Foreign and Security Policy* (Europe: European Union). Available online at: https://www.eeas.europa.eu/eeas/global-strategy-european-unions-foreign-and-security-policy_en.

Environmental Investigation Agency (2022). Convention on plastic pollution – Essential elements: Financial aspects. Available online at: https://eia-international.org/report/convention-on-plastic-pollution-essential-elements-reporting-and-monitoring/ (Accessed September 7, 2024).

EPA (2006). Marine Debrissch Research, Prevention and Reduction Act. Available online at: https://www.epa.gov/beaches/epas-role-protecting-beaches (Accessed August 14, 2024).

EPA (2024). Learn about Risk Assessment. Available online at: https://www.epa.gov/risk/about-risk-assessment (Accessed September 7, 2024).

Eriksen, M., Lebreton, L. C. M., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., et al. (2014). Plastic pollution in the world's oceans: More than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PloS One* 9, e111913. doi: 10.1371/journal.pone.0111913

EU (1991a). *Treaty on the European Union* (Europe). Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/? uri=OJ:C:2016:202:TOC.

EU (1991b). *Treaty on Functioning of the European Union* (Europe: Official Journal of the European Union). Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/? uri=celex%3A12012E%2FTXT.

EU (2008). *DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)* (Europe). Available online at: https://eur-lex.europa.eu/eli/dir/2008/56/oj.

EU (2019a). *DIRECTIVE 2019/904 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on the reduction of the impact of certain plastic products on the environment* (Europe). Available online at: https://eur-lex.europa.eu/eli/dir/2019/904/oj.

EU (2019b). *DIRECTIVE 2019/883 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 April 2019 on port reception facilities for the delivery of waste from ships, amending Directive 2010/65/EU* (Europe). Available online at: https://eur-lex.europa.eu/eli/dir/2019/883/oj.

European Commission (2018). A European strategy for plastics in a circular economy. Available online at: http://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf (Accessed August 13, 2024).

FDA (2022). The Microbead-Free Waters Act: FAQs. Available online at: https://www.fda.gov/cosmetics/cosmetics-laws-regulations/microbead-free-waters-act-faqs (Accessed August 13, 2024).

GAIA (2019). Plastics Exposed: How Waste Assessments and Brand Audits Are Helping Philippine Cities Fight Plastic Pollution (GAIA). Available online at: https://www.no-burn.org/wp-content/uploads/PlasticsExposed-3.pdf (Accessed July 11, 2019).

General Office of the State Council of PRC (2007). Notice on Restricting the Production, Sales, and Use of Plastic Shopping Bags in 2007. Available online at: https://www.gov.cn/zhengce/zhengceku/2008-03/28/content_4869.htm (Accessed September 23, 2024).

Giacovelli, C. (2018). Single-Use Plastics: A Roadmap for Sustainability (UN Environment: Technology for Environment). Available online at: https://stg-wedocs.unep.org/handle/20.500.11822/25496 (Accessed 5 May, 2021).

Gilardi, K. V. K., Antonelis, K., Galgani, F., and Wang, L. (2020). Sea-based sources of marine litter–A review of current knowledge and assessment of data gaps. *Second. Interim. Rep. GESAMP. Working. Group.* 43, 8. Available online at: http://www.gesamp.org/publications/sea-based-sources-of-marine-litter.

Global Times (2022). Microplastics found in human breast milk for the first time. Available online at: https://www.globaltimes.cn/page/202210/1276815.shtml (Accessed August 13, 2024).

Godfrey, L. (2019). Waste plastic, the challenge facing developing countries—ban it, change it, collect it? *Recycling* 4, 3. doi: 10.3390/recycling4010003

Goldberg, O. (2012). Biodegradable plastics: A stopgap solution for the intractable marine debris problem. *Texas. Environ. Law Joumal.* 42, 307.

Gonzalo, B. (1994). Latin america and the basel convention on hazardous wastes. *COLO. J. INT'l. ENVTL. L. POL'y.* 5, 333.

Hartley, B. L., Pahl, S., Veiga, J., Vlachogianni, T., Vasconcelos, L., Maes, T., et al. (2018). Exploring public views on marine litter in Europe: Perceived causes, consequences and pathways to change. *Mar. pollut. Bull.* 133, 945–955. doi: 10.1016/j.marpolbul.2018.05.061

Hussain, A., Akrofi, D. F., Bibi, B., and Sohail, A. (2023). Strengthening global hydrospheric plastic regulation: toward an overarching plastic treaty. *Int'l. J.L. Mgmt. Hum.* 6 (2), 1967. doi: 10.10000/IJLMH.114606

IMO (1973). *MARPOL Convention* (London). Available online at: https://www.imo.org/en/KnowledgeCentre/ConferencesMeetings/pages/Marpol.aspx.

International Alliance of Waste Pickers (2023). Submission from the International Alliance of Waste-Pickers for INC-2 on Plastic Pollution, January 13, 2023, Second session of the Intergovernmental Negotiating Committee to develop an international legally binding instrument on plastic pollution, including in the marine environment, 29 May – 2 June 2023 (Paris, France). Available online at: https://apps1.unep.org/resolutions/uploads/230113_international_alliance_of_waste-pickers.pdf (Accessed September 7, 2024).

Iroegbu, A. O. C., Ray, S. S., Mbarane, V., Bordado, J. C., and Sardinha, J. P. (2021). Plastic pollution: A perspective on matters arising: challenges and opportunities, (2021). *ACS Omega.* 6, 19343–19355. doi: 10.1021/acsomega.1c02760

Jambeck, J. R., Roland Geyer, C. W., Siegler, T. R., Miriam Perryman, A. A., Narayan, R., and Lavender Law, K. (2015). Plastic waste inputs from land into the ocean. *Science* 347, 768–771. doi: 10.1126/science.1260352

Karbalaeis, H. P., Hanachi, P. T., Walker, R., and Cole, M. (2018). Occurrence, sources, human health impacts and mitigation of microplastic pollution. *Environ. Sci. pollut. Res.* 25, 36046–36063. doi: 10.1007/s11356-018-3508-7

Kaza, S., Yao, L. C., Bhada-Tata, P., and Van Woerden, F. (2018). What a waste 2.0: A global snapshot of solid waste management to 2050. Available online at: https://openknowledge.worldbank.org/handle/10986/30317 (Accessed August 13, 2024).

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., et al. (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. *Sci. Rep.* 8, 4666. doi: 10.1038/s41598-018-22939-w

Zwet der van, J., Damsteeg, J.-W., Slat, B., Andrady, A., and Reisser, J. (2017). River plastic emissions to the world's oceans. *Nat. Commun.* 8, 1–10. doi: 10.1038/ncomms15611

Li, J., Qu, X., Su, L., Zhang, W., Yang, D., Kolandhasamy, P., et al. (2016). Microplastics in mussels along the coastal waters of China. *Environ. pollut.* 214, 177–184. doi: 10.1016/j.envpol.2016.04.012

Li, W. C., Tse, H. F., and Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. *Sci. Total. Environ.* 566–567, 333–349. doi: 10.1016/j.scitotenv.2016.05.084

Liu, B. (2020). A milestone in regulating the cross-border transfer of plastic waste: the impact of the amendment to the Basel Convention. *Business. Econ. Law Rev.* 2, 47–59. Available online at: https://kns.cnki.net/kcms2/article/abstract?v=acR2UJ02YhSsglFkGFSilWS0D3VnSlKv0czDJ1u9XkbfLrCAfgnUWRFS1tAdDmlo1QTNz8iwXOgLrXNRgf63nIqTRExAD-awOJjMVaphzAthuNfXTgCF5I04Odu8Q8SVMVp6KmYsP47OyHl1fPj_2ht8k_D8rQoUXcmeuMvR_xgGQndpQiqkmiOiqfoFCTUkwvhE2RWaoMI=&uniplatform=NZKPT&language=CHS.

Ludwig, W., Probst, J.-L., and Kempe, S. (1996). Predicting the oceanic input of organic carbon by continental erosion. *Global Biogeochem. Cycles.* 10, 23–41. doi: 10.1029/95GB02925

Maheim,, and Bruce, S. Jr (1988). Annex V of the MARPOL convention: will it stop marine plastic pollution. *Geo. Int'l. Envtl. L. Rev.* 1, 71.

McCormick, E., Murray, B., Fonbuena, C., Kijewski, L., Saraçoglu, G., Fullerton, J., et al. (2019).Where Does Your Plastic go? Global Investigation Reveals America's Dirty Secret. In: *The Guardian*. Available online at: https://www.theguardian.com/us-news/2019/jun/17/recycled-plastic-america-global-crisis (Accessed 20 May, 2021).

Ministry of Commerce of PRC (2008). *Management measures for the Paid Use of Plastic Shopping Bags in Retail Places* (China). Available online at: https://www.gov.cn/gongbao/content/2008/content_1157917.htm.

Ministry of Ecology and Environment of the PRC (2004). *Environmental protection industry standards of PRC: Technical Guidelines for Environmental Risk Assessment on Projects (HJ/T169-2004)* (China). Available online at: https://english.mee.gov.cn/Resources/standards/others1/Technical_Guideline_EIA/200710/t20071024_112078.shtml.

Mintz, J. A. (2001). Two cheers for global POPs: A summary and assessment of the stockholm convention on persistent organic pollutants. *Georgetown. Int. Environ. Law Rev.* 14, 319–332.

Nathan, J.B., Juan José, A., Ferguson, C. E., Blythe, J., Morgera, E., Boyd, D., et al. (2022). *Environmental Justice in the Ocean*. THE UNIVERSITY OF BRITISH COLUMBIA Institute for the Oceans and Fisheries WORKING PAPER SERIES Working Paper, ResearchGate.

National Academies of Sciences (2022). *Engineering, and Medicine, Reckoning with the U.S. Role in Global Ocean Plastic Waste* (Washington, DC: The National Academies Press).

National Development and Reform Commission, Ministry of Ecology and Environment, Ministry of Industry and Information Technology, Ministry of Housing and Urban-Rural Development and Ministry of Agriculture and Rural Affairs, Ministry of Commerce, et al. (2020). The opinions on further strengthening plastic pollution control. Available online at: https://www.ndrc.gov.cn/xxgk/zcfb/tz/202001/t20200119_1219275_ext.html (Accessed August 13, 2024).

National Development and Reform Commission, Ministry of Ecology and Environment, Ministry of Industry and Information Technology, Ministry of Housing and Urban-Rural Development, Ministry of Agriculture and Rural Affairs and Ministry of Commerce, et al. (2020). *Notice on Solidly Promoting the Control of Plastic Pollution* (China). Available online at: https://www.gov.cn/zhengce/zhengceku/2020-07/17/content_5527666.htm.

National Geographic (2024). Great Pacific Garbage Patch. Available online at: http://education.nationalgeographic.com/education/encyclopedia/great-pacific-garbage-patch/?ar-a=1 (Accessed August 13, 2024).

Nicholas, J.S. (2016). Microplastic Pollution in the great lakes: state, federal, and common law solutions. *93. U. Det. Mercy. L. Rev.* 273, 292. Available online at: https://digitalcommons.wayne.edu/lawfrp/409.

Nixon, R. (2011). *Slow Violence and the Environmentalism of the Poor* (Cambridge, MA: Harvard University Press). doi: 10.4159/harvard.9780674061194

NOAA (2022). The Marine Debris Act. Available online at: https://marinedebris.noaa.gov/about-our-program/marine-debris-act (Accessed August 13, 2024).

NPC Standing Committee (2012). *Cleaner Production Promotion Law of the People's Republic of China* (China: China Legal Publishing House).

NPC Standing Committee (2017). *Marine Environmental Protection Law of the People's Republic of China, (2017 Amendment): Chapter 7, Article 55* (China: China Rule of Law Publishing House).

Orellana, M. (2021).Report of the Special Rapporteur on the implications for human rights of the environmentally sound management and disposal of hazardous substances and wastes. Available online at: https://documents-dds-ny.un.org/doc/UNDOC/GEN/G21/200/24/PDF/G2120024.pdf (Accessed September 7, 2024). ?Open Element.

Otum, P., Black, J., Margaret Spring & Carlton Waterhouse (2023). The environmental justice implications of plastic pollution. *Environ. Law* 53, 10791.

Paul, E.H., and Michael, P.W. (2005). The stockholm convention on persistent organic pollutants. *Nat. Resour. ENV't.* 19, 49. doi: 10.2307/40924611

Pei, Q. (2018). Global progress on energy efficiency targets in the United Nations Sustainable Development Goals. *China Population. Resour. Environ.* 2, 7–11. Available online at: ttps://kns.cnki.net/kcms2/article/abstract?v=acR2UJ02YhS2yvGT5YqzSx27lTSKzBoLjtRx4UEroJEAW78yZf19bKhRehSvbeg_b1iVYizIkmqqNagb_yKYzxXithspA1_eWsTEgfOTJMjBTi1RpajojVt_mL3P_NskU6hZKvmW9aDWl5dYRX3We3QmoFmpW8RnnTd5ErG6t5ILDVa1ewuPRZ7eswMAaWTCrNHjl6atiqg=&uniplatform=NZKPT&language=CHS.

Penca, J. (2018). European plastics strategy: What promise for global marine litter? *Mar. Policy* 97, 197–201. doi: 10.1016/j.marpol.2018.06.004

People's Daily (2018). Microplastics have been found in "healthy" people for the first time, and are they harmful to health? Here's the answer. Available online at: https://baijiahao.baidu.com/s?id=1616289762240159705&wfr=spider&for=pc (Accessed August 13, 2024).

Qin, T. (2022a). The legal guarantee of achieving the goal of peak carbon neutrality from the perspective of holistic system view. *Legal. Sci. (J. Northwest. Univ. Political. Sci. Law).* 2, 101–112. doi: 10.16290/j.cnki.1674-5205.2022.02.010

Qin, T. (2022b). Important exposition of Xi Jinping's thought of rule of law on the guarantee of rule of law in ecological civilization construction from the perspective of holistic system view. *Tribune. Political. Sci. Law* 5, 3–13. Available online at: https://link.cnki.net/urlid/11.5608.D.20220823.0842.004.

Rochman, C. M., Browne, M. A., Underwood, A. J., van Franeker, J. A., Thompson, R. C., and Amaral-Zettler, L. A. (2016). The ecological impacts of marine debris: Unraveling the demonstrated evidence from what is perceived. *Ecology* 97, 302–312. doi: 10.1890/14-2070.1

Rummel-Bulska, I. (1994). The basel convention: A global approach for the management of hazardous wastes. *ENVTL. POL'y. L.* 24, 13. doi: 10.3233/EPL-1992-22102

Schmidt, C., Krauth, T., and Wagner, S. (2017). Export of plastic debris by rivers into the sea. *Environ. Sci. Technol.* 51, 12246–12253. doi: 10.1021/acs.est.7b02368

Schroeck, N. J. (2016). Microplastic pollution in the Great Lake: state, federal, and common law solution. *Univ. Detroit. Mercy. Law Rev.* 93, 273–291.

Sellar, P., and Abdel-Qader, S. (2021). *The Stockholm Convention's 20th Anniversary. 4 IRCL* (Berlin: Lexxion). 4, 119.

Small, C., and Nicholls, R. J. (2003). A global analysis of human settlementin coastal zones. *J. Coast. Res.* 19 (3), 584–599. doi: 10.2307/4299200

Stoett, P. (2022). Plastic pollution: A global challenge in need of multi-level justice centered solutions. *One Earth* 5, 593–596. doi: 10.1016/j.oneear.2022.05.017

The Government of Peru (2022). Contributions of Peru to the Process of the Intergovernmental Negotiating Committee (INC). Available online at: https://apps1.unep.org/resolutions/uploads/peru_submission_inc_plastics_eng_rev.pdfoverlay-context=node/344%3Fq%3Dnode/344 (Accessed September 7, 2024).

Tickler, D., Meeuwig, J. J., Palomares, M. L., Pauly, D., and Zeller, D.. (2018). Far from home: distance patterns of global fishing fleets. *Sci. Adv.* 4, 16. doi: 10.1126/sciadv.aar3279

Ulrich, B. (2003). *Risk Society (Bowen He, Trans.)* (China: Yilin Publishing House).

UN (2014a). *UNEP Year Book 2014: Emerging Issues in Our Global Environment* (Geneva). Available online at: https://www.unep.org/resources/report/unep-year-book-2014-emerging-issues-our-global-environment.

UN (2014b). *Valuing Plastic: The Business Case for Measuring* (Geneva: Managing and Disclosing Plastic Use in the Consumer Goods Industry). Available online at: https://www.pops.int/TheConvention/Overview/TextoftheConvention/tabid/2232/Default.aspx.

UNEP (2001). *Stockholm Convention* (Stockholm: United Nations Environment Programme).

UNEP (2014). *UNEP Year Book 2014: Emerging Issues in Our Global Environment* Available at: http://www.tanjiaoyi.com/article-6281-1.html. (Accessed October 10, 2024). (Geneva).

UNEP (2016a). Resolution I/6 on Marine Litter and Micro-plastics. Available online at: https://digitallibrary.un.org/record/3969797?ln=en&v=pdf (Accessed September 7, 2024).

UNEP (2016b). Resolution II/11 on Marine Litter and Micro-plastics. Available online at: https://digitallibrary.un.org/record/3969797?ln=en&v=pdf (Accessed September 7, 2024).

UNEP (2016c). Resolution III/7 on Marine Litter and Micro-plastics. Available online at: https://digitallibrary.un.org/record/3969797?ln=en&v=pdf (Accessed September 7, 2024).

UNEP (2016d). Resolution IV/6 on Marine Litter and Micro-plastics. Available online at: https://digitallibrary.un.org/record/3969797?ln=en&v=pdf (Accessed September 7, 2024).

UNEP (2016e). Resolution IV/9 on Disposable Plastic Products. Available online at: https://digitallibrary.un.org/record/3969797?ln=en&v=pdf (Accessed September 7, 2024).

UNEP/PP/INC.3/4 (2023). Zero draft text of the international legally binding instrument on plastic pollution, including in the marine environment. Available online at: https://www.circularonline.co.uk/news/un-plastic-treaty-draft-to-mandate-reuse-and-repair-targets/ (Accessed October 11, 2024).

UNEP/PP/INC.4/3 (2024). Revised draft text of the international legally binding instrument on plastic pollution, including in the marine Environment. Available online at: https://mp.weixin.qq.com/s?src=11&timestamp=1725701662&ver=5492&signature=pPreOKBPZ08n12nEofEv7QmEtg7JYgUJwYRNsGXQZJZM*-V3kcG7ME*R-aysVtuX-SYHwZcYL5RYx*RXwiBHbjwylatj1KbwMu8Q3-0spRJPmVpdUKmHylvrJAZ9y55x&new=1 (Accessed October 11, 2024).

UNGA (2017). Records of the ninetieth plenary meeting of the seventy-first session. Available online at: https://www.un.org/zh/ga/71/docs/pv.shtml (Accessed September 7, 2024).

United Nations Human Rights Council (2021). *The human right to a clean, healthy and sustainable environment (HRC resolution 48/13)* (Geneva). Available online at: https://digitallibrary.un.org/record/3945636?ln=en&v=pdf.

Veinla, H. (2018). Which adverse environmental impacts of an economic activity are legally acceptable and on what conditions. *Juridica Int.* 1, 61–68. doi: 10.12697/JI.2018.27.06

Wagner, M., and Scott, L. (2018). Freshwater microplastics: emerging environmental contaminants? *Springer. Nat.* 58, 1–303. doi: 10.1007/978-3-319-61615-5

Wang, L. (2024). *The fourth negotiation of the "Plastic Treaty" ended, and the global plastic pollution control is still unclear* (Beijing, China: China Sustainability Tribune), 40–43. Available online at: https://kns.cnki.net/kcms2/article/abstract?v=RE1hRqpi5T1OIVD1m_a-t3XZvpFsbuI7XqVpJXwZgeWvV9MRdfM-6CeH8Rkt3iZ3YxAJU2N35qNR6GoZh_dyTiToJPI9uNZCxQH5VyHH-YX0ZgbSCN30Xl47i5Y6LEeG07Dye1Rud-L0uTL36ISmnpOw0JO0VmnR4tXtO44bNu41C3KotSCDScz66aor3cY6h2UVCUE76iA=&uniplatform=NZKPT&language=CHS.

Wang, Y., and Li, J. (2022). Global plastic pollution control enters a new stage. *World Environ.* 2, 24–28. Available online at: https://kns.cnki.net/kcms2/article/abstract?v=acR2UJ02YhSUx -XqEO3NYhm0PBRy4-mjB4y6lZ_QVIKab9bPTjrMCEgH2RNMTWvWRKJtpD10zEx5OKUS-D0MOu9LgahpUflGD3cDdEwCqQeN66SdKDrrzXMntuy64HXxZAYRgNsinUG9XtXAIi5GHLR59CJeXqPbeA7T8GRVtFDNO9FGOS4VlvOmPr_CpsPDdLDy_gOvpPA=&uniplatform=NZKPT&language=CHS

Wilcox, C., Mallos, N. J., Leonard, G. H., Rodriguez, A., and Hardesty, B. D. (2016). Using expert elicitation to estimate the impacts of plastic pollution on marine wildlife. *Mar. Policy* 65, 107–114. doi: 10.1016/j.marpol.2015.10.014

Wood, S. F. (2018). Move over diamonds—plastics are forever: how the rise of plastic pollution in water can be regulated. *Villanova. Environ. Law J.* 29, 172–173. Available online at: https://digitalcommons.law.villanova.edu/elj/vol29/iss1/6.

Woodall, L. C., Sanchez-Vidal, A., Canals, M., Paterson, G. L. J., Coppock, R., Sleight, V., et al. (2014). The deep sea is a major sink for microplastic debris. *R. Soc. Open Sci.* 1, 140317. doi: 10.1098/rsos.140317

Yang, S., and Ding, X. (2022). Historic resolution to tackle plastic pollution - The UN Environment Assembly has agreed to develop an international agreement to combat plastic pollution. *World Environ.* 2, 32–35. Available online at: https://kns.cnki.net/kcms2/article/

abstract?v=acR2UJ02YhT94Y38xTcmSLppzyq4nmm5p2RlV-K7cMXf4ub1eTmvbRirmnweh71dmO4pjzXfLPXVrf7g4p5XEpZgQb_LNVqiXw-HWQrha0CUv-bDTc2pQyifA17ZEFukXaYDXePm7VES3WePWZqj2cdgq9wuAGGcFmvRIyXYLYLBUioSKp8ONzZRWDfk1CCxoy_Lu0jntak=&uniplatform=NZKP.

Zhang, J., Liu, Q., and Zhang, C. (2019). Legislative research on Marine plastics and microplastics management. *Mar. Environ. Sci.* 2, 171. doi: 10.13634/j.cnki.mes.2019.02.002

Zheng, Z., and Chen, D. (2022). Legal regulation of microplastic pollution from the perspective of risk society. *China Soft. Sci.* 5, 9–21. Available online at: https://kns.cnki.net/kcms2/article/abstract?v=acR2UJ02YhRyIHDIWaI1E7FzQqrquOcfmcm5nqa4G2oMKrLUi3x7TkgSd2pKMBpLNX2qThqyPpauKmBqPRh-jQ8TfsPzu_y75VU3BGi-QjPok6yvOItmr08TKnRzopaOCIBA7knBUeKOmbvR3_Lp2D_ZNQ_5ab0vCWqUXGZZhpARNtb5UwE70LaM-eR4iMaT8Doy7siGPI0=&uniplatform=NZKPT&language=CHS.

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 12 November 2024
DOI 10.3389/fmars.2024.1479528

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Qiuwen Wang,
East China University of Political Science and Law, China
Mehran Idris Khan,
University of International Business and Economics, China

*CORRESPONDENCE
Zhengliang Hu
zlhu@shmtu.edu.cn

RECEIVED 12 August 2024
ACCEPTED 23 September 2024
PUBLISHED 12 November 2024

CITATION
Li W and Hu Z (2024) Pathways in the governance of shipping decarbonization from perspective of balancing the conflicting interests.
Front. Mar. Sci. 11:1479528.
doi: 10.3389/fmars.2024.1479528

COPYRIGHT
© 2024 Li and Hu. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Pathways in the governance of shipping decarbonization from perspective of balancing the conflicting interests

Wenwen Li and Zhengliang Hu*

School of Law, Shanghai Maritime University, Shanghai, China

The shipping industry is featured by high carbon emissions. The 2023 IMO Strategy on Reduction of GHG Emissions from Ships sets forth the global goals of shipping decarbonization. Shipping decarbonization involves complicated issues of economy, technology, policy and law etc., and implies the conflicts between economic interests and environmental interests, between individual interests and public interests, between individual States' interests and international common interests and between current interests and long-term interests. This research suggests that balancing such conflicting interests need to follow the principle of prioritizing the international public environmental interests while taking into account the other interests because protection of environmental interests should be taken as the basic value orientation in shipping decarbonization governance and the principle of collaborating governmental intervention and market mechanisms by reference to the theory on the relationship between government and market in economics. Under the guidance of these principle, by reference to the equilibrium analysis method in economics and following the progressive decision theory in management, this research demonstrates that the main pathways in achieving such balance may include: making strategic plan and basic policy for reducing GHG emissions from ships by the government, implementing economic incentive policies such as tax incentives and fiscal subsidies, implementing ship energy efficiency measures, prudently implementing shipping carbon emissions trading mechanism, accelerating the establishment of alternative marine fuel supply chain, innovating alternative marine fuel technology and ship propulsion technology, and actively engaging in international cooperation.

KEYWORDS

shipping decarbonization, conflict of interests, alternative marine fuel, economic incentive, carbon emission trading mechanism, supply chain, technology innovation

1 Introduction

With the intensification of global climate change and the continuous increase of responsibility for greenhouse gas (GHG) emissions, reduction of GHG emissions from ships and ultimate net zero emissions are increasingly attracting attention from the international community (Shao and Wang, 2011). GHGs are gas components in the atmosphere that contribute to the greenhouse effect and CO_2 is the most significant one. Usually, GHG emissions are summarized as CO_2 emissions or carbon emissions for short, and the reduction of GHG emissions and ultimately net zero emissions are summarized as decarbonization. Shipping is a general term for maritime transport and inland navigation. The shipping industry is featured by high carbon emissions (Bullock et al., 2020). GHG emissions in shipping industry are mainly manifested as GHG emissions from ships, while other GHG emissions such as those originated from port facilities are rather few. The GHGs emitted from a ship while her main engine, auxiliary engine and boiler consume the conventional fossil fuel oils are composed of carbon dioxide (CO_2), sulphur oxides (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), unburned coals (HC), and particulate matters (PM2.5, PM10) all of which contribute to the climate change (Richter et al., 2004; Traut et al., 2018).

Shipping activities have the global nature and, as a result, the impact of GHG emissions from ships on climate change is not limited to the scope of individual counties. Therefore, their governance depends not only on the individual actions of the shipping countries, but more importantly on the joint efforts of the international community. The system of the United Nations Framework Convention on Climate Change (UNFCCC) does not regulate the GHG emissions from ships and these emissions are governed by International Maritime Organization (IMO). For this purpose, IMO has made great efforts to support the UN Sustainable Development Goal 13, i.e. taking urgent action to combat climate change and its impacts, in line with the 2015 Paris Agreement to cut GHG emissions (IMO, 2024). Besides IMO, other governmental organizations, NGOs, EU as regional organization and national governments have taken or are taking efforts in this regard at various levels.

Shipping decarbonization is an irreversible global trend and is rife with challenges. It involves complex issues of economy, technology, policy and law etc., and implies the severe conflicts of various interests, especially the conflicts between economic interests and environmental interests. In essence, balancing the conflicting interests is balance between the responsibility for reducing carbon emissions and the rights to development and is an issue of carbon justice (Ying and Jun, 2024). Presumably, how to balance the conflicting interests plays an important role of theoretical guidance in the shipping decarbonization governance, because shipping decarbonization should be achieved on the basis of the balanced interests. However, balancing the conflicting interests involves many complicated factors and is by no means easy to be achieved. Therefore, it needs to analyze the manifestations and reasons of the conflicts of interests, the principles to be followed and the main pathways to be taken in shipping decarbonization governance from the perspective of balancing the conflicting interests.

2 Materials and methods

2.1 Materials

The materials contained in the literatures reviewed in this research focus on the following four aspects:

2.1.1 Examinations of the extent of GHG emissions from ships and their contributions to the climate change

GHG emissions from ships are recognized as main contributors to the global climate change. The Fourth IMO Greenhouse Gas Study 2020 estimated that the share of shipping emissions in global anthropogenic emissions increased to 2.89% in 2018 (IMO, 2020). The United Nations Commission on International Trade Law (UNCTAD) estimates in Review of Maritime Transport 2023 that international shipping is responsible for nearly 3% of all global GHG emissions and shipping GHG emissions increased by 20% in the past decade (UNCTAD, 2024). International Chamber of Shipping (ICS) estimated that shipping GHG emissions was about 3% in the global GHG emissions (ICS, 2022). Longspur Research estimated in its report Methanol and Shipping issued on 25 January 2022 that shipping represented 3-4% of global GHG emissions, roughly equivalent to Germany's emissions (Longspur Research, 2022). A few academic literatures also estimated that currently shipping GHG emissions was about 3% in the global GHG emissions (Dong et al., 2022; Zheng and Wang, 2022). Presumably, this percentage has an increasing trend if no effective measures are to be taken to reduce the emissions.

2.1.2 Efforts made globally, regionally or nationally to reduce GHG emissions from ships

IMO has been actively engaged in a global approach to enhance ship's energy efficiency and develop measures to reduce GHG emissions from ships (Longspur Research, 2022). The IMO's efforts have mainly achieved the following results:

First, enactment of ship's energy efficiency standards.

In 2011, IMO adopted Resolution MEPC.203(62) on amendments to Annex VI to MARPOL 73/78 to mandate technical and operational energy efficiency measures, i.e. the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) which entered into force on 1 January 2013 (IMO, 2011). Figure 1 shows the importance of EEDI and SEEMP in reducing GHG emissions from ships.

In 2021, IMO adopted Resolution MEPC.328(76) to enforce the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) which entered into force on 1 January 2023 (IMO, 2021).

EEDI and EEXI are technical measures incentivizing the use of energy-efficient technologies, and SEEMP and CII are operational measures optimizing the operational performance of a ship, both

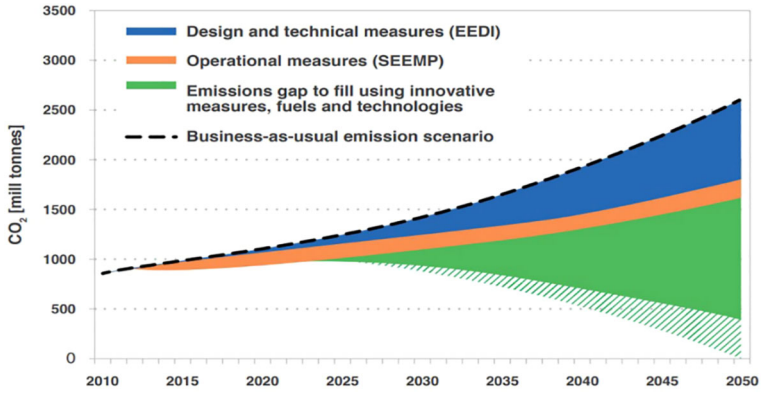


FIGURE 1
IMO GHG reduction pathway of EEDI and SEEMP Source: Fourth IMO Greenhouse Gas Study 2020.

for the purpose of reducing the amount of CO_2 emissions from international ships. In tandem with the alternative marine fuel switch, technology should be leveraged for greater energy efficiency gains (UNCTAD, 2024). China Classification Society (CCS) envisages that IMO will complete the evaluation of these short-term measures as required by Annex VI to MARPOL 73/78 (CCS, 2023).

Second, promulgation of strategies on reduction of GHG emissions from ships.

In April 2018, IMO adopted Resolution MEPC.304(72) on the Initial IMO Strategy on reduction of GHG emissions from ships (IMO, 2018). This Strategy envisaged to reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, as compared to 2008, and the total annual GHG emissions from international shipping should be reduced by at least 50% by 2050 as compared to 2008.

In July 2023, IMO adopted Resolution MEPC.377(80) on 2023 IMO Strategy on Reduction of GHG Emissions from Ships (IMO, 2023). This revised Strategy includes a commitment to ensure an uptake of alternative zero and near-zero GHG fuels by 2030, as well as indicative check-points for international shipping to reach net-zero GHG emissions for 2030 (by at least 20%, striving for 30%) and 2040 (by at least 70%, striving for 80%), and an enhanced ambition to reach net-zero GHG emissions from international shipping by or around 2050. IMO will amend the 2023 IMO Strategy in 2028 according to the situations (CCS, 2023).

Concurrently, national and regional regulations are influencing the global process of reducing GHG emissions from ships.

Besides implementation of the mandatory provisions of Annex VI to MARPOL 73/78, national regulations and policies focus on the adoption of market-based mechanisms in some countries (Kirval and Çalişkan, 2022), France, Japan, South Korea, Sweden and UK etc. are implementing carbon emission tax and/or trading scheme (Liao, 2022; Peng, 2020). Such mechanisms are designed to internalize the external costs of GHG emissions based on the polluter-pays principle (Wright, 2021) and provide economic incentives relating to GHG emissions reduction (HariLaos, 2012). Such market transaction policies are considered to enhance the economic and emission reduction potential more than the command control policy can (Wang et al., 2016).

Regional regulations are adopted at EU level and apply to ships calling at European ports. In July 2021, the European Commission released the package GHG reduction scheme called "Fit for 55" aiming at achieving the EU's goal of reducing net carbon emissions by 55% by 2030 as compared to 1990 level and climate neutrality in 2050 (European Council, 2021; Hu et al., 2023). In July 2023, the FuelEU Maritime Initiative was adopted by the European Council (European Council, 2023; European Union, 2023). As a key part of the EU's "Fit for 55" package, the main objectives of this initiative are to increase the demand for and consistent use of renewable and low-carbon fuels and to reduce GHG emissions from the shipping sector, while ensuring the smooth operation of maritime traffic and avoiding distortions in the internal market. In detail, it mandates that shipping reduce GHG intensity for energy used on board a ship by 2% from 2025, 6% from 2030, 14.5% from 2035, 31% from 2040, 62% from 2045 and 80% from 2050 (Tunagur, 2023). This initiative will apply to the CO_2, CH_4 and N_2O emissions from all ships with gross tonnage of 5,000 tons or more calling at EU ports. Ships that comply with the regulations will be issued a FuelEU Document of Compliance, and ships without holding the document will face penalties in the form of fines, expulsion, prohibition and/or detention. An obvious feature of the initiative is putting maritime transport into the European Union Emissions Trading Scheme (EU ETS) from 1 January 2024 (Zheng and Wang, 2022). The years of 2024 and 2025 are the transitional period and shipping companies covered by EU ETS are required to pay their quotas of 40% and 70% respectively of the applicable CO_2 emissions. 100% quota payment will be implemented from 1 January 2026. Currently, EU ETS covers CO_2 emissions, but will also cover CH_4 and N_2O emissions from 1 January 2026. It currently applies to the cargo ships and passenger ships with gross tonnage of 5,000 tons or more, but will also cover offshore engineering ships with gross tonnage of 5,000 tons or more from 1 January 2027. Based on the estimated EU carbon emission quota price of 95 euros per ton, the quota cost per ton of fuel will presumably increase by approximately 300 euros

(CCS, 2023). The impact of the Initiative on the shipping industry is expected to exceed that of EU ETS in both breadth and depth (CCS, 2023).

2.1.3 Examination of the current use of alternative marine fuels and its prospect

Shipping needs to replace the conventional fossil fuels with alternative marine fuels or renewable energy that emit fewer or no GHGs across their entire life cycle (well-to-wake) (UNCTAD, 2024). This has become a universal understanding. The introduction of alternative marine fuels and renewable energy is considered as an important strategy for shipping decarbonization (OECD, 2016; Chen et al., 2019). Alternative marine fuels and renewable energy may include liquefied natural gas (LNG), methanol, hydrogen, ammonia, liquefied biogas (LBG), ethanol, hydrotreated vegetable oil (HVO), fuel cells, nuclear power, wind power, solar power, and electricity (ITF, 2018; Wang and Wright, 2021; Santos et al., 2022; Wang et al., 2023). Within the scope of renewable energy, batteries are only suitable for short range (Wang et al., 2023), because as it stands today with the current battery technology, all electric vessels are primarily used for shorter distances in harbors and coastal shipping (Longspur Research, 2022); wind power can only assist propulsion, i.e. wind-assisted ship propulsion (WASP) (Longspur Research, 2022); nuclear power does not emit GHGs, but involves extremely high costs in construction and very high requirements of safety, operation and maintenance, resulting in its current application almost solely to big navy ships or submarines (Wang, 2020). Therefore, the introduction of alternative marine fuels is required to reduce the climate impact of shipping (Hansson et al., 2020). As a whole, many attentions have been paid to LNG, but more attentions are now paid to methanol, ammonia and hydrogen fuels (Ampah et al., 2021). Hydrogen, ammonia, methanol and biomethane are considered as the key contenders (Longspur Research, 2022). There is an increasing global demand for ammonia to be used as a versatile marine fuel (Cheliotis et al., 2021). One prediction is that ammonia will become one of the three most promising fuels in 2050 and its proportion in the marine fuels will increase from 7% in 2030 to 20% in 2050 (Sun, 2021). It is also predicted that a sustainable global energy future can be attained by utilizing hydrogen fuel in addition to other alternative fuels (Al-Enazi et al., 2021).

Life cycle (well-to-wake) emissions of alternative marine fuels from extraction and energy production to final use of the fuels in the ships is analyzed, covering well-to-tank emissions and tank-to-wake emissions (Figure 2) (Longspur Research, 2022). These emissions need be taken into account in evaluating particular alternative marine fuels.

Noticeably, each alternative fuel has its advantages and disadvantages from perspectives of GHG reduction potential, density, cost, useability as shown in Table 1 and Longspur Research concludes that, taking all the above factors into account, methanol is the best solution available today (Longspur Research, 2022).

Table 1 above indicates that the conventional heavy fuel oil (HFO) has the lowest GHG reduction potential, although it has the advantage of density and cost and that hydrogen, ammonia, methanol, LNG and li-ion have the advantage of GHG reduction potential. However, the use of hydrogen, ammonia, LNG or li-ion currently involves high costs. In addition, the density of hydrogen and li-ion is low, which means their use may significantly reduce a ship's cargo carrying capacity.

Noticeably, hydrogen, ammonia and methanol are divided into gray, blue and green categories according to the energy used and process adopted. In simple terms, gray fuels are produced by using fossil energy such as coal or natural gas. Blue fuels are produced by using fossil energy, but the refining process uses the technology of carbon capture and storage (CCS) to reduce carbon emissions. Green fuels are produced by using renewable energy such as solar energy or wind power.

CCS estimates that in the life circle and as compared to HFO, green methanol can reduce 63%-99% of GHG emissions; grey hydrogen has higher GHG emissions than HFO, but green hydrogen can reduce 96% of GHG emissions; coal-to-ammonia

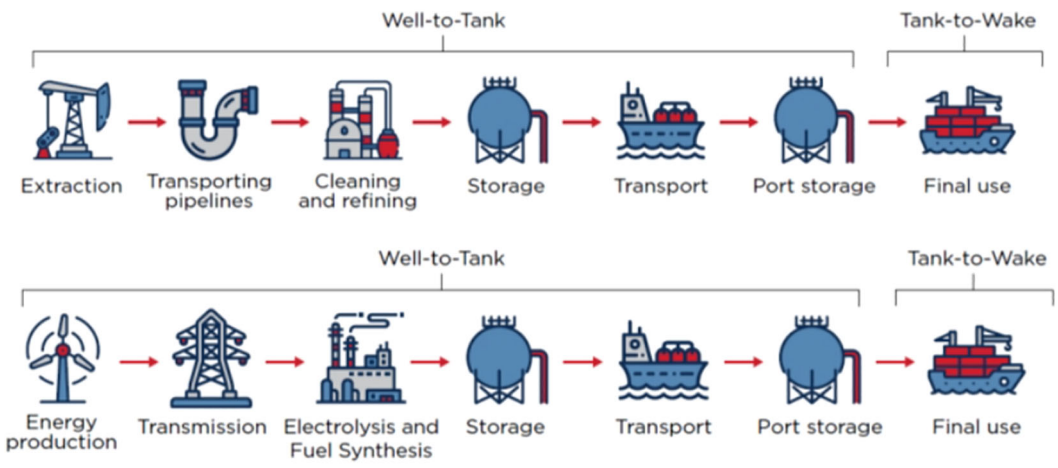


FIGURE 2
Shipping fuels and energy life circle (well to wake). Source: Longspur Research, 2022.

TABLE 1 Sustainable fuel options summarized.

Criterirum	Hydrogen	Ammonia	Methanol	LNG	Li-ion	HFO
GHG reduction potential	5	4	5	5	5	1
Density	2	3	4	4	1	5
Cost	2	1	3	1	2	5
Useability	4	3	4	3	4	3
Average	3	3	4	3	3	4

Source: Longspur Research, 2022.

has higher GHG emissions than HFO, and natural gas synthesis of ammonia can only reduce about 9% of GHG emissions, but green ammonia can reduce 93%-100% of GHG emissions. Therefore, using green methanol may achieve the medium and long-term emission reduction targets, and using green hydrogen and green ammonia may achieve the long-term emission reduction targets. Noticeably, grey fuels mean low costs, but have low GHG reduction potential or even cannot reduce any emission. To the contrary, green fuels mean much higher costs, but have much higher GHG reduction potential. To achieve zero GHG emissions in their life circle, grey alternative fuels need to be progressively transited to green ones.

In practice, LNG or methanol was chosen either as dual fuel or single fuel in most newbuilding of ships using alternative fuels in the past two years, and the percentage of using LNG or methanol in new shipbuilding seems roughly equal (CCS, 2023).

Worldwide use of alternative marine fuels has a long way to go. By the end of 2023, a mere 6% of the global fleet was equipped to operate alternative fuels and the nascent stage of the maritime decarbonization ecosystem means that alternative zero-carbon fuels are still in scare supply (OECD, 2023). Currently, rapid shipping energy transition and decarbonization depends on alternative fuel availability and costs, fuel technology maturation levels, technical feasibility, safety, bunkering infrastructure requirements and onboard storage, in addition to ship and engine design, and crew skills and capabilities (UNCTAD, 2024). So far as the availability of methanol is concerned, Zhongmin Zhonghang New Energy Science and Technology Group Co., Ltd. (ZMZH) estimated that nearly 65% was LNG-to-methanol, nearly 35% was coal-to-methanol, and bio-methanol was less than 1% in the world in 2023 (ZMZH, 2024). Bio-methanol has much higher GHG reduction potential than fossil methanol including LNG-to-methanol and coal-to-methanol, but the current availability of bio-methanol is far from satisfactory. Similar situation exists with respect to green hydrogen and green ammonia. Nevertheless, due to the progressive nature of introducing alternative marine fuels in the shipping industry, the share of conventional fuel oils in shipping energy will gradually decrease over a long period of time, but it is predicted that these oils will not be dramatically replaced (CCS, 2023).

2.1.4 The negative impacts of shipping decarbonization

Shipping decarbonization requires a transition in technology and operations, and an uptake of alternative low and zero GHG fuels. However, it entails increase in maritime logistics costs, because huge investments are required to generate the alternative marine fuels, to adjust ship designs, engines and operations, driving up costs for shipowners, industry and ultimately trade and the final consumers (UNCTAD, 2024). The most critical issues in the use of alternative marine fuels are envisaged to be: high costs (Prussi et al., 2021; Salmon and Bañares-Alcántara, 2021; Martin, 2021), GHG emissions (Pavlenko et al., 2020; Prussi et al., 2021; Jang et al., 2021), including emissions during manufacturing process, e.g., a large amount of GHG emissions is produced during the methanol manufacturing process (Martin, 2021), technical maturity (Valera-Medina et al., 2021; Van Hoecke et al., 2021), safety regulation (Deniz and Zincir, 2016), and expertise needed (Prussi et al., 2021), etc. In particular, green hydrogen and green ammonia have the potential of zero GHG emission, but involve the issues of operational safety and high prices (Hansson et al., 2020; Wang et al., 2021b). However, with the continuous development of technologies in the production, transport and utilization of alternative marine fuels, the full life-cycle GHG emissions intensity of the fuels such as methanol and ammonia will gradually decrease in the future (CCS, 2023).

Besides, the cost of building ships using alternative marine fuels or dual fuels will also increase. For example, the cost of building a new LNG-powered ship is estimated at around 10%–20% higher than a conventional ship.

2.2 Methods

Shipping decarbonization entails the conflicts between various interests, especially between the economic interests of the shipping industry on one hand and the international environmental interests on the other. Achieving the shipping decarbonization goals involves complicated issues of economy, technology, policy and law, etc. This research aims at exploring and examining the main pathways relating to the governance in shipping decarbonization from perspective of balancing the conflicting interests. For this purpose, this research makes reference to: (a) the theory on the relationship between government and market in economics in addressing the principle of collaborating governmental intervention and market mechanisms in Section 3.2.2 and its application in Sections 3.3.2, 3.3.5 and 3.3.6, because shipping decarbonization needs the governmental intervention and the market mechanisms to play their respective roles; (b) the progressive decision theory in management in

addressing the measure of formulating strategic plans and specific policies for shipping decarbonization by government in Section 3.3.1, because shipping decarbonization is a long process involving high costs and difficulties in technology innovation; (c) the equilibrium analysis method in economics in exploring the main pathway in shipping decarbonization in Section 3.3, because the measures should be taken on the basis of balance of the conflicting interests.

The basic analytical framework in this research is as follows: first, based upon the examinations of the available data sources used and other materials introduced in Section 2, critically examining the conflicting interests inherent in shipping decarbonization in Section 3.1; secondly, analyzing and putting forward the principles to be followed as guiding ideology in balancing the conflicting interests in Section 3.2; thirdly, on these bases and partly by reference to the empirical analysis of the situations in China, exploring the main pathways in the shipping decarbonization governance in Section 3.3.

3 Discussion

3.1 Manifestation and reasons of conflicts of interests in shipping decarbonization

Global climate change is an environmental crisis currently facing all the people in the world and entails the conflicts of interests around the environment. The new environmental perspective believes that the environmental benefits are no longer the currently existing benefits and human interests only, but involves conflicts between current interests and future interests, between national interests and international interests, and that the conflicts between economic interests and environmental interests are undoubtedly very prominent (Zhou, 2009). All these interests and their conflicts are reflected in the process of shipping decarbonization.

3.1.1 Conflict between economic interests and environmental interests

Environmental interests may be understood as the satisfaction of people's material or spiritual needs by good natural environment. Presumably, people may strive to pursuing maximum economic profits from the natural world or develop the economy without duly considering the environmental costs, whereby transferring the environmental costs to society and others and causing external diseconomies and, as a result, the economic development sacrifices the environmental interests (Zhou, 2009).

It is well recognized that the GHGs into the atmosphere cause climate change resulting in various hazards including sea level rise, increase in water areas, disease and other harm to human health, mass extinction of living organisms, ecosystem destruction, storms, floods and drought, grain reduction and other economic losses. All these are reflections of harms to the environmental interests.

The ship's GHGs into the atmosphere mainly come from the exhaust emissions caused by the use of conventional fuel oils by ship engines. These oils used in large ships are mainly diesel oil and HFO. Diesel oil includes marine gas oil (MGO) and marine diesel oil (MDO). The price of diesel oil is about twice that of HFO. Obviously, the use of HFO is to reduce fuel costs because fuel oils are the biggest cost of ship operation and conventional fuel oils account for approximately 30% -35% of the total operating costs of a ship. The level of harm to the climate caused by exhaust emissions from HFO is much greater than that of diesel oils.

The conflict between economic interests and environmental interests in the GHG emissions from ships is evident. On one hand, maritime transport has the feature of large capacity and low freights as compared to other modes of transport and is vital to the international trade. The use of HFO is a crucial factor of low freights. Over 80% of all cargo trade in the world flows through the high seas (UNCTAD, 2024). In China, nearly 95% of the goods in international trade were transported by sea in 2023 (MOT, 2024a). Therefore, it's not an exaggeration to say that maritime transport ensures the development of international cargo trade and has brought enormous economic interests to the traders and shipowners, as well as the trading countries and the international community. On the other hand, however, GHG emissions from ships cause harm to the climate and thus the environmental interests. To decarbonize shipping, the fundamental solution lies in using alternative marine fuels or other energy sources to replace the conventional fossil fuels (Hansson et al., 2020). However, the use of alternative fuels currently and in the near future will significantly increase the shipbuilding costs and ship operating costs, resulting potentially significant increase of freights and consequently higher commodity prices, and may even involve the issues of operational safety. No doubt, this means a significant negative impact on the above economic interests generated by shipping.

3.1.2 Conflict between individual interests and public interests

Conflict between individual interests and public interests often occurs, because the individuals often pursue their economic interests in their production and business activities at the cost of damaging the environment. Consequently, the interests they pursue will bring harm to the public interests. So far as maritime transport is concerned, the individual shipping companies aim to reduce ship operating costs and improve economic efficiency by using low-cost HFO, but the GHG emissions cause harm to the climate, thereby damaging the public interest of the environment. To the contrary, using alternative marine fuels can reduce GHG emissions or achieve zero emission and thus benefit the public interest of the environment, but causes harm to the individual interests of shipping companies and cargo traders.

From perspective of a country, the conflict between individual interests and public interests can also be used to interpret the conflict between the interests of the shipping industry and the overall interests of the country. This is because using HFO serves the interests of the shipping industry, but GHG emissions from ships using HFO harms the overall environmental interests of the country.

3.1.3 Conflict between interests of individual countries and public interests of the international community

In front of the natural environment, countries around the world are a community with a shared future. All countries on earth can benefit together from the natural world, but also have to bear the natural catastrophic harms together (Xiang, 2003). From global perspective, where the policy and law of a country relax environment protection for the purpose of pursuing economic interests in a certain field, the economic activities in that country will not only have the effect of damaging the environment within its borders, but may also have cross-border negative environmental impacts, thereby causing harm to the public environmental interests of the international community.

Due to air circulation, the GHG emissions from ships into the atmosphere will not only damage the atmospheric environment of the country where the emissions are located, but will also damage that of the neighboring countries. The navigation range of international ships is not limited to the waters of the flag State. Therefore, where a ship is sailing in the waters of other countries or on the high seas, her emissions of GHG will damage the atmospheric environment of other countries or the international atmospheric environment, consequently damaging the international environmental interests. As a result, conflict between the economic interests of individual countries and the public environmental interests of the international community arises. Such conflict of interests well implies that reducing the negative impact of GHG emissions from ships in shipping decarbonization cannot be achieved through the efforts of several individual countries only, but should rely on the joint efforts of the international community.

3.1.4 Conflict between current interests and long-term interests

Such conflict is also called intergenerational conflict of interests (Hou and Nie, 2016), and is unique in the area of environmental protection. Presumably, damage to the environment by contemporary people may bring damage to the interests to the future generations because atmospheric self-purification is rather slow and the purifying effect of large-scale afforestation on the air is quite limited and as a result, recovery of the severely damaged environment often takes very long time and/or incurs huge costs. Therefore, if the contemporary people fail to pay sufficient attention to the environmental protection as driven by the current interests, the damaged environment will harm the environmental interests of the future generations and as a result, intergenerational conflict will arise.

For this reason, the atmospheric environment severely damaged by the emission of GHG into the atmosphere from ships and other sources of pollution may cause the conflict of intergenerational interests, i.e. conflict between the economic interest of the contemporary people and the environmental interests of the future generations.

3.2 Principles to be followed in balancing conflicting interests in shipping decarbonization governance

Balance of conflicting interests means the state of relatively peaceful coexistence within a certain pattern and system of interests (Feng, 2007). When conflict of interests cannot be resolved through spontaneous social adjustment, balancing interests through external means is needed to coordinate the conflicting factors, whereby maximizing the satisfaction of the interests and needs of all conflicting parties, and at the same time trying utmost to avoid wasting resources. Needless to say, the principles to be followed in balancing the conflicting interests in shipping decarbonization governance are crucial. This research suggests that the following two principles to be followed.

3.2.1 The principle of prioritizing international public environmental interests while taking into account the other interests

The rationale of this principle is mainly the basic value orientation in balancing the conflicting interests in shipping decarbonization. Theoretically, balancing the conflicting interests needs to be guided by specific basic values. In legal terms, the balance of interests serves as a standard of basic value judgment of law and plays a guiding role in the selection of interests in the process of social resource allocation (Luo, 2012). Shipping decarbonization is within the category of environmental protection, but involves many factors such as economy, technology, policy and law among which the economic and technological factors are the basis of formulating policy and law. Therefore, balancing the conflicting interests in shipping decarbonization should take the protection of public environmental interests as the basic value orientation and consequently adhere to prioritizing international public environmental interests.

International public environmental interests may be understood as the common interests of all or most members of the international community benefited from good natural environment. Such interests are environmental interests firstly, public interests secondly and international interests finally. As aforementioned, when conflict occurs between public interests and individual interests, decisions and actions should be guided by the priority of public interests. Where free competition causes damage to public interests, the government needs to use its public power to rectify in order to coordinate the development of public interests and individual rights (Yu, 2008). Due to the international nature of shipping and the air circulation, the GHG emissions from ships cause harm to the international public environmental interests. The goal of shipping decarbonization is to reduce GHG emissions from ships and ultimately achieve net zero emissions. Therefore, the protection of international public environmental interests should undoubtedly be the basic value orientation in shipping decarbonization. Consequently, such interests should be prioritized in balancing the various conflicting interests.

However, prioritizing the international public environmental interests cannot ignore other related interests. Instead, all the other related interests should also be taken into account. Theoretically, prioritizing public interests requires a moderate tilt in its protection by the individual States and their governments, but it is not a unilateral restriction or deprivation of rights and freedoms of individual persons. Instead, appropriate restrictions should be placed on public interests in order to achieve the optimal balance between natural resource allocation and utilization in social development. In other words, balancing the conflicting interests involved in shipping decarbonization is to achieve the goal that the protection of international public environmental interests is given priority, while the other related interests, especially the economic interests of maritime transport are taken into account. Otherwise, if no economic interests are pursued, environmental interests would be meaningless.

3.2.2 The principle of collaborating governmental intervention and market mechanisms

Noticeably, the IMO Policies and Practices Related to the Reduction of Greenhouse Gas Emissions from Ships adopted in 2003 indicate that the international community should adopt market mechanisms to address carbon emissions from ships (IMO, 2003). This is because IMO envisaged that due to the continuous growth of global trade volume in the future, the increase in carbon emissions caused by the increase in the number of ships would offset the reduction in carbon emissions due to the improvement in ship energy efficiency and, therefore, international shipping carbon emissions could not be controlled solely through technological means. Market mechanisms are considered an essential means to address carbon emissions from ships, as they can control the total carbon emissions from shipping within a certain range, and have dynamic efficiency to stimulate the shipping industry to invest in energy efficiency technology research and development (Zheng and Wang, 2022).

However, shipping activities are market behaviors and the climate change caused by the GHG emissions from ships is the negative externality of these behaviors. The consequential inability to achieve optimal allocation of atmospheric environmental resources is in the nature of market failure in economics. Therefore, the governmental intervention is needed to rectify such market failure. The theory on the relationship between government and market in economics believes that market failure requires governmental regulation on market mechanisms to compensate for the market deficiencies. Obviously, solving the external negative effect of market behaviors on the damage to the environment cannot solely rely on market mechanisms. Instead, the government needs adopt appropriate economic, legal and administrative measures for macroeconomic regulation and control. At the same time, however, the important role of the market mechanisms cannot be ignored in environmental governance. Under the guidance and constraints of government macro-control measures, it is necessary to leverage market mechanisms to effectively mobilize the enthusiasm of enterprises and other individuals, encouraging them to allocate resources according to market demand, reducing damage to the environment through environmental technology innovation and other environmental protection measures.

The necessity of governmental intervention can be further demonstrated by the role of the driving mechanism of governmental policies for shipping decarbonization. There are three main driving mechanisms for shipping decarbonization, i.e. governmental policy and law, moral and social responsibility, and economic interests of shipping companies. The first and second driving mechanisms are proactive, and the third one is passive. Undoubtedly, shipping decarbonization will increase operating costs significantly to shipping companies and is thus not preferred by the vast majority of shipping companies. Some big shipping companies, e.g. the major international container lines have expressed to support shipping decarbonization mainly because of the constraints of EU ETS and other currently applicable or potential regulatory schemes including the 2023 IMO Strategy, although partly in consideration of moral and social responsibility and of the need for maintaining or promoting competitiveness in the market. Therefore, the driving force generated by the third mechanism is rather week, while that generated by the second mechanism is quite limited. Reducing GHG emissions from ships entails the industries and enterprises relating to the production and supply of alternative fuels and renewable energy, green technology innovation, equipment manufacturing, ship operation, financing, standard setting, and market transaction, etc., far exceeding the scope of traditional shipping supply chain (CCS, 2023). The industries and enterprises need to jointly promote the safe application of alternative fuels, renewable energy and green technology in the shipping industry, and build green and sustainable shipping development industry chain (CCS, 2023). In so doing, however, the industries and enterprises need the governmental guidance and support. As a result, shipping decarbonization shall mainly rely on the first mechanism and consequently needs necessary governmental intervention.

3.3 Specific pathways in shipping decarbonization governance

Following the above two principles and the equilibrium analysis method in economics, this research explores and suggests the following specific pathways in shipping decarbonization governance from perspective of balancing the conflicting interests.

3.3.1 Formulating strategic plans and specific policies for shipping decarbonization by government

Formulating strategic plans and specific policies is within the governmental functions and is important in shipping decarbonization. As aforementioned, shipping decarbonization will significantly increase the shipbuilding costs and ship operating costs, thereby causing harm to the interests of shipping and cargo trading companies, as well as the overall economic interests of shipping countries. In addition, shipping decarbonization requires the

empowerment of alternative marine fuel technology and ship propulsion technology. However, the development and mature application of such new technology at reasonable costs requires a long process. In addition, shipping decarbonization closely relates to international public environmental interest. Therefore, shipping decarbonization will be inevitably a global and long-term goal and task and thus needs to be viewed from strategic perspective and thinking, requires effective collaboration between governments and industries. Primarily, the governments need to formulate targeted strategic plans and specific unified development policies. This kind of planning has a guiding role for shipping companies and other relevant stakeholders to take actions, and are the basis for the governments to formulate policies and for the legislative organs to formulate laws and regulations as well as for their implementation. Such planning and specific policies should adhere to the principle of prioritizing the protection of environmental public interests and taking other interests into account, and adopt a progressive path.

Noticeably, according to the progressive decision theory in management, any hasty approach will make it difficult to coordinate and balance the conflicting interests during any revolutionary transition like ultimately net zero GHG emissions from ships. In particular, while protecting the international public environment interests in shipping decarbonization, it is necessary to maintain the long-term survival and development interests of many medium-sized and small shipping enterprises. As aforementioned, progressive reduction of GHG emissions from ships and ultimately achieving net zero emissions is also the pathway adopted by IMO and EU. Furthermore, it is crucial that the governmental policies are systematic, objective, transparent and efficient and have continuity without radical and significant change thereof in order to ensure the market certainty, because the shipping companies and other related stakeholder need a steady policy environment which help them to predict the potential risks of costs, technology etc. and to avoid or minimize the risks in making big and long-term investments for the purpose of ship decarbonization.

Det Norske Veritas (DNV) indicates in Energy Transition Outlook China 2024 that in China, the central government formulates the policy direction and goals and has the authority to ensure their implementation (DNV, 2024a). In the context of China's national situations, therefore, the role of governmental intervention in shipping decarbonization process is particularly evident and feasible. Till now, China has not developed specific strategy plan for shipping decarbonization yet. However, On 31 July 2024, the CPC Central Committee and the State Council jointly released the Opinions on Accelerating the Comprehensive Green Transformation of Economic and Social Development (CPC and State Council, 2024) which may be deemed as the current general policy of greenization in China. The Opinions emphasize the general requirements of collaboration, innovation and safety in green transformation. So far as shipping decarbonization is or may be concerned, the Opinions require promoting non-fossil energy to replace fossil energy safely, reliably and progressively, encouraging innovation, production and use marine fuels of zero-carbon emission, accelerating innovation of key technologies, establishing sound financial and tax policies and market mechanisms, promoting national carbon emission trading market and voluntary GHG emissions reduction trading market, formulating green development standard system, and strengthening international cooperation. In addition, several instruments have been individually or jointly released by the Ministry of Transport (MOT) and other ministerial department under the State Council which describe China's general active attitude and directions or specifying the goals of development in shipping decarbonization. It can be envisaged that China will follow its pragmatic pace in shipping decarbonization (DNV, 2024a). At present, China needs to develop specific strategy plan for reducing GHG emissions from ships in response to the 2023 IMO Strategy and based on its own specific situations. As a whole, China is a shipping and trading power in the world. Besides China COSCO Shipping, China Merchants Energy Shipping and a few large shipping enterprises, however, China has many medium-sized and small shipping enterprises causing significant structural imbalance of the shipping industry. This situation necessitates the Chinese government to take positive and prudent attitude towards shipping decarbonization policy. Especially, adopting progressive measures in shipping decarbonization is of particular significance in China. However, when IMO's mandatory standards of reducing GHG emissions from ships through amendment to Annex VI to MAROPOL 73/78 come into force, these standards are envisaged to be strictly implemented in China.

3.3.2 Implementing economic incentive measures

Theoretically, when individual interests are harmed due to the need for the protection of public interests, the government is required to provide compensation, whereby achieving a balance between the public interests and the individual interests (Fan, 2009). In shipping decarbonization, the economic incentives are necessitated by the significant increase in the construction and operating costs of ships and the need for ensuring the steady development of shipping industry.

Currently, two main technical measures have been taken to significantly reduce GHG emissions from ships by using alternative marine fuels, i.e. (a) dual fuel design for ships by which their engines can simultaneously use conventional fossil fuels and alternative fuels, mainly methanol and LNG, and (b) ship's use of single alternative fuel. However, it is estimated that dual fuel design for a ship normally increases the construction cost by 10%-20%, and that currently the delivery prices of alternative fuels are about twice that of HFO and even higher. Figure 3 shows DNV's estimation of increase of shipping costs of three main kinds of ships by using alternative marine fuels in short, medium and long term respectively.

The significant increase of the construction and operating costs of ships in shipping decarbonization will bring two consequences. First, it will affect the enthusiasm and initiative of shipping companies to participate in shipping decarbonization transition. Secondly, the significant increase in operating costs of ships will be passed on to the cargo traders through the increase in freights and ultimately passed on to the commodity consumers (UNCTAD, 2024).

Presumably, rapidly and dramatically implementing high-intensity mechanism for reducing GHG emissions from ships may force many small and even medium-sized shipping

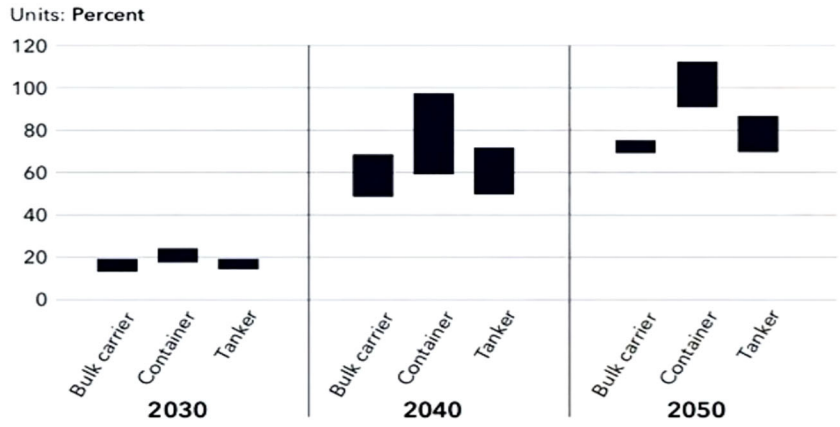


FIGURE 3
Range of increase in total costs per transport work (USD/DWT-nm for baulk and tank, USD/TEU-nm for containers) from decarbonization in 2030, 2040, and 2050, relative to a business-as-usual scenario. Source: DNV. 2024 edition of Maritime Forecast to 2050 (DNV, 2024b).

companies to exit the market and consequently may even affect the international competitiveness of shipping industry and foreign trade in a shipping country like China. In order to avoid or minimize the damage to industry interests and even the overall economic interests of a shipping country, balancing the conflicts between the industry interests and national overall interests on one hand and the international public environmental interests on the other hand, it is necessary for the government to implement appropriate economic incentive measures in the form of tax incentives, financial subsidies, etc. in the initial stage of shipping decarbonization, ensuring the steady supply and reasonable pricing of alternative fuels for ships, and encouraging the innovation and application of new technologies regarding alternative fuel safety and ship propulsion. However, the economic incentives shall be provided by the governments on the condition of non-violation of the rules of anti-subsidies and other competition rules in anti-monopoly law. Inevitably. the economic incentives are subject to the government's financial capability and consequently may become problems of the week countries. These countries shall do according to their respective capability and international assistance in called for.

Limited economic incentive measures have been implemented or are being implemented to support shipping decarbonization in China. For examples, Shanghai, Shenzhen and several other cities implement financial subsidies for ship projects using LNG instead of conventional fuel oils (Yang et al., 2023). The ships which save energy or use new energy may be exempted from tax on vessel by virtue of Article 4 of the Vehicle and Vessel Tax Law of 2011 as amended in 2019. On 2 August 2024, MOT and the National Development and Reform Commission under the State Council jointly released the Implementation Rules on Subsidies for Scrapping and Updating Old Operating Ships in Transportation (MOT, 2024b). By virtue of Article 7 of these Rules, the owners of a newly-built vessel engaged in transport in inland waters or coastal waters may apply for financial subsidy where the vessel's main propulsion uses LNG, methanol, hydrogen, ammonia or battery, or uses dual fuels of LNG and fossil oil if the fossil oil substitution rate of more than 60% or dual fuels of methanol and fossil oil if the fossil oil substitution rate of more than 50%. However, currently the amounts of these economic incentives are rather limited and incentives are not applicable to ships engaged in international transport. Therefore, the economic incentive policies in China need be updated as time goes on.

3.3.3 Implementing energy efficiency measures for ships

The rationale of this pathway is that implementing the technical measures (EEDI and EEXI) and the operational measures (SEEMP and CII) currently meet the needs of progressive shipping decarbonization development. It is estimated that adopting corresponding GHG emissions control technologies and operational measures by international shipping industry may be able to reduce the existing GHG emissions from ships by 25%-50% (Nast, 2013). DNV estimates in the 2024 edition of Maritime Forecast to 2050 that implementing the technical and operational measures may reduce fuel consumptions by 4%-16% (DNV, 2024b).

While affirming the role of implementing these technical and operational measures in reducing GHG emissions, we need to recognize their limitations, because these measures cannot contribute to achieving net zero GHG emissions from ships and therefore are considered as short-term measures. However, due to the current limitations of technology, availability and pricing of alternative marine fuels, these measures currently suit to reducing GHG emissions from ships and are in line with the balance of conflicts between current interests and long-term interests, and between individual economic interests and international public environmental interests. Therefore, efforts need to be continued to play this role in shipping decarbonization. DNV emphasizes in the 2024 edition of Maritime Forecast to 2050 that before carbon neutral fuels become a viable option, prioritizing the development and application of technologies to reduce energy consumption is crucial for shipping emissions reduction (DNV, 2024b).

In China, the Maritime Safety Administration (MSA) released the Administrative Measures for Ship Energy Consumption Data and Carbon Intensity on 22 November 2022 (MSA, 2022), in order to implement the requirements of Annex VI to MARPOL73/78. The provisions relating to carbon intensity are applicable to the ships with gross tonnage of 5,000 tons or more which fly Chinese flag and are engaged in international shipping, but currently not applicable to the Chinese ships engaged in coastal trade or inland navigation.

3.3.4 Prudently implementing of shipping carbon emissions trading mechanism

Appropriate implementation of shipping carbon emissions trading mechanism is helpful for reducing GHG emissions from ships, because this market mechanism may control the total quantity of CO_2 emissions from ships by means of carbon emission quota trading under the regulations of the government. It seems this mechanism is widely regarded as a key for reducing carbon emissions from ships. It is even considered as an important direction for future emissions reduction in maritime industry (Peng, 2020; Liao, 2022).

While the role of this mechanism in reducing GHG emissions from ships should be acknowledged, however, its limitations are obvious. First, the establishment and operation of this mechanism involve complex factors with high implementation costs. Secondly, this mechanism can only help reduce GHG emissions from ships, but does not contribute to achieving net zero emissions. Thirdly, the allocation of carbon emission quotas involves the issues of fair value and conflicts of interests, because if the control on the total quantity carbon emissions is too strict and quota allocation is carried out through auction method, it is easy to lead to excessively high quota prices and even to market manipulation of pricing, as a result of which regardless of whether shipping companies purchase quotas at high prices or use low- or zero-carbon ship fuels at high prices, significant increase of the operating costs of shipping companies will result in higher freights, causing harm to the economic interests of the shipping and trading companies. Fourthly, this mechanism not only involves reduction of GHG emissions from ships, but may lie enormous economic benefits of a country behind it which may derogate from international public environmental interests. For these reasons, there have been critical comments from the academic circle in China regarding EU ETS. For examples, the EU's move is suspected of violating the UNFCCC and its Kyoto Protocol of 1997 (Zhu, 2015); EU ETS pursues the discourse power of green shipping industry in the name of environmental protection, and by setting stricter green shipping standards, adopts the strategy of long-arm jurisdiction in the shipping industry and expands its export share in energy-saving and emission reduction technologies (Chen et al., 2016). Unilateral mechanism to reduce GHG emissions from ships may also possibly form green trade barriers. Presumably, all these mean that the functions of this mechanism cannot be exaggerated. In particular, its functions should be ensured to solely reduce GHG emissions from ships. Consequently, this mechanism needs to be implemented prudently in order to overcome its limitations to the utmost extent.

In China, carbon emission trading started in 2021. Currently it applies to power plants only, and there is no specific schedule to apply it to GHG emissions from ships. The only exception is that 31 shipping companies based in Shanghai have been incorporated into the local carbon emission trading market conducted by Shanghai Environment and Energy Exchange. The Global Green Shipping Development Report 2023 issued Shanghai International Shipping Institute (SISI) shows that in 2023, the trading volume of carbon emission allowances (CEA) with respect to shipping was 770,000 tons and the transition amount was CNY55 million (SISI, 2024). It can be envisaged that China will take a prudent attitude towards nationwide shipping carbon emission trading mechanism after considering the balance of multiple interests.

3.3.5 Accelerating the establishment of alternative marine fuels supply chain

Shipping decarbonization is mainly dependent upon deploying alternative marine fuels, especially green marine fuels and such deploying on a large scale needs the establishment of their supply chain. As a result of adaptability analysis of alternative marine fuels based upon comprehensive consideration of their availability, economic acceptability, technological maturity, environmental adaptability and regulatory completeness together the current situation of being attempted or in the research and development stage, low- or zero-carbon liquid fuels mainly include LNG, methanol, ammonia and hydrogen. However, the development of alternative marine fuels is mainly in the hands of out-of-sector stakeholders (fuel producers and suppliers, engine manufacturers, shipyards, etc.) and therefore collaboration across the wide-ranging stakeholders including shipping companies, port and terminal operators, manufacturers, cargo traders, investors, energy producers and distributors from inside and outside the shipping sector is crucial (UNCTAD, 2024). The establishment of the supply chain will become an important factor in measuring a country's competitiveness in the international shipping market.

Noticeably, the establishment of such a supply chain has two features. One is that the establishment requires large investment (DNV, 2022; Krantz et al., 2020). The other is that, besides the research and application of new energy technologies and ship propulsion technologies, establishing such a supply chain requires collaboration among upstream and downstream stakeholders of production, transport, storage, refueling, etc. as well as shipping and shipbuilding companies. These two features imply that in the initial stage of establishing such a supply chain, the two principles put forward in Section 3.2 need to be guided. Especially, it needs the play of joint role of government intervention and market mechanisms, and progressive but rapid advancing. For this purpose, it is vital for the government to carry out comprehensive planning, provide necessary concessional loans, tax incentives, financial subsidies or other economic support to balance the conflicting interests concerned.

In China, some big projects for producing, transporting, storing or refueling alternative marine fuels are currently either in progress or already planned. The port of Shanghai as the busiest container terminal in the world became the first port in China and the third

port in the world capable of ship-to-ship refueling bonded LNG and successfully refueled LNG of 260 million m^3 in 2023 (DNV, 2024a). However, the currently available capacity of alternative marine fuel supply is still very limited in China as a whole as compared to the China's position as the largest port State in the world. Therefore, it is an urgent need to establish alternative marine fuels supply chain in China which shall be planned, laid out and implemented as a national strategic goal, to ensure the availability, safety, certainty and reasonable pricing of alternative marine fuels.

3.3.6 Innovating the alternative marine fuel technology and ship propulsion technology

As aforementioned, the key to achieve reduction of GHG emissions from ships and ultimate net zero emissions is to use alternative marine fuels, especially green fuels. Such use requires the empowerment of new energy technologies and ship propulsion technologies to overcome the impact of shortcomings of each alternative fuel.

For examples of such shortcomings, the density of liquid methanol needs be increased to reduce its impact on the cargo carrying capacity of ships. LNG faces problems such as methane slip, 'well-to-tank' emissions and difficulty in storage at a temperature of minus 161.5°C. The production process of ammonia consumes a large amount of energy and grey ammonia generates a large amount of CO_2 emissions. Ammonia poses a risk of explosion due to improper use, and has significant toxicity and its leakage may cause personal injury to crewmembers on board or other persons (Yadav and Jeong, 2022). Liquid hydrogen needs to be stored in an environment of minus 253 °C and is difficult to transport, causing a significant increase in the prices of refueling to ships. In addition, ammonia and hydrogen have the shortcoming of refueling prices much higher than the conventional HFO, causing significant increase of ship operating costs (Wang et al., 2021a; Hansson et al., 2020). Therefore, corresponding high-cost technical and operational measures are often required in the use of alternative fuels as a safety guarantee (Xing et al., 2021; Salmon and Bañares-Alcátara, 2021).

It is believable that the continuous development of technologies in alternative fuel production, transport, storage and utilization will gradually overcome the above shortcomings in the future, including decrease of the full life-cycle GHG emissions intensity of methanol and ammonia (CCS, 2023). Consequently, innovation and mature application of technology are essential to ensure the availability, safety of use and reasonableness of pricing of alternative fuels, so as to achieve the value orientation of protecting international public environmental interests and the balance of various conflicting interests involved. However, technical innovation has uncertainties and such uncertainties are an important concern of the shipping industry. Consequently, the governments should take such uncertainties into account in formulating shipping decarbonization strategies and policies in this regard.

In recent years, driven by the background of reducing GHG emissions from ships in the international shipping industry, China has introduced the policy of developing the innovation of alternative fuel technology and ship propulsion technology. Noticeably, such innovation is original and revolutionary, and guarantees the sustainable development of shipping and maritime trading industry. It can be envisaged that more and more efforts will be made in this regard in China.

3.3.7 Actively engaging in international cooperation

Global environmental issues have the feature of transcending ethnicity and ideology, and involving the current and long-term interests of all humanity. This commonality and interconnectedness require to overcome the biases of nations, ethnicities and groups beyond ideological differences, to strengthen cooperation and jointly promote the resolution of global environmental issues (Yang, 2007). As international environmental cooperation transcends national borders and regions, and involves cooperation on a global scale, multilateral mechanisms are crucial by taking the international public environment interests as the basic value orientation, and emphasizing equality and common interests among countries. Meanwhile, it is vital that international organizations play the role as bridges among different countries, and that inclusive and universal international rules are jointly established through consultations and dialogues and effectively implemented.

Obviously, the measures for reducing GHG emissions from ships taken by individual countries or regions can play a certain role. However, their effects have obvious limitations, because it is not difficult for shipping companies to evade them, and they may also make international governance fragmented and may even be driven by underlying economic interests of a country or region to form green trade barriers. From international perspective, promoting international cooperation should be regarded as an important means to respond to global climate change and to achieve carbon peak and carbon neutrality, and pragmatic cooperation among all parties under various international mechanisms should be promoted (Wang, 2023). The sharing of concepts, goals, information and technology, and the coordination of policies, laws, standards and management, etc. are the connotations of international cooperation in shipping decarbonization.

As a conclusion, the fundamental governance of shipping decarbonization requires unified actions from the international community and countries need to actively cooperate under the regulations and guidance of IMO.

In particular, it is vital to establish international standards and implementation methods for shipping decarbonization through the future revision of Annex VI of MARPOL 73/78 or formulation of other international instruments. Such standards and methods are international public policies in essence and their formulation need the joint participation and interest consultation of the international community to find out the balance point that maximizes the satisfaction of all parties and conflicting interests.

It is also vital to share resources including shipping decarbonization technology in the international community. The level of technological innovation and application is bound to experience an international imbalance and technical barriers may easily be formed for competitive considerations. Currently, this

kind of technological developments are basically dominated by several EU members and a few other developed countries (Zheng et al., 2020). However, environmental interests have no borders and as a result, the technologies used to protect the environment should be taken as public goods without borders. Therefore, application of the alternative marine fuel technology and ship propulsion technology achieved in a country needs to be allowed in other countries under market mechanisms. Otherwise, the shipping industry of countries lacking such technology may drag the international shipping decarbonization back, making it difficult or even impossible to reduce GHG emissions and ultimately achieve net zero emission from ships. From perspective of balancing the interests of different individual countries and the protection of international public environmental interests, technical barriers should be eliminated and technology transfer at excessively high costs should be avoided.

A country like China needs to have an open and cooperative development concept, maximize the integration of domestic and foreign advantageous resources, and enhance alternative marine fuel technology and ship propulsion technology and their application rapidly.

4 Conclusions

Shipping decarbonization entails various conflicts of inherent interests. Balancing these conflicting interests should follow the principle of prioritizing the international public environmental interests while taking into account the other interests and the principle of collaborating governmental intervention and market mechanisms. On this premises, the government in shipping decarbonization governance has its primary function of making strategic planning and basic development policies and ensuring their implementation, and such planning and policies shall focus on the governmental domination-based pathways including adopting necessary and appropriate economic incentive measures, enforcing ship's technical and operational energy efficiency measures, prudently implementing shipping carbon emissions trading mechanism, supporting the acceleration of establishing supply chain of alternative marine fuels, and encouraging the innovation of alternative marine fuel technology and ship propulsion technology. Meanwhile, the shipping and/or other related industry stakeholders need to focus on market-based pathways of ship's technical and operational energy efficiency measures, shipping carbon emissions trading mechanism, supply chain of alternative marine fuels, innovation of the new technologies under the guidance of the governmental plans and policies. In addition, both the governments and industry stakeholders need to attach importance to the international cooperation, and the IMO's continuous and unique role in this regard is essential in this regard.

Hopefully, the results of this research may be helpful for further study on shipping decarbonization governance, especially on formulating plans and policies of shipping decarbonization by individual States, and also on decarbonization governance in other fields due to the commonalities or similarities in decarbonization governance. However, this research has limitations due to the lack of sufficient empirical data resources of the application of alternative marine fuels and innovation of ship propulsion technology for utilizing such fuels as well as implementation of policies of individual States. Advisably, future study needs to pay attention to the potential development of IMO's strategy on and specific standards of reduction of GHG emissions from ships, progress of application of alternative marine fuels and new ship propulsion technology as well as the policies of individual States and regions for improving the existing solutions or for finding out new solutions in shipping decarbonization governance from the perspective of balancing the conflicts of interests.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

WL: Data curation, Supervision, Writing – review & editing. ZH: Writing – original draft.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Al-Enazi, A., Okonkwo, E. C., Bicer, Y., and Al-Ansari, T. (2021). A review of cleaner alternative fuels for maritime transportation. *Energy Rep.* 7, 1962–1985. doi: 10.1016/j.egyr.2021.03.036

Ampah, J. D., Yusuf, A. A., Afrane, S., Jin, C., and Liu, H. (2021). Reviewing two decades of cleaner alternative marine fuels: Towards IMO's decarbonization of the maritime transport sector. *J. Cleaner Production* 320, 128871. doi: 10.1016/j.jclepro.2021.128871

Bullock, S., Mason, J., Broderick, J., and Larking, A. (2020). Shipping and the Paris climate agreement: A focus on committed emissions. *BMC Energy* 2, 5. doi: 10.1186/s42500-020-00015-2

CCS (2023). *Outlook for low carbon development of shipping 2023*. Available online at: https://www.ccs.org.cn/ccswz/articleDetail?id=20231208125742748&columnId=20190000600000014 (Accessed October 31, 2024).

Cheliotis, M., Boulougouris, E., Trivyza, N. L., Theotokatos, G., Livanos, G., Mantalos, G., et al. (2021). Review on the safe use of ammonia fuel cells in the maritime industry. *Energies* 14, 3023. doi: 10.3390/en14113023

Chen, J., Zhang, H., and Luo, P. (2016). EU carbon tax on maritime transport: Industrial impact and coping strategy. *Taxation Economy* 5, 94–100.

Chen, J., Zheng, T., Garg, A., Xu, L., Li, S., and Fei, Y. (2019). Alternative maritime power application as a green port strategy: Barriers in China. *J. Cleaner Production* 213, 825–837. doi: 10.1016/j.jclepro.2018.12.177

CPC and State Council (2024). *Opinions on accelerating the comprehensive green transformation of economic and social development*. Available online at: https://www.gov.cn/xinwen/2021-02/22/content_5588304.htm (Accessed October 31, 2024).

Deniz, C., and Zincir, B. (2016). Environmental and economical assessment of alternative marine fuels. *J. Cleaner Production* 113, 438–449. doi: 10.1016/j.jclepro.2015.11.089

DNV (2022). *Maritime Forecast to 2050*. Available online at: https://www.dnv.com/publications/maritime-forecast-to-2050-2022-edition-235251/ (Accessed October 31, 2024).

DNV (2024a). *Energy transition outlook China 2024*. Available online at: https://www.dnv.com/publications/China-energy-transition-outlook/ (Accessed October 31, 2024).

DNV (2024b). *Maritime forecast to 2050*. Available online at: https://www.dnv.com/maritime/publications/maritime-forecast/ (Accessed October 31, 2024).

Dong, J., Zeng, J., Yang, Y., and Hua Wang, H. (2022). A review of law and policy on decarbonization of shipping. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.1076352

European Council (2021). *Council of the European union, fit for 55*. Available online at: https://www.consilium.europa.eu/en/search/?FormatFilters=PAGE&keyword=Council+of+the+European+Union%2C+Fit+for+55 (Accessed October 31, 2024).

European Council (2023). *FuelEU maritime initiative: Council adopts new law to decarbonise the maritime sector*. Available online at: https://www.consilium.europa.eu/en/press/press-releases/2023/07/25/fueleu-maritime-initiative-council-adopts-new-law-to-decarbonise-the-maritime-sector/ (Accessed October 31, 2024).

European Union (2023). *Regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC*. Available online at: https://data.consilium.europa.eu/doc/document/PE-26-2023-INIT/en/pdf (Accessed October 31, 2024).

Fan, X. (2009). On the balance between public interest and individual interest. *Yunnan Soc. Sci.* 6, 43–47.

Feng, X. (2007). On the principle of balance of interests and its application in intellectual property law. *Jianghai Acad. J.* 1, 141–146.

Hansson, J., Brynolf, S., Fridell, E., and Lehtveer, M. (2020). The potential role of ammonia as marine fuel - based on energy systems modeling and multi-criteria decision analysis. *Sustainability* 12, 3265. doi: 10.3390/su12083265

HariLaos, N. (2012). Market-based measures for greenhouse gas emissions from ships: A review. *WMU J. Maritime Affairs* 11, 211–232. doi: 10.1007/s13437-012-0030-5

Hou, Y., and Nie, B. (2016). Analysis of the issues of current ecological intergenerational justice in China. *J. @ Soc. Sci. Harbin Normal Univ.* 3, 32–34.

Hu, Z., Huang., Y., Sun., L., Qi, X., and Pan, X. (2023). Study on international carbon emission quota allocation of shipping industry-based on fairness and efficiency. *Front. Mar. Sci.* 10. doi: doi: 10.3389/fmars.2023.1269643

ICS (2022). *Shipping, world trade and the reduction of CO_2 emissions - United Nations framework convention on climate change (UNFCCC)*. Available online at: https://www.ics-shipping.org/publication/shipping-world-trade-andthe-reduction-of-co2-emissions-needs-compressing-no-clear-date/ (Accessed October 31, 2024).

IMO (2003). *IMO policies and practices related to the reduction of greenhouse gas emission from ships*. Available online at: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/AssemblyDocuments/A.963(23).pdf (Accessed October 31, 2024).

IMO (2011). *Amendments to the annex of the protocol of 1997 to amend the international convention for the prevention of pollution from ships 1973, as Modified by the Protocol of 1978 Relating thereto*. Available online at: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.203(62).pdf (Accessed October 31, 2024).

IMO (2018). *Resolution of initial IMO strategy on reduction of GHG emissions from ships*. Available online at: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.304(72).pdf (Accessed October 31, 2024).

IMO (2020). *Fourth IMO greenhouse gas study 2020*. Available online at: https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx (Accessed October 31, 2024).

IMO (2021). *Resolution MEPC.328(76) Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution from Ships 1973, as Modified by the Protocol of 1978 Relating thereto 2021 Revised MARPOL Annex VI*. Available online at: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.328(76).pdf (Accessed October 31, 2024).

IMO (2023). *Resolution MEPC.377(80) on 2023 IMO Strategy on Reduction of GHG emissions from Ships*. Available online at: https://wwwcdn.imo.org/localresources/en/MediaCentre/PressBriefings/Documents/Resolution%20MEPC.377(80).pdf (Accessed October 31, 2024).

IMO (2024). *IMO's work to cut GHG emissions from ships*. Available online at: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx (Accessed October 31, 2024).

ITF (2018). *Decarbonising maritime transport:* Pathways to zero-carbon shipping by 2035. *International transport forum policy papers* (Paris: OECD Publishing). doi: 10.1787/b1a7632c-en

Jang, H., Jeong, B., Zhou, P., Ha, S., and Nam, D. (2021). Demystifying the lifecycle environmental benefits and harms of LNG as marine fuel. *Appl. Energy* 292, 116869. doi: 10.1016/j.apenergy.2021.116869

Kirval, L., and Çalişkan, U. Y. (2022). Influence of the European union (EU) on international maritime organization (IMO) about the market-based measures on emissions. *Int. J. Environ. Geoinformatics* 9, 146–153. doi: 10.30897/ijegeo.1047467

Krantz, R., Søgaard, K., and Smith, T. (2020). *The scale of investment needed to decarbonize international shipping*. Available online at: https://www.globalmaritimeforum.org/content/2020/01/Getting-toZero-Coalition_Insight-brief_Scale-of-investment.pdf (Accessed October 31, 2024).

Liao, B. (2022). Research on the path to carbon neutrality of China's shipping industry under the double carbon target. *Pacific J.* 12, 89–100.

Longspur Research (2022). *Methanol and shipping*. Available online at: https://www.methanol.org/wp-content/uploads/2022/01/Methanol-and-Shipping-Longspur-Research-25-Jan-2022.pdf (Accessed October 31, 2024).

Luo, F. (2012). On the interest relationship between trademark owners and trademark value creators. *Intellectual Property* 10, 65–69.

Martin, A. (2021). *A step forward for green methanol and its potential to deliver deep GHG reductions in maritime shipping*. Available online at: https://theicct.org/a-step-forward-for-green-methanol-and-its-potential-to-deliver-deep-ghg-reductions-in-maritime-shipping%E2%80%AF/ (Accessed October 31, 2024).

MOT (2024a). *Announcement of China maritime day 2024*. Available online at: https://www.miit.gov.cn/jgsj/zbes/gzdt/art/2024/art_da0df71fbf9a461594464cf02f98a51c.html (Accessed October 31, 2024).

MOT (2024b). *Implementation rules on subsidies for scrapping and updating old operating ships in transportation*. Available online at: https://xxgk.mot.gov.cn/jigou/zhghs/202408/t20240802_4145816.html (Accessed October 31, 2024).

MSA (2022). *Administrative measures for ship energy consumption data and carbon intensity*. Available online at: https://www.msa.gov.cn/html/xxgk/tzgg/wgfw/20221124/E40C898D-11DD-41E4-8D97-62C28D65B.html (Accessed October 31, 2024).

Nast, T. (2013). The response of the international shipping industry to global climate change. *J. Maritime Law Commerce* 1, 29–45.

OECD (2016). *The ocean economy in 2030* (Paris: OECD Publishing). doi: 10.1787/9789264251724-en

OECD (2023). *Charting a course to net aero: The crucial role of shipbuilding in greening the maritime sector*. Available online at: https://www.oecd.org/en/blogs/2023/12/charting-a-course-to-net-zero-the-crucial-role-of-shipbuilding-in-greening-the-maritime-sector.html (Accessed October 31, 2024).

Pavlenko, N., Comer, B., Zhou, Y., Clark, N., and Rutherford, D. (2020). *The climate implications of using LNG as a marine fuel*. Available online at: https://www.stand.earth/sites/stand/files/20200128-ICCT-StandEarth-Climate-Implications-LNG-As-Marine-Fuel.pdf (Accessed October 31, 2024).

Peng, X. (2020). Comparison of carbon emission trading mechanisms among multiple countries under the background of reducing greenhouse gas emissions in maritime transportation and China's countermeasures. *World Shipping* 5, 1–5.

Prussi, M., Scarlat, N., Acciaro, M., and Kosmas, V. (2021). Potential and limiting factors in the use of alternative fuels in the European maritime sector. *J. Cleaner Production* 291, 125849. doi: 10.1016/j.jclepro.2021.125849

Richter, A., Eyring, V., Burrows, J. P., Bovensmann, H., Lauer, A., Sierk, B., et al. (2004). Satellite measurements of NO2 from international shipping emissions. *Geophysical Res. Lett.* 31, L23110. doi: 10.1029/2004GL020822

Salmon, N., and Bañares-Alcántara, R. (2021). Green ammonia as a spatial energy vector: A review. *Sustain. Energy Fuels* 5, 2814–2839. doi: 10.1039/D1SE00345C

Santos, V. A., Silva, P. P., and Serrano, L. M. V. (2022). The maritime sector and its problematic decarbonization: A systematic review of the contribution of alternative fuels. *Energies* 15, 3571. doi: 10.3390/en15103571

Shao, Y., and Wang, H. (2011). New issues of climate change: Legal regulation on GHG emissions from ships. *Environ. Economy* 3, 61–62.

SISI (2024). *Global green shipping development report*. Available online at: http://www.sisi-smu.org/2024/0527/c8957a234886/page.htm (Accessed October 31, 2024).

Sun, D. (2021). Can ammonia become the fuel of the future? *Ship Economy Trade? Ship Economy Trade* 9, 6–11.

Traut, M., Larkin, A., Anderson, K., McGlade, C., Sharmina, M., and Smith, T. (2018). CO2 abatement goals for international shipping. *Climate Policy*. 18, 1066–1075. doi: 10.1080/14693062.2018.1461059

Tunagur, E. (2023). FuelEU Maritime explained: What the new EU rules mean for shipping. *Lloyd s List* 7, 1–2.

UNCTAD (2024). *Review of maritime transport 2023*. Available online at: https://www.unctad.org/publication/review-maritime-transport-2023 (Accessed October 31, 2024).

Valera-Medina, A., Amer-Hatem, F., Azad, A. K., Dedoussi, I. C., Joannon, M., Fernandes, R. X., et al. (2021). Review on ammonia as a potential fuel: From synthesis to economics. *Energy Fuels* 35, 6964–7029. doi: 10.1021/acs.energyfuels.0c03685

Van Hoecke, L., Laffineur, L., Campe, R., Perreault, P., Verbruggen, S. W., and Lenaerts, S. (2021). Challenges in the use of hydrogen for maritime applications. *Energy Environ. Sci.* 14, 815–843. doi: 10.1039/D0EE01545H

Wang, H. (2020). Analysis of the current status of ship fuel and future trends in clean fuel development. *Technol. Innovation Appl.* 30, 10–12.

Wang, S. (2023). Significance and practical path of strengthening international cooperation on blue carbon. *Contemp. World* 11, 62–65.

Wang, Y., and Wright, L. A. (2021). A comparative review of alternative fuels for the maritime sector: Economic, technology, and policy challenges for clean energy implementation. *World* 2, 456–481. doi: 10.3390/world2040029

Wang, K., Xian, Y., Zhang, J., Li, Y., and Che, L. (2016). Potential carbon emission abatement cost recovery from carbon emission trading in China. *J. Model. Manage.* 11, 842–854. doi: 10.1108/jm2-03-2016-0027

Wang, Q., Zhang, H., Huang, J., and Zhang, P. (2023). The use of alternative fuels for maritime decarbonization: Special marine environmental risks and solutions from an international law perspective. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.1082453

Wang, S., Zhen, L., Psaraftis, H. N., and Yan, R. (2021a). Implications of the EU's inclusion of maritime transport in the emissions trading system for shipping companies. *Engineering* 7, 554–557. doi: 10.1016/j.eng.2021.01.007

Wang, Y., Zhou, X., and Liu, L. (2021b). Theoretical investigation of the combustion performance of ammonia/hydrogen mixtures on a marine diesel engine. *Int. J. Hydrogen Energy* 46, 14805–14812. doi: 10.1016/j.ijhydene.2021.01.233

Wright, L. (2021). A comparative review of alternative fuels for the maritime sector: Economic, technology, and policy challenges for clean energy implementation. *World.* 2, 456–481. doi: 10.3390/world2040029

Xiang, Y. (2003). Ethical analysis of conflicts in international environmental interests. *Morality Civilization* 2, 64–66.

Xing, H., Stuart, C., Spence, S., and Chen, H. (2021). Alternative fuel options for low carbon maritime transportation: Pathways to 2050. *J. Cleaner Production* 297, 126651. doi: 10.1016/j.jclepro.2021.126651

Yadav, A., and Jeong, B. (2022). Safety evaluation of using ammonia as marine fuel by analysing gas dispersion in a ship engine room using CFD. *J. Int. Maritime Saf. Environ. Affairs Shipping* 6, 99–116. doi: 10.1080/25725084.2022.2083295

Yang, Q. (2007). Global environmental problem and international environmental cooperation. *New Thinking* 5, 66–76.

Yang, W., Chen, X., and Liu, Y. (2023). Review and reflections of legislation and policies on shipping decarbonization under China's "dual carbon" target. *Front. Mar. Sci.* 10. doi: 10.3389/fmars.2023.1131552

Ying, T., and Jun, P. (2024). Promoting the achievement of carbon neutrality targets: systematic review of research dimensions and measure methods on carbon equity in China. *Environ. Sci. Technol.* 58, 9912–9924. doi: 10.1021/acs.est.3c09782

Yu, S. (2008). On the conflict and coordination between public interest and individual rights. *Tsinghua Law Rev.* 2, 142–149.

Zheng, J., Liu, C., and Lin, Z. (2020). Low-carbon development of green ships and related strategies. *Strategic Study CAE* 6, 94–101. doi: 10.15302/J-SSCAE-2020.06.012

Zheng, S., and Wang, H. (2022). On the international trading mechanism of carbon emission from shipping in the context of Shipping greenization. *J. Zhejiang Ocean Univ. (Humanities Soc. Sci. Ed.)* 5, 1–6.

Zhou, C. (2009). On the balance of interest conflicts in environmental law. *Yunnan Soc. Sci.* 3, 105–108.

Zhu, Z. (2015). Legitimacy of maritime shipping emission reduction policy of EU. *Navigation China* 4, 102–105.

ZMZH (2024). *How will green methanol as carbon reduction tool shape the Future of energy?* Available online at: https://mp.weixin.qq.com/s?:biz=Mzk0NTMyNzE4Ng==&mid=2247521537&idx (Accessed October 31, 2024).

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 18 November 2024
DOI 10.3389/fmars.2024.1478669

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
University of International Business and Economics, China

REVIEWED BY
Maizatul Farisah Mohd Mokhtar,
Universiti Sains Islam Malaysia, Malaysia
Hani Alharbi,
University of Business and Technology, Saudi Arabia

*CORRESPONDENCE
Asif Khan
khan.asiff@yahoo.com

RECEIVED 10 August 2024
ACCEPTED 25 October 2024
PUBLISHED 18 November 2024

CITATION
Khan A and Ullah M (2024) The Pakistan-China FTA: legal challenges and solutions for marine environmental protection.
Front. Mar. Sci. 11:1478669.
doi: 10.3389/fmars.2024.1478669

COPYRIGHT
© 2024 Khan and Ullah. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

The Pakistan-China FTA: legal challenges and solutions for marine environmental protection

Asif Khan[1]* and Maseeh Ullah[2]

[1]School of Law, Hainan University, Haikou, China, [2]School of Law, Zhongnan University of Economics and Law, Wuhan, China

Marine ecosystems play a vital role in development, human life, and health, thereby promoting sustainable development. However, due to rapid industrialization and urbanization, as well as intense exploitation of marine resources, among other phenomena, both Pakistani and Chinese marine ecosystems face severe challenges such as pollution, overfishing, and habitat destruction. In particular, the Pakistan-China Free Trade Agreement, which aims to boost economic growth, exacerbates these environmental issues due to the increased trade volume. The purpose of this article is to discuss the challenges of legal standards regulating marine environmental protection within the context of the Pakistan-China Free Trade Agreement. By examining the current state of the mentioned agreement as well as regional judicial practice, the current study demonstrates the need to adopt a number of legal measures, such as including specific teeth provisions within the Free Trade Agreement, establishing a special joint environmental commission, increasing public participation, and boosting national environmental law, in order to reduce the adverse effect on marine ecosystems and properly mitigate such effects with a view to achieving sustainability.

KEYWORDS

legal framework, marine economic growth, marine environmental protection, marine environmental challenges, Pakistan-China Free Trade Agreement (FTA), sustainable development

1 Introduction

Marine environment protection, marine biodiversity preservation, and the sustainable utilization of marine resources are significant to the survival and development of human society and a matter of inter-generational equity and need to be in the joint efforts of the international community. The economic cooperation between Pakistan and China, especially the Pakistan-China FTA, has been striving to drive economic growth and development; however, the fast development of rapid industrialization, urbanization, and intensified utilization of marine resources have brought challenges to the environment (Chang and Khan, 2019). Both Pakistan and China's marine ecosystems are experiencing severe pollution, a decline in marine plant and animal resources, and impaired ecological

function of coastal zones. However, the enhancement of the FTA has heightened the risks to these ecosystems, as increased trade activities have contributed to the growth of marine pollution. Furthermore, the FTA intensified maritime transport, overfishing, and habitat destruction to achieve this goal. Moreover, the marine economic ratio in China's national economy has also been promoted. Gross marine product occupies a certain proportion of China's gross domestic product. Pakistan, where the FTA is also in effect, also exhibits similar trends (Khan and Chang, 2021).

On the other hand, as human society rapidly develops, the negative impact of human activities on the marine ecosystem is gradually increasing. The marine ecosystem's carrying capacity has been declining, posing a significant challenge to the ecological environment. The legal framework of the FTA has impacted trade and economic cooperation, yet it lacks the necessary standards to safeguard the marine environment. Regulating overexploitation or pollution to a greater extent could pose a threat to the sustainability of the marine ecosystem. Pollution and the destruction of the marine environment's resources align with the interests of the majority. Such destruction and pollution cause adverse effects on the water environment as such, the marine organisms as the aquatic plants and animals, and the pollution. Traditional measures to protect environmental public goods have a disadvantage in that they require the use of traditional legal criteria to evaluate the impact of damage to environmental public goods, a process that is challenging due to the complexity, latency, and cumulative nature of such damage (Idrees and Rehna Gul, 2022).

Furthermore, the maritime trade between China and Pakistan from 2015 to 2023 has witnessed significant growth, driven by strategic economic partnerships and infrastructural developments. Central to this trade dynamic is the China-Pakistan Economic Corridor (CPEC), which has facilitated enhanced connectivity and logistics through ports like Gwadar. This period marked not only an increase in the volume of goods exchanged but also a diversification of traded commodities, including textiles, electronics, and agricultural products. However, this trade expansion has not been without challenges, particularly concerning legal frameworks governing maritime operations and environmental sustainability. Issues such as customs regulations, shipping security, and the impact of trade on marine ecosystems require comprehensive legal assessments to ensure sustainable practices. Overall, the evolving maritime trade landscape between China and Pakistan reflects broader geopolitical trends and economic strategies, underscoring the need for robust legal mechanisms to support and regulate this critical economic relationship (see Table 1).

The table detailing Trade Between China and Pakistan Through Marine Routes (2015-2023) highlights the significant growth in bilateral trade facilitated by maritime activities. Over the years, total trade volume has steadily increased, with projections suggesting a continued upward trend into 2023. Notably, exports from Pakistan have shown substantial growth, reflecting the country's increasing integration into global supply chains. However, this surge in trade is accompanied by rising shipping traffic, which has heightened concerns regarding marine environmental degradation. As outlined in the table, incidents of pollution, overfishing, and habitat destruction have escalated alongside trade growth, underscoring the urgent need for robust marine environmental protection measures within the framework of the China-Pakistan FTA. The correlation between increased trade activities and the subsequent environmental challenges emphasizes the critical importance of incorporating specific environmental provisions to mitigate these impacts and ensure sustainable trade practices moving forward.

TABLE 1 Trade between China and Pakistan through marine routes (2015-2023) (Ministry of Commerce, Pakistan, 2024).

Year	Billion)	Billion)	Billion)	Key Commodities Traded
2015	10.2	7.5	2.7	Machinery, Electronics, Textiles, Chemicals
2016	11.4	8.2	3.2	Machinery, Textiles, Agricultural Products
2017	13.0	9.0	4.0	Electronics, Textiles, Minerals, Chemicals
2018	14.5	10.2	4.3	Electronics, Textiles, Agricultural Products
2019	15.8	11.0	4.8	Machinery, Electronics, Textiles, Chemicals
2020	16.3	11.5	4.8	Electronics, Textiles, Agricultural Products
2021	17.5	12.3	5.2	Machinery, Electronics, Chemicals, Minerals
2022	18.6	13.1	5.5	Electronics, Textiles, Minerals, Agricultural Products
2023	19.8	14.0	5.8	Machinery, Textiles, Chemicals, Electronics

This article focuses on a specific legal challenges, namely the challenge that FTA poses for marine environmental protection, and possible solutions to the challenge. The FTA can have a positive impact on the environment by accepting specific clauses for marine protection, creating a joint environmental commission, maximally involving the public, and strengthening national environmental laws to meet the needs of the FTA. Finally, we introduce a solution to make the agreement environmentally friendly by combining it with international environmental standards and regional cooperation frameworks.

2 Research methodology

For this study, a qualitative research methodology has been implemented. It emphasizes the importance of a thorough review of primary and secondary materials in order to develop a profound understanding of the analyzed subject. The primary sources in this study include official trade data, governmental reports, and legal documentation of activities related to the FTA and marine environmental protection. Such resource-based analysis allows for obtaining firsthand information on the trade dynamics of the relations between two countries and the frameworks of their interrelations. As for the secondary sources, they include scholarly

and academic articles, books, and policy papers that analyze their implications on marine environments, trade activity, and legal frameworks. Such sources assist in reviewing existing research on the subject and the author's positions. So, the qualitative approach helps to do a deep analysis that brings together information from various sources and focuses on finding gaps in FTA's provisions for marine environmental protection and their effects on the environment. It also comes up with suggestions for how to keep sustainable development going for the trade case that was looked at.

3 Overview status of the Pakistan-China Free Trade Agreement

The FTA is the legal agreement signed between Pakistan and China, where it was first inked during the year 2006 and subsequently revised in 2019 (FTA, 2006). The objective of the FTA is to enhance bilateral trade between Pakistan and China. In every other way, the agreement should also focus on promoting economic growth by easing the imposition of tariffs and trade barriers in the areas of goods, services, and investments. The FTA has played a crucial role in significantly increasing trade between the two countries, and in one way or another, it helped in building and creating strong and closer economic ties between the two countries (Hussain and Ali Shah, 2017). The agreement ranges from liberalizing trade in goods and services to trying to facilitate investment. With the less burdensome trading atmosphere, FTA has ensured to promote increased market access, in the process creating more economic opportunities for either country. This way, FTA has been able to strengthen the economic relations between China and Pakistan. Although FTA has brought many economic benefits, the environmental disadvantages of such interactions have not been considered to date, especially in marine ecosystems. With the growth of trade volumes and the emergence of new economic partnerships, the effects of economic activities on natural environments and marine ecosystems in particular have become more pronounced. Increased marine pollution, reduced quality of habitats, and overfishing are just a few identified issues. However, the lack of environmental provisions in the FTA's text results in the so-called governance gap. As a result, the FTA's text increasingly ignores or fails to effectively address environmental problems. Changes in the FTA's text is necessary to integrate environmental protection mechanisms into the agreement (Irshad, 2017).

3.1 Phase I of the China-Pakistan Free Trade Agreement

The China-Pakistan FTA Phase I signed in 2006 commenced a strategic partnership that is meant to enhance economic cooperation. The agreement stipulated the implementation of measures aimed at liberalizing trade and investment. The non-discriminatory actions included the removal of barriers and tariffs between the two nations and coverage of the agricultural, therapeutic, and telecommunication sectors (Dastgeer et al., 2023).

3.1.1 Tariff reductions

One of the pivotal Phase I features of the FTA was a sharp decrease in tariffs on a wide range of goods. The agreement included a detail that aimed to eliminate trade barriers and significantly accelerate economic exchange between the two states. Moreover, both Pakistan and China benefited equally from the decline in goods. It means that the list of goods included both primary commodities, industrial products, and consumer products that were in common use for the nations. The reduction in tariffs created an environment in which one of the parties found the product's price more beneficial for the consumer market. Such detail was expected to be one of the crucial aspects that would increase the trade volumes due to a more affordable price of the imported product (Khan et al., 2019).

In the meantime, for Pakistan, the implication was most likely beneficial, as cheapen and more accessible Chinese wares, from electronics to machinery, on the one hand, while the country's position in the Chinese market could be strengthened on the other, due to the demand growth for Pakistani products, primarily textiles, and agricultural goods, among others, which had become cheaper. Therefore, we anticipated that the reduced tariffs on specific products would enable Pakistan and China to leverage their comparative advantages, thereby enhancing their trade freedom and efficiency (Irshad, 2015). However, the ultimate aim of the reduced tariffs was to enhance bilateral trade and further economic integration between Pakistan and China. This process would regularize the removal or notable reduction of trade barriers and other restrictions that impede trade development. Such an outcome implied not only the growth of the volume of trade between the countries, but also a more profound economic integration, characterized by higher levels of interdependence. This integration was critical for creating a more dynamic type of economic relations that could promote investment and improve market access for both countries. Such integration was expected to function in the long-term perspective and, thus, was likely to have a long-lasting positive effect on the growth of trade and economic development. However, the agreement did not adequately address the negative environmental implications of the growing trade between the two countries, particularly the impact on marine ecosystems, indicating that future agreements should prioritize the environmental side of the issue (Uzair and Nawaz, 2018).

3.1.2 Trade facilitation

Whereas the first phase of the FTA concerned primarily tariff reductions, the agreement also contained a number of provisions intended to facilitate trade by means of simplifying customs processes and fostering operational efficiency. These provisions, or trade facilitation measures, were intended to address and eliminate logistical and administrative barriers and facilitate the smooth flow of goods between the two countries. Consequently, a significant number of these provisions relate to the simplification and acceleration of customs procedures. The parties called for the overcoming of bureaucratic barriers, which are one of the primary causes of trade slowdowns. That is why the parties attempted to reduce the time and energy spent on customs procedures. That means that the documentation required, and procedures used,

should be as efficient as possible to avoid unnecessary hold-ups in the process of goods transfer. As a result, the primary aim of these provisions was to facilitate a quicker and more predictable customs process and make trade between Pakistan and China as smooth as possible (Abbas et al., 2023).

To facilitate trade, another crucial aspect was improved border management. Firstly, we developed modern infrastructure to ensure the smooth and quick processing of cargo and minimize the risk of congestion. This aspect may be critical because various logistics-related issues and other factors could pose a significant threat. Additionally, both countries' customs authorities recognized a shift in their communication and made efforts to enhance coordination and information sharing, ensuring adherence to similar conditions. Phase I of the Intergovernmental Agreement saw the implementation of various trade facilitation policies, particularly in document handling and administration, which significantly reduced non-tariff trading costs. Thus, the frequency of trading activities between China and Pakistan has increased substantially. Simultaneously, we must acknowledge that the number of trades can only increase if these transactions become affordable, and the associated costs decrease. In other words, these policies imply that Chinese and Pakistani products are more competitive in both countries. The results for the countries' economies indicate that trade facilitation policies were an important driver of trade and economic cooperation between Pakistan and China (Chaudhry et al., 2017).

3.1.3 Investment promotion

Investment promotion was one of the key fields in phase one of the China-Pakistan FTA, apart from tariff reduction and trade facilitation. The agreement aimed to promote economic relationships between Pakistan and China by creating predictable and calm conditions suitable for foreign direct investment. The investment safeguards included a variety of critical provisions for securing the investment and their fair treatment. The investment safeguards aimed to protect investors and ease their concerns about the security and safety of their investments in the investment environment. The aforementioned provisions also enabled agents to operate in the best interest of the investors and to transfer their investments between the two countries. The investment promotion's primary goal was to attract and maintain investments in Pakistan and China (Shah et al., 2022). The factors that made the goal achievable were the efforts to create a relatively stable framework and environment for investments while protecting the interests of the investors made the goal achievable. In this case, it was hoped that the relatively stable environment would help in minimizing the levels of risk involved in investing in both countries. As a result, a significant surge in the levels of FDI was expected to be recorded in the respective countries. Additionally, we expected the increase in investment levels to enrich the respective countries by stimulating growth in both investments and companies. Finally, the fit measures aim at ensuring that the investments receive fair and equal treatment by preventing any form of discrimination against another investment or their investors. The two countries designed the measures to enhance their investment climate. Overall, the measures were very important (Fazal-ur-Rahman, 2010).

It is noteworthy that, even as the growth in Pakistan's exports to China exceeded that to the rest of the world, its imports from China increased even more. The consequence of this was that the trade deficit with China grew even bigger. It already accounted for a quarter of Pakistan's entire trade deficit in 2007, and by 2018, it stood at 35 percent. In addition, the CPFTA received widespread condemnation among business groups in Pakistan, which thought that it was disastrous. They argued that the country's negotiators had performed dismally in terms of the access to China for the country's most competitive exports and also when it came to the goods that would be let to flood the Pakistani market from China. This latter group of goods is what is believed to have played an essentially catalytic role in the process of premature deindustrialization (PBC, 2024). see (Table 2).

Phase I of the FTA successfully created a foundation for a more long-lasting and robust economic partnership, but it did not involve consideration or mitigation of potential environmental impacts that are associated with an increase in trade. While the economic implications of this phase are clear, it failed to provide support and establish a framework for addressing and mitigating the environmental implications of extending and increasing trade. Specifically, it was noted that an increase in the volume of trade will have a large negative impact on marine ecosystems, and thus the future phases of the agreement feature measures, which affect these resources (PBC, 2024).

Figure 1 below summarizes the concessions made in both program phases and displays the timelines.

3.2 Phase II of the China-Pakistan FTA

In 2019, the document regulating the trade between an economic powerhouse, China, and a developing country, Pakistan, had been upgraded. The China-Pakistan FTA's Phase II represents a crucial milestone in advancing the economic relationship between the two countries. In particular, the expansion of trade coverage, or the inclusion of more products and sectors in the agreement, facilitated the enhancement of the transition to Phase II. This improvement was bound to have

TABLE 2 Pakistan China trade 2007-2018 (PBC, 2024).

		2007	2018	Growth (%)
Trade with all countries		50	84	66
China	Exports	0.6	1.8	196
	Imports	4.2	14.5	249
	Trade balance	(3.6)	(12.7)	258
	Total trade	4.8	16.4	242
Rest of the world (excluding China)	Exports	17	20	16
	Imports	28	46	60
	Trade balance	(11)	(26)	129
	Total trade	46	66	44



FIGURE 1
Timeline for the FTA Pakistan and China (PBC, 2024).

multiple positive effects, including improved market access and the creation of new economic opportunities (Sahibzada, 2021).

These were the other key outcomes. First and foremost, the agreements of the former type facilitated deeper tariff reductions. Crucially, these reductions encompassed a wider range of goods; consequently, the documents aimed to intensify the impact of these measures by expanding the scope of the policy. As a result of this effort, it aimed to make the process of goods exchange between the two countries more efficient and less costly. In addition, the adoption and implementation of the respective agreements are known to have set the foundation for the improved investment framework. The agreement contributed to the adoption of more robust measures aimed at protecting and promoting investments, such as improved dispute prevention and settlement tools and arrangements aimed at ensuring that investments undertaken in the host country are secure. These improvements clearly aim to enhance the predictability of the investment climate. In turn, the increase in such predictability was supposed to result in higher investment levels and greater inflows of foreign direct investment (Abbas and Ali, 2018).

Nevertheless, Phase II of the FTA omitted environmentally significant issues. The sharp growth of trade volumes and economic activities between Pakistan and China, however, had a significant adverse effect on the environment, with a focus on marine ecosystems. Phase II's lack of specific provisions for environmental protection measures underscored the agreement's shortcomings, and future updates should incorporate these necessary measures (see Table 3). At the same time, it is crucial to include environmental issues in the FTA to ensure that the framework of agreements supports both economic growth and environmental balance, both of which are crucial for long-term sustainable development (PBC, 2024).

Furthermore, there is no proper regulation of marine environmental protection, in contrast to the free trade agreements that China has with other countries or unions. For instance, the China-Australia Free Trade Agreement includes a chapter that, with its rigidity and speed, focuses on sustainable development and the preservation of marine resources. The China-New Zealand Free Trade Agreement provides a separate chapter that promotes environmental cooperation. Furthermore, the Regional Comprehensive Economic Partnership decided to ensure sustainable fisheries use and marine biodiversity protection. To achieve the same results, officials should consider amending the China and Pakistan FTA to include specific provisions on marine environmental protection.

4 FTA and marine environmental challenges

The increased trade activities resulting from the FTA between Pakistan and China have led to several significant marine environmental issues. These challenges include pollution, overfishing, and habitat destruction, each of which poses substantial risks to marine ecosystems and biodiversity. (see the Figure 2)

4.1 Pollution

The first problem is marine pollution, which has become even more serious as ship traffic between Pakistan and China has increased. The main factor contributing to the marine environment's pollution is that the increased number of vessels in this arrangement leads to increased oil spills. Oil spills in seawater have several consequences, including contamination of the water, the death of numerous aquatic animals, and disruption of the ecological balance. Oil fills the whole water surface and sticks to the bodies of marine creatures, killing and poisoning them. Even when the oil spills evaporate, it still absorbs many other chemicals and never totally disappears, remaining in the water and animals for many years. The polluted seawater will stay unclean for decades and even centuries, affecting the whole food chain (Butt, 2021). In addition to this, ships dampen many other types of waste, such as plastics and various chemicals. The waste cycles are particularly dangerous for the environment since it takes many hundreds of years for plastics to decay and become harmless. Many predators in the ocean mistake plastics for their normal food, allowing them to enter their bodies.

TABLE 3 Marine environmental protection provisions in Phase I and Phase II of FTA.

Aspect	Phase I of FTA	Phase II of FTA
Environmental Focus	Limited focus on environmental protection, with no specific provisions dedicated to marine environments.	Some progress in recognizing environmental concerns, but still lacking explicit provisions for marine environmental protection.
Pollution Control Measures	No specific measures addressing marine pollution from increased trade activities.	General environmental clauses are present, but they are non-specific and non-enforceable regarding marine pollution.
Sustainable Fishing Practices	No mention of sustainable fishing practices or regulations to protect marine biodiversity.	Similar to Phase I, there is a lack of detailed provisions on sustainable fishing, leaving a regulatory gap in addressing overfishing.
Habitat Protection	No provisions for the protection of critical marine habitats like coral reefs, mangroves, or seagrass beds.	While Phase II expands trade coverage, it continues to overlook the protection of marine habitats, which are increasingly at risk due to infrastructure development.
Monitoring and Compliance	No mechanisms established for monitoring the environmental impact of trade activities on marine ecosystems.	Phase II remains without robust monitoring and compliance mechanisms for marine environmental protection, continuing the gap from Phase I.
Environmental Cooperation	Environmental cooperation between Pakistan and China is not a focus, with no provisions encouraging joint efforts to protect marine environments.	Although there is a broader recognition of environmental issues, Phase II does not establish a framework for bilateral cooperation specifically aimed at marine environmental protection.

This can lead to issues such as blocking the food channel and puncturing the stomach or intestine lining, which can result in animal death. Furthermore, plastics break down into smaller particles known as microplastics, which small aquatic animals consume and end up on human food tables (Mohsin et al., 2018).

Mainly, chemical pollutants such as heavy metals and toxic compounds infiltrate the marine environment through ship discharges and industrial runoff due to increased trading activities. These chemicals bioaccumulate in marine organisms, resulting in a variety of health complications, including reproductive and neurological developmental diseases. Additionally, toxic chemicals negatively impact the marine ecosystem by distorting the physiology and behavior of marine animals, resulting in the decline of several marine species' populations and changes in the composition of marine communities (Chang and Khan, 2019).

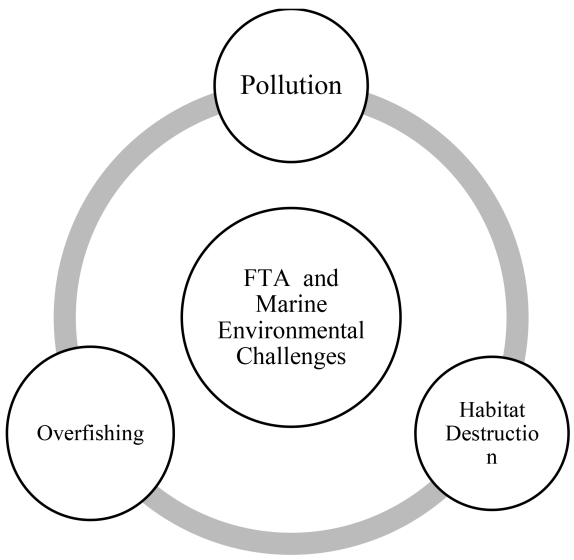


FIGURE 2
FTA and marine environmental challenges (Khan, 2022).

The overview of pathogens and invasive species is not the only harm caused by the discharge of other hazardous substances, such as untreated sewage and ballast water from ships. These substances have the potential to outcompete native species, which can lead to a decline in biodiversity and changes in the ecosystem. The pollutants add to the soil, which loses all its filtering capacities and can no longer purify the water. Marine organisms cannot use the contaminated water as a source of oxygen and nutrition, and people cannot use it for drinking and cooking. The impact on the health and stability of marine habitats is significant, leading to a rapid decrease in diversity. Contaminants concentrate in the coastal area, making it the most dangerous zone where species lose their habitats and people have limited recreational opportunities (Qayuum, 2021).

Numerous strategies exist to address marine pollution problems. Still, strict regulations and more effective waste management, such as sewage, known as black water, are required. Moreover, only international efforts and cooperation, along with improved monitoring systems, better sewage processing plants, and the use of pure fuel, can effectively control marine pollution. Ultimately, these measures could aid in mitigating the pollution impacts stemming from increased water traffic and the expansion of water-related infrastructure. If people implement these improvements and enhance the sustainability of their strategies by safeguarding the marine environment, humanity can benefit from increased trade and sustain this practice for future generations (Lin, 2018).

4.2 Overfishing

Overfishing is a significant challenge that arises from the increased market demand for seafood, which is a result of improved trade activities. Overfishing decreases the fish stock, thereby disturbing the natural balance of marine systems. To create the above balance, various fish species tend to be significant to the food chain. When fish stock

declines, the number of fish species in the system decreases. This imbalance has a wide-ranging impact on associated marine life and other marine systems. The decreased fish stock will lead to fish preying on other species to achieve abundance within the system. Eating will now be excessive, leading to the elimination of marine vegetation such as seagrass beds and coral colonies (Zulfiqar et al., 2023). The species in the system depend on such vegetation as breeding and feeding centers, and their reduction will have a significant impact. The impacted species will become extinct as a result of a lack of food for survival, the impacted species will become extinct. Inadequate food in the systems will also deter the few available species from reproduction, culminating in their extinction over time.

Overfishing affects local communities that depend on fishing, adding to the socio-economic implications of degradation. Small fishing businesses often fail to compete with the industrial scale and disappear from the market. Often, overexploitation leads to economic difficulties and the loss of traditional living structures. Overfishing can lead to increased competition between fishing businesses and countries. To preserve marine life, it is necessary to support the variety of fish by designing sustainable measures, such as catch limitations, seasonal closure periods, and marine protected areas. Application of sustainable aquaculture can also alleviate the pressure on the wild fish population and give the public access to a safe alternative source of seafood (Khan and Xu, 2021). Advanced fisheries management often relied on effective monitoring and enforcement of existing regulations. Various means, including the use of advanced technologies, can help detect numerous violations and ensure that all fisheries operate in compliance. For example, there are satellite tracking and electronic log and reporting systems that detect overfishing or illegal attempted overfishing. Such monitoring is especially important since the long transboundary nature of marine resources calls for international cooperation to be addressed. Public education and awareness can also be an effective tool, since nowadays many consumers are ready to make a difference by not purchasing fish that has been overfished. As a conclusion, it is possible to say that the problem of overfishing is a complex one, and it calls for both comprehensive ecological studies and the analysis of local social and economic particulars. Although the expansion of trade and fisheries is a good thing, it should be implemented in a way that preserves the so-called carrying capacity of marine ecosystems. In other words, sustainable management of marine resources is needed to address the problem (Lakhani, 2016).

4.3 Habitat destruction

Infrastructure for enhancing trade, e.g., ports and shipping lanes, requires the destruction of vital marine habitats. Nearly all marine species depend on these habitats, composed of mangroves, coral reefs, and seagrass beds, for their survival. Firstly, they provide a breeding and feeding ground. Additionally, they preserve marine biodiversity and produce and sustain certain ecological services. Mangroves can reduce the coast's vulnerability to flooding and erosion from hurricanes and storms. They are a barrier to the wind, waves, and other water-related activities. They also serve as a barrier to other human establishments along the coastline. Furthermore, they act as a nursery for several fish species. They remain in the mangroves until they grow large enough to venture into the open waters. For instance, schnappers, mullets, tilapia fish, and lobsters nest in the mangroves and fertilize the sand. The destruction of mangroves is lethal for the species that live in them and will increase the chances for hurricanes to devastate coastlines (Hassan Daud Butt and Majeed, 2022).

Another crucial type of habitat is coral reefs. Often called the "rainforest of the sea" for their stunning level of diversity, they provide habitat and refuge to about 25% of all marine life. Surprisingly, they make up less than 1% of the ocean floor (Siig et al., 2023). It is also important for local economies since coral reefs support both tourism and fishing industries. However, the construction of ports and shipping lanes often destroys the physical structure of reefs, produces pollution from the construction processes, and increases sedimentation, which quickly smothers the coral and reduces its rate of photosynthesis and growth. Another equally important type of habitat is seagrass beds, which serve as food and habitat for many different types of sea life, such as marine mammals, fish, and endangered species, including sea turtles and dugongs (Amir, 2022). Furthermore, seagrass beds are vital for the purposes of carbon sequestration; seagrass captures the carbon and breathe out oxygen, and the climate crisis is one of the anthropogenic factors that contributes to the destruction of seagrass beds.

Habitat destruction is destructive because it disrupts the natural processes that enable marine life to exist. Firstly, the fragmentation and reduction of habitats pose a threat to organisms that seek food, reproduce, and migrate. Thus, the population of various marine animals tends to decline, leading to their extinction in other cases. In addition, biodiversity alters the adaptability of such ecosystems. The greater the diversity, the more resilient. Given the existing processes, it is crucial to devise methods for conserving these habitats (Solangi et al., 2018). One example is the use of marine protected areas to curb destructive activities. In addition, an example is that after digging the institution in such habitats, the law requiring people to operate in the habitats can be implemented. Restoration can also serve as a method; one example is the replanting of mangroves and coral.

Sustainable development is the right approach to balance economic interests and environmental protection. For example, using eco-friendly materials in construction and planning infrastructure projects in a way that does not affect sensitive habitats in the world's oceans would reduce habitat destruction. Furthermore, when individuals actively participate in safeguarding certain marine habitats and gain a deeper understanding of the vitality of these ecosystems, they can reduce habitat destruction by encouraging their stewardship and backing of conservation initiatives. Therefore, we can counteract habitat destruction by creating new frameworks that reinforce the importance of environmental protection in trade and development policies. Trade policies can preserve biodiversity, ecosystem services, and the future health of marine systems if they prioritize the protection and restoration of vital marine habitats (Naz and Parveen, 2022).

A specific approach to solving these problems is that future agreements considering the agreement between Canada and Pakistan should drive robust environmental protection as one of the viable strategy aspects. Future phases of the agreement may be

focused on new provisions of reducing the risks of trade for marine environments. New measures presuppose focusing on pollution control and sustainable fisheries implementation, including the protection of specific habitats. Thus, it is expected that the new regulations will be strictly implemented through new conditions of the agreement. This approach is likely to restore the affected marine environments, while ensuring trade practices align with sustainability principles. In this way, both aims, economic growth, and environmental protection will have been achieved.

5 Legal framework governing marine environmental protection

5.1 International legal instruments

5.1.1 United Nations Convention on the Law of the Sea

Protection of the maritime environment, the responsibility of both countries, is presented under the UNCLOS. Considered as the "constitution for the oceans," the act establishes a set of rules aimed at ensuring the sustainable use and protection of the marine environment. Both countries are required to take measures to prevent, reduce, and control pollution of the sea and nature. Generally, both Pakistan and China are members of the convention that formulates a regime for protecting the maritime environment (Suncls and Cai, 1982).

a. Stricter Regulations on Pollution Control:

UNCLOS mandates that states take all necessary measures to prevent, reduce, and control pollution of the marine environment from various sources, including land-based activities, seabed activities, dumping, and vessel-source pollution. This framework requires states to adopt laws and regulations to mitigate the adverse effects of pollution on marine ecosystems. To align with these obligations, future phases of the FTA should incorporate stricter pollution control measures. Enhanced monitoring and enforcement mechanisms are essential to ensure compliance with pollution regulations by shipping companies and industrial operators. Advanced technologies such as satellite tracking and real-time water quality monitoring can help detect and respond to pollution incidents more effectively (Wardhana, 2015). Additionally, mandating the use of cleaner fuels and advanced waste treatment systems on ships can significantly reduce the discharge of harmful pollutants into the ocean. Regulations should also require ships to minimize their ballast water discharge to prevent the spread of invasive species. Implementing pollution prevention programs that focus on reducing waste generation and promoting the use of environmentally friendly materials can further aid in minimizing environmental damage.

b. Sustainable Fishing Practices.

UNCLOS, in addition to maritime economic zones, deals with the conservation and management of marine living resources. The treaty requires the states to maintain populations of harvested species at levels capable of producing a sustained yield. The FTA should introduce sustainable fishing practices to fight overfishing and ensure the long-term viability of fish populations. A set of scientifically determined catch limits, or quotas, would provide early warning of overexploitation of a fish population and prevent the onset of long-term decline. To adapt the measures to changing conditions, they should be based on the best available scientific data and reviewed periodically (Stougaard-Andresen, 2023). The FTA should also enforce seasonal and area restrictions to provide marine species with critical breeding and feeding grounds in which to recover. Marine protected areas should be created to act as safe havens for marine species and ensure biodiversity in the oceans. Certification and labeling programs should be promoted for consumers who wish to choose seafood that has been produced using sustainable fishing methods. Market incentives will help promote the FTA in the fisheries.

c. Protection of Critical Marine Habitats.

According to UNCLOS, states *"shall take, individually or in cooperation with other States or international organizations, all measures consistent with this Convention that are necessary to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened, or endangered species and other forms of marine life."* Therefore, protecting and restoring critical marine habitats is vital for ensuring biodiversity and ecological balance. In future phases of the FTA, there may be requirements and provisions for funding and supporting habitat restoration projects. For instance, the projects may incorporate measures for mangrove reforestation, coral reef restoration, and seagrass bed rehabilitation. These measures will help restore the degraded habitats and improve their ecological functions, supporting coastal protection, carbon sequestration, and various marine life forms. Additionally, Comprehensive Environmental Impact Assessments (EIAs) (Glasson and Therivel, 2013) should be required for all major infrastructure trade-related projects. These assessments should include evaluating the risks for marine habitats and proposing mitigation measures to reduce the harm. Additionally, the FTA can establish partnerships with local communities, NGOs, and international organizations to bolster conservation efforts and guarantee the implementation of environmental protection measures (Camara Sanchez, 2011).

Incorporating the principles and obligations elucidated by UNCLOS with regards to the FTA paradigm would ensure that Pakistan and China's trading practices and their enterprises are compatible with the convention's general and particular objectives. This step would not only confirm relevant international standards and laws, but it would also facilitate the long-term protection and stability of marine resource availability, striving to preserve a balance between developmental economic benefits and the natural environment (Nguyen, 2023).

5.1.2 Convention on Biological Diversity

In 1992, the Earth Summit in Rio de Janeiro adopted the CBD as an international document. The CBD is a serious international document that aims to conserve biological diversity, promote sustainable use of its components, and ensure equitable sharing of benefits from genetic resources. It is clear that conservation of the

web of life on our planet is necessary for safe and healthy ecosystems, as well as for humanity's well-being (De Oliveira et al., 2011).

There are three primary goals set by the CBD. The first one is biological diversity conservation. This is a fundamental goal to which the two others will also refer. The CBD promotes the protection of ecosystems, species, and genetic diversity. The conservation effort aims to maintain the vitality of ecosystems that provide humans with essential services like clean air, water, and fertile soil. The other two objectives pertain to the prudent and sustainable utilization of biological diversity. Second, the CBD advocates the sustainable use of diversity. A balance should be achieved between the usage of such diversity for the existing needs and for generations to come. It could be explained by the necessity to preserve the integrity of ecosystems and to provide the proper functioning of the latter. Finally, the third goal is the fair and equitable sharing of benefits from such genetic resources. It refers to the need to recognize the efforts that Latin American communities and indigenous people have employed to sustain and use their resources (Chandra and Idrisova, 2011).

From the perspective of marine biodiversity, the CBD contains several significant provisions. This convention places an emphasis on maintaining marine and coastal areas and places the importance of habitats at its core. Coral reefs, mangroves, and seagrass beds are essential to the marine biosphere and provide life-supporting functions for the world community as they protect the shores and sequester carbon. Moreover, the CBD promotes the creation and management of marine protected areas as a vital means to protect biodiversity. These areas can be used for protecting the habitats, stopping the depletion of the populations that are under threat, and helping the recovery of such species.

Yet another notable feature of the CBD is its access and benefit sharing mechanism. By putting the provision in place, the CBD ascertained that countries and communities that provided genetic resources would receive a fair share of benefits from their use. The elaborate ABS arrangement aims to enhance equity and development sustainability by crediting those who have kept and used their genetic resources over the years (Marino et al., 2015).

The CBD is primarily a capacity-building instrument, aimed at ensuring that nations are able to conserve biodiversity in accordance with the three objectives. It usually operates through regular meetings of the Conference of the Parties, in which member states review their progress, adopt decisions to enforce the treaty, and develop new goals to further its effectiveness. The CBD's Secretariat assists countries with respect to their commitments and facilitates the sharing of knowledge among governments, scientists, and other stakeholders.

Ensuring that economic development and trade operations do not jeopardize their conservation goals is appropriate. An example of this is the incorporation of CBD principles into the China-Pakistan FTA, as future phases should incorporate requirements that align with the objectives of CBD. These objectives encompass the sustainable use of marine resources, the preservation of marine ecosystems, and the identification of equitable methods for sharing all potential benefits derived from these resources. Once the FTA adopts CBD objectives, they will integrate these goals into the trade policy, thereby promoting a balance between economic growth and environmental protection principles (Secretariat, 2001).

5.1.3 International Convention for the Prevention of Pollution from Ships

The International Convention for the Prevention of Pollution from Ships, or MARPOL, is the central international agreement that aims to reduce the effect of marine pollution from shipping. First adopted in 1973, the Protocol of 1978, though altered and made more inclusive, represents an international regime that actively manages the substances ships may discharge into the sea. It is a coordinated effort by member states to protect the marine environment from the negative impacts of maritime pollution. MARPOL's primary goal is to prevent and control ship-based marine pollution. The convention divides into multiple annexes, each focusing on a specific type or source of pollution, to achieve this goal. For example, Annex I deal with oil pollution, specifying the standards for discharging oil and oily mixtures from ships. Additionally, Annex I mandate the use and maintenance of oil filtering equipment, details the records required for oil discharge by ships, and outlines procedures for both operational and accidental spills to occur on the smallest possible scale (MEPC, 2011).

Pollution from noxious liquid substances carried in bulk is the subject of Annex II. It specifies criteria to prevent maritime pollution by regulating every facet of these substances discharged. Similarly, Annex III deals with the disposal of harmful substances packaged in containers and includes the corresponding requirements for the safe handling, packaging, and transport of these noxious liquid substances. Annex IV of MARPOL also plays a significant role, as it deals with sewage pollution from ships. This annex makes it mandatory to use onboard sewage treatment systems and establishes discharge limits. In order to lessen the impact of garbage on the marine environment, Annex V regulates the discharge of various types of waste from ships, including plastics and food (Club and Thomas, 2013). Annex VI is the latest addition that affects the atmospheric problems involving air pollution from ships. It outlines limits that apply to conditions such as the emissions of sulfur oxides, nitrogen oxides, and particulate matter from ship engines, along with additional measures to reduce the emissions of greenhouse gases that contribute to pollution. This initiative aims to mitigate the impact of shipping on pollution emissions and climate change.

MARPOL's enforcement is contingent on a combination of national and international measures. National states enforce MARPOL by implementing its provisions in their territories. The states bear the responsibility of conducting inspections and ensuring the compliance of ships flying their flag with the convention. The International Maritime Organization oversees MARPOL and provides guidance, updates, and fosters international cooperation to effectively implement the treaty. At present, integrating MARPOL's standards into trade agreements, such as the China-Pakistan FTA, is crucial for ensuring that increased maritime trade does not generate higher levels of marine pollution. Future phases of FTA should include provisions that align with MARPOL's requirements, including more strict pollution control measures and improved waste management practices. By introducing these measures, trade policies could support sustainable maritime activities, decrease the environmental impact of shipping, and protect marine ecosystems.

Because MARPOL is a core component of the existing international framework for marine environment protection, integrating trade agreements with its standards is critical for balancing economic development and the need to maintain the environment (Jea, 2011).

5.2 National legal frameworks

5.2.1 Pakistan's legal framework for marine environmental protection

Marine environmental protection in Pakistan relies primarily on two major legal instruments, one of which is the Pakistan Environmental Protection Act, 1997, and the other is the Marine Fisheries Ordinance, 1983. The first-mentioned Act is a comprehensive piece of legislation that aims to protect the environment on Pakistan's territories, including its marine environment. This Act establishes the Pakistan Environmental Protection Agency, which is responsible for implementing governmental policy in the environmental field and ensuring compliance with the proper standards and regulations. The Act contains provisions relating to environmental impact assessment, pollution control, and environmental quality standards formulation. However, despite the Act's excellent framework for formulating objectives and technical means for their implementation, numerous enforcement difficulties often hinder the effectiveness and implementation of these regulations (Ullah et al., 2021).

The Marine Fisheries Ordinance, 1983, is another legal instrument that specifically relates to marine fisheries and fishery resource management. The ordinance's establishment aims to regulate, prevent, and control overfishing in the sea, thereby preserving its biodiversity. Its functions include licensing, registration, monitoring, controlling, and regulating fishing practices, as well as the use of fishery resources in the marine environment. The World Fisheries Conference and the Food and Agriculture Organization support the provisions of this ordinance. However, like the Environmental Protection Act, there is inadequate enforcement of the law, leading to numerous cases of illegal fishing. Additionally, poor monitoring frequently leads to incidents. Furthermore, the federal government faces significant challenges in effectively coordinating the activities of various agencies. As a result, the enforcement of the laws is also inadequate. Despite the challenges in enforcing these two laws, as previously mentioned, what steps would you take to guarantee the effective protection of Pakistan's marine environment and the effectiveness of these laws (Lau, 2018).

Furthermore, the Sindh Marine Fishing Ordinance, 1980 is the legislation that governs the coastal areas of Sindh. The ordinance aims to safeguard the management and conservation of marine resources by regulating fishing licenses and prohibiting practices that lead to overfishing of specific species or jeopardize marine diversity. It is complemented by the Pakistan Wildlife Protection Act, 1972, which covers all of the wildlife and is not limited to the marine species, as that act provides the legal grounds for protection of fauna, including prohibiting hunting and trade of certain species and encouraging conservation of environmental resources. The Coastal Development Authority Act, 1994 addresses the development of Pakistan's coastal areas, providing solutions to infrastructure-related issues, managing land use, and preserving coastal ecosystems. The National Water Policy, 2018, is the final act relevant to the preservation of diminishing marine resources in Pakistan. It provides a comprehensive and voiced approach to the topic of water management in Pakistan.

5.2.2 China legal framework for marine environmental protection

China has established a legal framework in the field of marine conservation through the legislation of the Marine Environment Protection Law and the Fisheries Law. These documents have been critical in regulating marine environmental protection and managing fisheries resources. The Marine Environment Protection Law is the primary legislation that seeks to conserve and enhance the marine environment. It contains an extensive array of regulations targeted at the prevention and control of marine pollution, integrated coastal zone management, and conservation of marine biodiversity. As such, it requires pollution control by limiting the number of contaminants discharged into the sea through shipping and industrial activities. The law also requires an environmental impact assessment to evaluate environmentally sound marine project activities. The law also addresses a variety of issues related to the conservation of marine ecosystems and the protection of marine species. Despite the law's broad scope, its implementation has encountered numerous challenges. These include issues such as insufficient enforcement and monitoring capabilities and inadequate public awareness (Chang et al., 2020).

The law focuses mainly on the sustainable management of fishery resources and the protection of aquatic environments. It includes provisions on regulating fishing activities, among other critical aspects of fishing. The law mandates that relevant government agencies and departments, as well as any other institution responsible for managing or regulating fishery resources, must obtain licenses before conducting any fishing operations. The law also requires that these responsible institutions establish firm management and quotas of fish to and from the country. However, similar to the law on the protection of the marine environment, China's Fisheries Law encounters numerous challenges in its implementation. Among other issues, the society confronts a significant challenge in the form of illegal fishing in the seas and oceans, both within and outside China. Insufficient enforcement and monitoring of the law also limits its practical application (Mahaseth, 2021).

The implementation of the law that emphasizes the protection of China's seas and oceans presents several key challenges. Most often, the implementation of the law in question faces challenges when all relevant parties are not involved in the law enforcement activities. Moreover, the absence or scarcity of crucial organs and equipment necessary for monitoring and enforcing the law can pose a significant challenge to its implementation. Inadequate management and coordination of other efforts in support of the law may lead to additional challenges. Finally, inadequate public involvement in supporting the law may pose a challenge to its implementation (Guo, 2020).

5.3 Provisions within the Pakistan-China FTA

The FTA between Pakistan and China brought revolutionary changes in economic relations between the two countries; however, one of the limitations of the agreement is that it does not have concrete provisions related to marine environmental protection. Furthermore, the general framing and non-enforcement of environmental clauses hinders the effective management of marine environmental impacts linked to heightened trade.

Generally framed and not enforceable, environmental clauses in the existing framework do not specifically assist in mitigating environmental impact issues. Such a clause's nature is vague and not specific. The general environmental clauses are connotative, containing general commitments for environmental sustainability or detailing the parties' adherence to existing environmental regulations. However, the specific clauses do not address the impact of trade on the marine ecological system. For example, the FTA may not have addressed the distribution and pollution aspects of increased shipping activities. It may not have addressed the overfishing issues and failed to provide specific measures for protecting marine ecosystems related to trade and development (Idrees and Rehna Gul, 2022).

This means the agreement is unenforceable for any environmental measure. In addition to that, the lack of enforceable environmental measures means that there is little to no accountability concerning the environmental effects of trade activities. The FTA lacks a mechanism to prevent trade from damaging the environment, as it lacks specific and rigorous requirements regarding the issue and does not allow for concrete data to pinpoint possible instances of marine pollution, overfishing, and habitat destruction. Therefore, these challenges highlight the difficulties in incorporating environmental factors into a formal trade agreement, particularly when the expansion and expansion of globally significant businesses trump environmental objectives.

A future phase of the FTA should have detailed and enforceable environmental provisions to address these weaknesses. It can include clear prescriptions for pollution control, guidelines on sustainable fishing, as well as measures to protect marine habitats. These clear provisions will help to ensure that both countries are able to regulate their trade properly and reduce the environmental impact of their activities, which will support the sustainability of their marine ecosystems. Such an approach would help to align trade with environmental protection efforts while also improving the overall effectiveness of the FTA in supporting a balanced and sustainable economic relationship (Abbas et al., 2023).

6 Identifying gaps and challenges

6.1 Inadequate environmental provisions in the FTA

The Pakistan and China FTA aims to promote economic integration and bilateral trade, and it contributes to marine environmental protection to a lesser extent. While China and Pakistan's FTA may have broad commitments to environmental preservation, it lacks explicit and detailed environmental provisions, resulting in the absence of legal bias to address and control the environmental impact of increased trade. The current environmental provisions generally frame the marine environmental problem without specificity. It implies that the agreement may have a general reference to environmental issues and sustainability. However, the agreement does not show specific concerns with respect to marine pollution, overfishing, and the destruction of habitats. The current provisions are limited due to their lack of emphasis on the specific environmental issues. It does not provide any concrete measures, programs, or implementation modalities. It also does not specify the necessary national capacities and enforceable or institutional provisions to implement marine environmental protection. For example, the terms of the agreement do not contain provisions that regulate marine pollution related to increased transportation or control the unloading of waste and oil from vehicles. Additionally, there are no special provisions that would prevent overfishing due to increased trade or protect the vulnerable marine stenoses and mangroves from habitat loss linked to trade. Thus, because of the general nature of the environmental clauses, there is no formal mechanism that would ensure that trade does not affect the environment in this way (Irshad, 2017).

This legislative gap is part of a broader issue relative to incorporating environmental provisions within trade agreements. As a result, the current issues listed in Table 1 cannot be effectively prevented because there are no precise provisions that could be enforced to guarantee that any economic activities unrelated to trade would not be harmful to the marine environment. Therefore, to bridge the gap between economic growth and environmental sustainability within the FTA, specific, concise, and enforceable provisions addressing pollution, overfishing, and habitat destruction should accompany the development of future regulations.

6.2 Weak enforcement mechanisms

Pakistan and China are unable to effectively enforce the existing environmental laws. This situation exacerbates the challenges in protecting marine environments under the FTA. Several factors primarily drive this issue, including the lack of sufficient resources, the lack of coordination among the concerned entities, and the lack of political will. Insufficient provision of facilities by the concerned agencies hinders the execution of environmental laws in Pakistan. Pakistan Environmental Protection Agency (EPA) and the other involved bodies suffer financial, technical, and human resource deficit. This limits their scope of proper monitoring and execution of environmental standards, including those that pertain to the protection of marine environment. Some government bodies work in isolation, which may not deliver success in executing environmental laws. China faces similar challenges in terms of enforcing the law to protect its marine environment. Despite the country's extensive legal framework, which includes statutes and regulations like the Marine Environment Protection Law and the Fisheries Law, the lack of resources and proper monitoring systems

may hinder the implementation of these legal instruments. Another issue is the decentralization of regulatory control, with different responsibilities shared by government agencies across various levels. The low political priority of marine environmental issues complicates this state of affairs, resulting in inconsistent enforcement and a diminished determination to enforce them (Khan and Chang, 2021).

Furthermore, a lack of public awareness and attentiveness hinders the enforcement of environmental protection laws. Both countries struggle to generate strong support for environmental protection initiatives and keep stakeholders engaged in monitoring and reporting breaches. Moreover, the absence of proper public participation and accountability in enforcing the law amplifies the inadequacies in the implementation of environmental protection measures. The process of meeting the challenges and opportunities of the implementation of laws includes the current capacities and resources of the relevant regulatory and other bodies and political organizations, as well as the commitment of political leadership to use them. The discussion also highlighted the importance of fostering public awareness and participation, which is crucial for monitoring and reporting illegal and inappropriate activities. Both nations should act to capitalize on these points and enforce their environmental protection laws accordingly to protect marine environments during the rise in trade flows (Guo, 2020).

6.3 Economic vs. environmental priorities

Trade agreements such as the FTA are often marred by considerable tension in relation to economic and environmental priorities. The primary issue lies in the perception that economic priorities often overshadow the imperative for environmentally sustainable practices. This is because a FTA primarily aims to increase trade volume, increase investments, and realize the development of economic potential. In the case of the FTA between China and Pakistan, representatives from both countries warn about the need to reduce tariffs both in China and Pakistan to encourage trading and investments and to ensure better economic growth. In other words, the principal priority of the economic agreement is to improve the trade relationship between both countries, create more jobs, and accelerate the growth of industries (Jea, 2011).

However, the issue with economic growth is that it often comes at the expense of specific environmental conditions. For example, the FTA agreement facilitates accelerated trade, which results in increased traffic from shipping, industrial operations, and resource extraction. This, in turn, leads to an increase in sea, fishing, and marine traffic, which further contributes to sea pollution, overfishing, and habitat destruction. However, for various reasons, people often overlook the environmental effects of pursuing economic growth. Economic objectives are more urgent and measurable, which implies that they represent a more critical problem requiring an immediate solution. Simultaneously, we can view environmental difficulties as a lower priority issue that we can address at a later time. This argument suggests that we choose unsustainable development because its short-term benefits to economic development outweigh its long-term negative environmental consequences (Amir, 2022).

Therefore, reconciling economic and environmental goals requires a more integrated approach. Therefore, such agreements as FTA should imply adequate environmental provisions that are compatible with the governments' economic objectives. This necessitates the implementation of policies and laws that mitigate environmental harm, encourage environmentally sustainable practices, and guarantee the attainment of economic objectives without negatively impacting environmental quality. If both countries can achieve a balance, which is not an unattainable goal, it should be possible for China and Pakistan to achieve strong economic development while protecting their marine environment.

7 Proposed legal solutions

7.1 Incorporating specific environmental clauses in the FTA

There are major imbalances in the FTA between Pakistan and China when it comes to the availability of the right set of political tools to protect the marine environment. This is why any future revisions should include separate clauses for environmental sustainability. To ensure that trade operations do not adversely affect marine ecosystems, these clauses should aim to establish viable, enforceable standards and create thorough monitoring and compliance mechanisms.

Future versions of FTA should have distinct environmental standards targeting key spheres: pollution control, sustainable fishing, and habitat protection. Thus, we can implement specific measures to regulate shipping-related pollution and manage waste and oil spills. As regards fishing practices, the agreement can set catch limits, define unsafe seasons and areas, and introduce measures that protect endangered species. Equally important is developing enforceable standards, which are precise and supported with detailed guidelines on acceptable practices and non-compliance fines. In this manner, everyone involved will understand their responsibilities and feel motivated to enhance their practices to meet the agreement's standards (Monteiro, 2016).

The compliance and control mechanisms must assist in tracking and, if necessary, limiting the impact of trade on environmental standards. An important measure would be to establish a joint body empowered to control the effects of trade on the marine environment. Specifically, we should mandate the latter to conduct routine checks of the situation, assess the degree of compliance with existing environmental standards, and address non-compliance problems. The monitoring and control mechanisms will imply that both countries have established data collection and range requirements. This will allow us to track the sufficiency of the measures and determine if more radical steps are required. The open-data policy is also necessary to improve accountability on the part of both countries and build trust with the stakeholders.

It would also be adequate to try and introduce some adjustments aimed at increasing the capacities of the regulatory bodies and employing closer cooperation between Pakistan and China. For instance, it is possible to offer to cooperate with both countries and provide resources and training to the enforcement agencies to optimize their ability to follow and enforce environmental standards. Additionally, we can propose closer cooperation with China to exchange valuable information, thereby increasing the efficiency of all environmental measures taken by both countries. With the propositions for the environmental clauses described above, it will be feasible to incorporate the clauses regarding the protection of marine environments into the FTA. As a result, it will contribute to both preventing the adverse effects of the booming trade, such as the pollution of marine environments, and ensuring that the economic cooperation with China remains stable and free from serious disputes (Monteiro, 2016).

A comparison with other international agreements with environmental protection clauses would take the discussion of the proposed legal measures to the next level of relevance. One of the possible examples mentioned in the module is the North American Agreement on Environmental Cooperation, which is a side agreement to the North American Free Trade Agreement. The European Union's trade agreements employ a similar structure with subsections concentrating on sustainable development, where signatories agree on their parties' compliance with the existing environmental standards and a dialogue on related issues. The Comprehensive and Progressive Agreement for Trans-Pacific Partnership includes binding clauses that dictate compliance with environmental standards and provide that the implementation of the agreement cannot undermine conservation efforts. Therefore, a comparative table of these templates would offer a thorough analysis of the successful implementation and operation of similar measures in other countries. By combining the best samples and their strong points with the shortcomings of others, we could outline prevailing environmental challenges that should be addressed in the FTA. Such comparison is also proof that environmental concerns should be taken into consideration in all trade agreements.

7.2 Establishing a Joint Environmental Commission

In order to resolve the environmental problems that have emerged as a result of the FTA between Pakistan and China, it is essential to create a Joint Environmental Commission. This commission will focus precisely on the environmental issues that led to the FTA, as well as the consequences of the agreement. An environmental commission would contribute to cooperation between the two countries and ensure the efficient and effective implementation of environmental provisions.

A Joint Environmental Commission will serve as a dedicated platform for bilateral environmental cooperation. Upon the establishment of such a commission, experts, policymakers, and other interested parties from both countries will be able to cooperate on pertinent environmental issues. With the commission in place, the countries may develop and pursue joint courses of action to address such issues as marine pollution, overfishing, and habitat destruction. Therefore, the level of cooperation between the two countries in the environmental management area will increase, leading to more coherent and effective environmental policies applicable to both countries and their respective and shared marine ecosystems.

The proposed commission aims to facilitate information sharing between Pakistan and China. This would imply the dissemination of data regarding the level and scale of environmental impact, trade activities, and adherence to the agreed standards among the parties. Both countries involved could benefit from a designated process for regular and convenient sharing of these data sets, which would keep them updated on new environmental issues and aid in evaluating the efficacy of adopted remedies. Furthermore, the commission can serve as a "*environmental data hub*" that stores all collected information, making it accessible to relevant stakeholders and the public. Building transparency in this area is of primary importance for developing trust and recognition among all involved parties.

The commission would also be responsible for implementing the FTA's environmental provisions. In other words, the commission would be responsible for monitoring compliance with the environmental standards, conducting the inspection, and dealing with the violations. Therefore, the establishment of clear enforcement mechanisms would help to ensure that both China and Pakistan would be in compliance with the agreed-upon measures. Furthermore, the commission would also have to review and, if needed, update the provisions based on the new information, technological development, or environmental changes (Ullah et al., 2021).

In addition to its obvious functions and activities of constant oversight and immediate execution, the Joint Environmental Commission may serve as an effective medium for capacity building and technical support to various stakeholders and regulatory agencies. As a result, it could devise training programs and workshops to popularize environmental management best practices, develop a series of monitoring and assessment tools, and promote the development of contacts between environmental and trade experts. In other words, such a commission enhances the capacity of the involved parties, thereby improving the performance of environmental protection and marine resource management. In summary, this approach represents a significant advancement in balancing trade profits and prudent economic growth through effective environmental activities.

The Gulf of Maine Council on the Marine Environment. The United States and Canada cooperated to form this commission. The development aims to safeguard and conserve the marine environment of the Gulf of Maine, highlighting the significance of cooperative management and sustainable development. The development places significant focus on safeguarding the environment. This joint commission's key goals are to develop a coordinated approach to marine area management, to promote human and ecosystem health, to protect and restore marine and coastal habitats, to reduce pollution and improve waste management, to sustain fisheries, and to reduce and mitigate

bycatch. This joint commission serves as a promising model for developing a joint commission that can improve the environmental conditions associated with the China-Pakistan Free Trade Agreement. Including such a purpose in the agreement will ensure that both countries work to mitigate possible negative effects of trade on the marine environment and promote sustainable practices for both parties.

7.3 Enhancing public participation and transparency

Increasing transparency and public administration involvement provide the key approaches to enhancing environmental governance under the FTA. As the agreements are being determined, trade-related conservation activities and allegations could be made transparent with the aim of assisting relevant parties in being heard, appealing, and adopting improved decision-making requirements. The benefit of more transparent agreements is that they effectively link environmental tendencies in the FTA and ensure an increased performance level. By making information available, the public, businesses, and non-governmental organizations can gain a deeper understanding of the environmental governance agreements, particularly the trends and stipulations they provide.

Additionally, the decision-making processes should incorporate public participation. Engaging civil society, including local communities, environmental NGOs, and other stakeholders, can improve the quality of environmental governance. Public participation allows taking into account a greater variety of perspectives and expertise, thus making the decisions more balanced and informed. There are several forms of such involvement, such as public consultations, stakeholder forums, and participatory assessments. The FTA can effectively address environmental concerns and ensure the interests of affected communities by incorporating the voices of various groups in the decision-making processes.

It would be beneficial to institutionalize public participation within the FTA framework by introducing mechanisms for regular consultations and feedback. This may take the form of advisory committees or working groups, with substantial representation from civil society, to provide guidance on increasing environmental protection, track policy implementation, and recommend improvements. In addition, the FTA may include provisions that require the availability of environmental information as well as reports about the state of the environment, allowing civil society to monitor the impacts of trade and environmental policies and engage on equal footing in the discussions of relevant issues. In summary, the FTA framework's guaranteed transparency and increased public participation will enhance environmental governance by integrating environmental considerations into overall decision-making. As a result, these measures will help the FTA reconcile economic growth with environmental sustainability and introduce a more inclusive, as well as accountable, approach to managing trade's environmental impacts (Lau, 2018).

The inclusion of examples from international agreements with relatively strong environmental provisions would greatly enhance the FTA. For example, the North American Agreement on Environmental Cooperation is part of NAFTA. Such provisions as public participation and information in the decision-making process clearly contribute to assuring environmentally responsible behavior of the participants. The Comprehensive and Progressive Agreement for Trans-Pacific Partnership, which countries signed after the USA withdrew from TTP, serves as another example. It includes a separate chapter, "Environment," which ensures sustainable resource management among the members of the agreement as well as adherence to environmental law. Finally, a table showing similar rules in other free trade agreements (FTAs) would help show why specific environmental clauses and more public participation need to be a part of the FTA.

7.4 Strengthening national environmental laws

To solve problems of ecological maintenance and implementation of the FTA, the national environment legislation must be improved and supplemented, taking it into conformity with contemporary requirements. From that point of view, both Pakistan and China have to hold qualifying reviews of environmental legislation, realizing the necessity to expand national environmental laws. The proposed legislation aims to enhance oversight and penalize violations. There is a need to extend the list of environmental abuse along with stringency of penalties and punishment. It is required to tighten pollution protection standards, to expand marine environment defense, and to improve the legislation in order to address environmental circumstances occurring due to trading activities.

Strengthening national laws with respect to increasing penalties for environmental violations is another important aspect to consider. Imposing higher fines and other penalties on violators appears to be an essential means to harshen the existing enforcement measures for harming the environment. Financial deterrence of noncompliance contributes to reducing the risk of illegal practices in businesses and by private individuals. Offenders should at least remunerate the costs of long-term recovery efforts and compensate the victims of environmental violations. Penalties against the offenders must be proportionate to the severity of environmental damage. In addition, it can be effective to enhance the capacity of the institutions with the regulatory function. Regulatory authorities must have sufficient resources, training, and other means to monitor compliance and solve environmental problems. This requires investing in environmental monitoring technologies, conducting the necessary inspections, and providing training programs for supervisory staff. Efficient enforcement also requires increased coordination between different regulatory bodies and transnational relations with international organizations (Dobson, 2005).

In addition, Pakistan and China should foster cooperation between the government, industry, and civil society organizations to effectively implement and uphold the legal standards.

Stakeholder awareness and other forms of engagement can assist the national government in monitoring compliance to ensure that all government and private agencies understand and follow the regulations and standards. The suggested improvements to the above steps suggest that Pakistan and China can effectively manage the environmental impacts of the FTA and ensure sustainable economic growth. In the long run, the new measures will help to put more restrictions in place to allow the exploitation of the marine ecosystem without causing a negative, long-lasting impact.

7.5 Promoting sustainable trade practices

It is crucial to promote sustainable trading practices, thus minimizing the environmental impacts of state activities that are associated with the FTA conclusion between China and Pakistan. The mentioned goal can be reached by applying the following measures: sustainable fishing promotion, marine pollution prevention, and green port investment. All of these approaches will greatly contribute to the successful completion of the deliberated task and promote environmentally friendly trade between Pakistan and China. Encouraging sustainable fishing practices is one of the most important ways to maintain the population and biodiversity of marine creatures. They suggest specific regulations aimed at curbing overfishing and preventing the overexploitation of any species. Laws should protect endangered animals, necessitating expert assessments of fisheries sustainability. As a result, quotas and catch limitation regulations could be based on scientific research. Furthermore, the FTA could obligate fishermen to use selective gear or practices and avoid bycatch, which could lead to harmful results not only for non-targeted species but also for the ocean as a whole. Thus, fishing practices may be considered sustainable by the FTA if they can help keep the balance between the income of all the groups involved and their negative effect on nature. Mitigation and reduction of marine pollution is a significant element of enhancing sustainable trading. Stricter requirements and expanded regulations regarding the management and control of ship-generated waste and other activities, the introduction of cleaner technologies, and the improvement of monitoring and control systems can control such activities. For instance, we can significantly lessen the adverse environmental effects of the maritime trade by enforcing stricter regulations on the discharge of garbage and waste on ships, as well as establishing standards for the use of clean fuel. By doing so, we can significantly reduce the pollution of the marine environment and preserve local habitats and organisms (Chang et al., 2020).

Promoting green port infrastructure is critical because it helps reduce and mitigate the environmental impact of increased trade. To understand, green port facilities usually imply that their operating procedures and technologies are environmentally friendly, or at least have minimal negative impact. To Promoting the infrastructure and greening of ports in trade-involving countries like Pakistan and China is crucial to achieve this. instance, there should be more energy-friendly and green lighting, green energy, recycling, and adequate waste management. To ensure that the operation of ports is green or near-green, some pollution should be avoided or mitigated. Such pollution pertains to air contamination and should be avoided, along with measures to limit water pollution, energy loss, and pollution of the marine environment around ports. Overall, the promotion of sustainable trade practices requires a complex of measures aimed at integrating environmental considerations into trade policies and infrastructure development. If the FTA sponsors sustainable fishing, marine pollution reduction, and green port infrastructure, China and Pakistan will be able to support a more balanced and sustainable economic relationship. These measures will ensure that trade continues to promote sustainable economic growth while protecting marine ecosystems and promoting their long-term health.

8 Conclusion

In conclusion, there is no doubt that the FTA between Pakistan and China has increased the level of bilateral trade. To a higher degree, such a fact implies that the nations' economic integration is also becoming deeper and more pronounced. In the meantime, increased trade intensity and intrusiveness have significant environmental consequences, especially for marine ecosystems. The overarching conclusion is that integration and trade, in general, should be complemented by more sophisticated consideration of economic and environmental balance and appropriate solutions to specific environmental issues. Trade-related pollution, overfishing, and critical habitat destruction are the environmental issues that are getting more severe as a result of increased shipping activity and the overall higher level of resource exploitation resulting from the FTA.

Although the FTA has some good economic effects, the overall policy lacks commitment to marine environmental protection. The FTA lacks specific environmental clauses and relies on weak compliance procedures for enforcement. The combination of missing clauses and weak enforcement causes double damage by creating regulatory gaps and failing to impose sanctions on countries focused on economic objectives. As a result, various practices regarding the exploitation of the seas reduce marine sustainability and lead to long-term problems.

Future FTA revisions should include specific environmental clauses dedicated to the protection of the marine environment to address the described problems. These revisions could involve the establishment of a joint environmental commission, which would facilitate enhanced collaboration and ensure the effective implementation of environmental clauses. Increasing the transparency of processes and provisions can enhance the public's involvement in environmental governance and decision-making processes. In addition, both countries should strengthen their national environmental laws and enforcement measures and promote sustainable trade, including responsible fishing, pollution reduction, and green port infrastructure investment.

Further research should be done in order to research the potential to integrate the most effective and comprehensive environmental provisions within a trade agreement and assess their effectiveness on the degree of environmental impact. Best practices from other international agreements and trade partnerships can be used to enhance the environmental framework of the FTA. Future studies of this issue can also look at the climatic, socio-economic, and other impacts of the net environmental degradation for local communities

and ecosystems. Such factors could especially dominate the degradation of natural areas on the border between the two states. Moreover, future agreements will involve policymakers, industries, environmental experts, and researchers who will strive to strike a balance between trade and the environment. Therefore, policymakers from states, green industries, and other stakeholders should collaborate to develop FTAs that are both economically beneficial and environmentally friendly.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

MU: Writing – review & editing, Investigation, Conceptualization. AK: Writing – original draft, Methodology, Funding acquisition, Formal analysis.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Abbas, A., and Ali, S. (2018). "China regional trade pattern and prospects for Pakistan," in *Centre of Excellence for China Pakistan Economic Corridor* (Islamabad, Pakistan: Center of excellence for CPEC), vol. 1, 1–10.

Abbas, A., Rauf, A., and Mumtaz, S. (2023). Evaluating the effect of tariff and non-tariff barriers on exports in the pre and post China-pak free trade agreement (FTA) period. *NUST J. Soc. Sci. Human.* 9, 156–173. doi: 10.51732/njssh.v9i2.167

Amir, A. (2022). Exclusive economic zone & Maritime potential of Pakistan. *J. Prof. Res. Soc. Sci.* 9, 1–17.

Butt, M. J. (2021). A comparative analysis of the environmental policies in China and Pakistan: developing a legal regime for sustainable China-Pakistan economic corridor (CPEC) under the Belt and Road Initiative (BRI). *IPRI J.* Vol. XXI (1), 28–120. doi: 10.31945/iprij.210104

Camara Sanchez, R. A. (2011). Climate change and the law of the sea convention. Master thesis, FACULTY OF LAW, Lund University.

Chandra, A., and Idrisova, A. (2011). Convention on Biological Diversity: a review of national challenges and opportunities for implementation. *Biodivers. Conserv.* 20, 3295–3316. doi: 10.1007/s10531-011-0141-x

Chang, Y. C., and Khan, M. I. (2019). China–Pakistan economic corridor and maritime security collaboration: A growing bilateral interests. *Maritime Business Rev.* 4, 217–235. doi: 10.1108/MABR-01-2019-0004

Chang, Y. C., Wang, C., Khan, M. I., and Wang, N. (2020). The legal system for environmental protection during exploration and exploitation of marine mineral resources in China. *Resour. Policy* 67, 101670. doi: 10.1016/j.resourpol.2020.101670

Chaudhry, T., Jamil, N., and Chaudhry, A. (2017). Pakistan's experience with the Pakistan–China FTA: lessons for CPEC. *The Lahore Journal of Economics* 22 (Special Edition), 1–24. doi: 10.35536/lje.v22.isp.a1

Club, U., and Thomas, B. (2013). How to comply with MARPOL annex V. Thomas Miller P&I Ltd, UK.

Dastgeer, A., Hassan, A., Husnain, M. A., Bhatti, M. K., and Javed, A. (2023). The impact of the China-Pakistan free trade agreement (FTA) on the economic growth of Pakistan. *Russian Law J.* 11, 2288–2299.

De Oliveira, J. P., Balaban, O., Doll, C. N., Moreno-Peñaranda, R., Gasparatos, A., Iossifova, D., et al. (2011). Cities and biodiversity: Perspectives and governance challenges for implementing the convention on biological diversity (CBD) at the city level. *Biol. Conserv.* 144, 1302–1313. doi: 10.1016/j.biocon.2010.12.007

Dobson, W. D. (2005). *Free trade agreements and the Doha round of WTO Negotiations–Implications for the US dairy industry, AgEcon search*. Available at: https://ageconsearch.umn.edu/record/37464/files/2005-02.en.pdf.

Fazal-ur-Rahman, M. (2010). Pakistan-China trade and investment relations. *Strat. Stud.* 30, 100–108.

FTA. (2006). *China-Pakistan free trade agreement phase I*. (Islamabad, Pakistan: Ministry of Commerce, Government of Pakistan). Available online at: https://www.commerce.gov.pk/about-us/trade-agreements/pak-China-free-trade-agreement-in-services/ (Accessed August 10, 2024).

Glasson, J., and Therivel, R. (2013). *Introduction to environmental impact assessment* (England, UK: Routledge).

Guo, J. (2020). The developments of marine environmental protection obligation in article 192 of UNCLOS and the operational impact on China's marine policy–A south China sea fisheries perspective. *Mar. Policy* 120, 104140. doi: 10.1016/j.marpol.2020.104140

Hassan Daud Butt, M. U. A., and Majeed, S. (2022). Leveraging CPFTA for national economic growth amidst global crises. *Pakistan J. Int. Affairs*. 5 (3), 15–37.

Hussain, C. M., and Ali Shah, S. Z. (2017). Quantitative assessment of Pakistan and China free trade agreement. *Pakistan J. Commerce Soc. Sci. (PJCSS)* 11, 293–308.

Idrees, R. Q., and Rehna Gul, D. S. K. (2022). The China trade model in the ambit of belt and road initiative Pakistan and international law perspective. *Pakistan J. Int. Affairs* 5, 626–667.

Irshad, M. S. (2015). Pakistan-China free trade agreement (PCFTA) treaty model: Capability, prospects and disputes. *Acad. Res. Int.* 6, 53–60. doi: 10.2139/ssrn.2690798

Irshad, M. S. (2017). SWOT analysis of Pakistan-China free trade agreement: Pros and Cons. *Int. J. Asian Soc. Sci.* 7, 45–53. doi: 10.18488/journal.1/2017.7.1/1.1.45.53

Jea, G. (2011). A study on the IMO regulatory instruments concerning the evaluation of safety and pollution hazards of chemicals in bulk transported by sea (based on MARPOL Annex II and IBC Code).

Khan, M. Z. (2022). Geopolitics of the Indian ocean region and challenges for the China-Pakistan economic corridor. *Pakistan Horizon* 75, 95–112.

Khan, M. I., and Chang, Y. C. (2021). Love for the climate in Sino–Pakistan economic romance: a perspective of environmental laws. *Clean Technol. Environ. Policy* 23, 387–399. doi: 10.1007/s10098-020-01938-4

Khan, R., Shaikh, A. S., and Masood, H. (2019). Impact of Pak-China free trade agreement (FTA) on trade and industry of Pakistan. *Electr. Res. J. Soc. Sci. Human.* 1, 1–33.

Khan, M. I., and Xu, Q. (2021). An assessment of environmental policy implications under the China-Pakistan economic corridor: A perspective of environmental laws and sustainable development. *Sustainability* 13, 11223. doi: 10.3390/su132011223

Lakhani, S. (2016). The China-Pakistan Economic Corridor: regional effects and recommendations for sustainable development and trade. *Denv. J. Int'l L. Pol'y* 45, 417.

Lau, M. (2018). The role of environmental tribunals in Pakistan: Challenges and Prospects. *YB Islam. Middle EL* 20, 1. doi: 10.1163/22112987_02001002

Lin, Y. (2018). Opportunities and challenges in current China–Pakistan economic and trade relations. *Annu. Rep. Dev. Indian Ocean Region (2017) Belt Road Initiative South Asia*, 213–236.

Mahaseth, H. (2021). Analysis of the law on marine environment protection of the People's Republic of China. *J. Hunan Univ. Natural Sci.* 48, 2034–2045.

Marino, D., Marucci, A., Palmieri, M., and Gaglioppa, P. (2015). Monitoring the Convention on Biological Diversity (CBD) framework using evaluation of effectiveness methods. The Italian case. *Ecol. Indic.* 55, 172–182. doi: 10.1016/j.ecolind.2015.02.025

MEPC, R. (2011). Amendments to the annex of the protocol of 1997 to amend the international convention for the prevention of pollution from ships 1973, as modified by the protocol of 1978 relating thereto. *Amendments to MARPOL Annex VI. MEPC* 70, 18.

Ministry of Commerce, Pakistan (2024). Available online at: https://www.commerce.gov.pk/wp-content/uploads/2019/09/Year-Book-2016-17.pdf (Accessed October 08, 2024).

Mohsin, M., Hengbin, Y., and Guilin, D. (2018). China-Pakistan cooperation in fishery trade: present status and future possibilities. *Indian Journal of Geo Marine Sciences* 47 (12), 2333–2342.

Monteiro, J. A. (2016). Typology of environment-related provisions in regional trade agreements. *WTO Working Paper ERSD-2016-13*, 04–1097. doi: 10.2139/ssrn.2825791

Naz, H., and Parveen, S. (2022). China Pakistan economic corridor: strategic significance for China and Pakistan. *J. Higher Educ. Dev. Stud. (JHEDS)* 2, 35–50. doi: 10.59219/jheds.v2i1.10

Nguyen, L. N. (2023). *The development of the law of the sea by UNCLOS dispute settlement bodies* (Cambridge, United Kingdom: Cambridge University Press).

PBC (2024). *Preliminary analysis of pak-China FTA phase II*. Available online at: https://www.pbc.org.pk/research/preliminary-analysis-of-pak-China-fta-phase-ii/ (Accessed October 08, 2024).

Qayuum, S. (2021). The strategic maritime environment of the Indian ocean: an analysis of the challenges and prospects for Pakistan. *P-JMR* 3, 81–118.

Sahibzada, F. (2021). Strengthening trade between Pakistan and China; A case study of free trade agreement. *J. Higher Educ. Dev. Stud. (JHEDS)* 1, 43–60. doi: 10.59219/jheds.v1i1.5

Secretariat of the Convention on Biological Diversity (2001). *Handbook of the convention on biological diversity* (Oxford, Oxfordshire, United Kingdom: Earthscan).

Shah, S. H., Kamal, M. A., and Yu, D. L. (2022). Did China-Pakistan free trade agreement promote trade and development in Pakistan? *Int. J. Finance Econ.* 27, 3459–3474.

Siig, K., Feldtmann, B., and Billing, F. M. (2023). *The United Nations Convention on the Law of the Sea: A System of Regulation* (United Kingdom: Taylor & Francis).

Solangi, H. U. R., Gilal, F. G., and Tunio, M. Z. (2018). One belt one road initiative: the origin, current status, and challenges of China-Pakistan economic corridor. *Int. J. Technol. Policy Manage.* 18, 313–335. doi: 10.1504/IJTPM.2018.096180

Stougaard-Andresen, R. A. C. (2023). Climate change and the law of the sea convention.

Suncls, A., and Cai, I. I. (1982).United Nations convention on the law of the sea. In: *United Nations*. Available online at: https://www.un.org/Depts/los/convention%5fagreements/texts/unclos/closindx.htm (Accessed 17 January 2024).

Ullah, Z., Wu, W., Wang, X. H., Pavase, T. R., Shah, S. B. H., and Pervez, R. (2021). Implementation of a marine spatial planning approach in Pakistan: An analysis of the benefits of an integrated approach to coastal and marine management. *Ocean Coast. Manage.* 205, 105545. doi: 10.1016/j.ocecoaman.2021.105545

Uzair, L., and Nawaz, A. (2018). Modelling welfare effects under Pakistan–China free trade agreement. *J. Chin. Econ. Foreign Trade Stud.* 11, 202–218. doi: 10.1108/JCEFTS-07-2018-0028

Wardhana, N. D. (2015). The implications of the implementation of part iii of the united nations convention on the law of the sea (UNCLOS) 1982 to the safety of navigation and marine environmental protection in the straits used for international navigation: The review of policy and cooperation, and future direction of the cooperative mechanism in the straits of Malacca and Singapore. Dissertation M.Sc. World Maritime University (Malmö, Sweden) 2015., World Maritime University Library.

Zulfiqar, K., Butt, M. J., and Chang, Y. C. (2023). Usage of term'Maritime"and its impacts on the literature on China-Pakistan economic (Maritime) corridor (CPEC). *P-JMR* 5, 156–118. doi: 10.53963/pjmr.2023.009.5

frontiers | Frontiers in Marine Science

TYPE Review
PUBLISHED 21 November 2024
DOI 10.3389/fmars.2024.1493647

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Qiuwen Wang,
East China University of Political Science and Law, China
Barbara Stępień,
Jagiellonian University, Poland

*CORRESPONDENCE
Ran He
heran0129@korea.edu

RECEIVED 09 September 2024
ACCEPTED 04 November 2024
PUBLISHED 21 November 2024

CITATION
Sun S and He R (2024) How to possess an electronic bill of lading as information? A comparative perspective of the legislation on the "possession problem" of electronic bills of lading.
Front. Mar. Sci. 11:1493647.
doi: 10.3389/fmars.2024.1493647

COPYRIGHT
© 2024 Sun and He. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

How to possess an electronic bill of lading as information? A comparative perspective of the legislation on the "possession problem" of electronic bills of lading

Siqi Sun[1] and Ran He[2]*

[1]Law School, Shanghai Maritime University, Shanghai, China, [2]Department of Law, Korea University, Seoul, Republic of Korea

The possession of the paper B/Ls is the basis of the function of a B/L as a document of title in common law systems and the delivery effect of B/Ls in civil law systems. The "possession problem" of eB/Ls is how to ensure that eB/Ls, as intangible objects, continue to have this basis. In the international level, the MLETR creates the concept of "control" of electronic transferable records as a functional equivalent to possession of paper B/Ls. Although the CMI Rules and the Rotterdam Rules involve control, neither of them makes specific provisions for control. In the national level, there are three solutions to the "possession problem": First, expand the objects of possession to cover eB/Ls, such as the United Kingdom. Second, adopt the same approach as the MLETR, creating a concept of control as a functional equivalent of possession, such as Singapore and Japan, which is in the process of legislating, as well as Abu Dhabi Global Market and other 6 jurisdictions which have directly transplanted Article 11 of the MLETR. Third, establish a central registry system so that possession of eB/Ls does not have to be demonstrated. A typical example is South Korea, where the legislation on eB/Ls preceded the MLETR. The revision of Chinese Maritime Code currently does not pay sufficient attention to the "possession problem" of eB/Ls. The countermeasure should be to first stipulate the delivery effect of paper B/Ls, and then provide a solution to the "possession problem" of eB/Ls.

KEYWORDS

electronic bills of lading, possession, control, MLETR, functional equivalent, Chinese Maritime Code

1 Introduction

The revolution in information and communications technology and electronic communication and processing has profoundly affected most spheres of commercial activity. Although the shipping industry is in many ways conservative in terms of speed of change to its documentation and practices, e-commerce is of increasing importance (Aikens et al., 2021). Whether it is called electronic bill of lading (*Korean Commercial Code*), electronic transport record (the *Rotterdam Rules*), electronic bill of lading record (*the Interim Draft for Reviewing Regulations Related to Bills of Lading*, Japan), electronic trade document (the *Electronic Trade Documents Act 2023*, UK) or other terms, the electronification of bills of lading (hereinafter referred to as "B/Ls") is one of the most important features of the current trend of digitalization in shipping industry, and it is also a direct result of the development of e-commerce in the shipping industry. However, after nearly 40 years of development, eB/Ls have not yet achieved widespread and stable application. One of the reasons the use of electronic commerce is not developing in line with technological capability is that there is little law governing its use. The exchange of data electronically does not itself pose a problem. However, when the data represents negotiable documents that cover valuable assets, an established legal structure is needed (Dubovec, 2006).

In response to this trend, the legislation of electronic bills of lading (hereinafter referred to as "eB/Ls") has become the focus of both international and domestic maritime legislation since the 2010s. South Korea is the first country to enact special legislation for eB/Ls, and formulated the *Regulations on Implementation of the Provisions of The Commercial Code Regarding Electronic Bills of Lading* in accordance with the *Korean Commercial Code* in 2008. The *UNCITRAL Model Law on Electronic Transferable Records* (hereinafter referred to as "*MLETR*") was adopted on 13 July 2017. The *MLETR* aims to enable the legal use of electronic transferable records (hereinafter referred to as "*ETRs*") both domestically and across borders. The *MLETR* applies to *ETRs* that are functionally equivalent to transferable documents or instruments, including B/Ls. Until August 2024, legislation based on or influenced by the *MLETR* has been adopted in 10 jurisdictions, including Bahrain (2018), Belize (2021), Kiribati (2021), Paraguay (2021), Singapore (2021), Abu Dhabi Global Market of United Arab Emirates (2021), Papua New Guinea (2022), United Kingdom (2023), Timor Leste (2024) and France (2024). In addition, Japan is currently working on eB/Ls legislation based on the revision of *Japanese Commercial Code* and has published an interim draft.

Whether in common law systems or civil law systems, possession of the B/L is the basis for the B/L to be used as a transferable transport document in international trade. Due to the key characteristic of eB/Ls as intangible objects, how to maintain this basis when using eB/Ls has also become the focus and difficulty of eB/Ls legislation, which is called the "possession problem". Although eB/Ls, as electronic information, should be the most transferable form of trade documents, but in terms of practicability, it is well known that the most cardinal drawback of the eB/L is the lack of negotiability. In contrast to the traditional B/L, whose negotiability is of great significance, the electronic bill is devoid of the particular feature on the ground that it is intangible. Especially at common law, the fact that the electronic bill is intangible means automatically that it is not negotiable, since negotiability derives from the bill's qualification as a document of title (Ziakas, 2018). Based on the perspective of comparative law, this paper will analyze the legislation or legislative progress on the "possession problem" of eB/Ls in international maritime legislation and major jurisdictions, and compare it with the ongoing revision of *Chinese Maritime Code*.

2 Why is possession important?

The B/L originated, as its name would imply, as no more than a receipt issued to merchants as a copy from the entries in the ship's books which were required to be kept by the ship by local law to evidence receipt by the carriers, in good condition, of cargoes laden on board their vessels (Bugden and Lamont-Black, 2013). But nowadays in international sales of goods, the most important value of the B/L is as a document representing the goods, which in the common law system is usually regarded as a document of title. This makes the B/L clearly distinguishable from other shipping documents such as sea waybills, as well as transport documents issued by rail, road and air carriers (often known as "consignment notes"), which are typically non-negotiable.

UNCITRAL is currently working on international legislation on negotiable cargo documents, which specifically explains why is there a demand for negotiable cargo documents and negotiable electronic cargo records. Documents of title can be transferred to another person, making it easier to buy and sell goods while in transit. This is particularly valuable in international trade where shipments can take some time or have to be reloaded during the voyage and the parties may wish to be able to sell or otherwise dispose of the goods for financial, operational, or strategic reasons. In addition, documents of title can provide better security for banks and financial institutions providing trade finance, such as the letter of credit. By becoming holders of documents of title, banks and financial institutions could exercise control over the goods. To sum up, documents of title can provide flexibility in international trade and can also facilitate the use of trade finance (United Nations Commission on International Trade Law, 2024). This makes documentary trade possible. The most important of these is that possession of the B/L is the basis for its transferability. Possession is a basic concept of property law in the civil law system, which means having actual control. And possession in common law systems means the fact of having or holding property in one's power (Garner, 2019). It can be seen that there is no substantial difference between the concept of possession itself in the civil law system and the common law system.

2.1 Common law systems

In common law systems, serving as a document of title is one of the three functions of a B/L. Although some statutory laws do provide for the definition of "document of title", such as Article 1(4)

of *Factors Act 1889* of UK and Article 1-201 of *Uniform Commercial Code* of USA, there is no authoritative definition of the document of title at common law, but it is submitted that in its original or traditional meaning the phrase refers to a document, the transfer of which operates as a transfer of the constructive possession of the goods covered by the document and may, if so intended, operate as a transfer of the property in them (Bridge, 2010). Therefore, the document of title is generally a document attesting title or possession (Greenberg, 2015), and the word "title" in document of title refers to the narrower concept of a right to possession (Rose and Reynolds, 2022). The ocean B/L is the only document of title to goods at common law presently recognized under the English common law. As such, the transfer of a B/L is capable of transferring to the transferee the constructive/symbolic possession of the goods (Aikens et al., 2021), and constructive possession means the control over a property without actual possession of it (Garner, 2019).

There are three purposes for which possession of the B/L may be regarded as equivalent to possession of the goods covered by it: (a) The holder of the B/L is entitled to delivery of the goods at the port of discharge. (b) The holder can transfer the ownership of the goods during transit merely by indorsing the B/L. (c) The B/L can be used as security for a debt. The development of the B/L as a document of title has been so successful that, over the years, it has come to exercise a tripartite function in relation to the contract of carriage, to the sale of goods in transit, and to the raising of a financial credit (Wilson, 2010). Therefore, possession of the B/L is the basis for the B/L to serve as a document of title. Therefore, the eB/L must establish the right of its holder to take possession of the goods. It must transfer rights and (where appropriate) liabilities under the carriage contract. It must be capable of transferring property, and the right to possess the goods. Crucially also though, if the carrier delivers goods against presentation, or if he refuses to deliver except against presentation, he should be protected from action, just as he is with a paper bill. Carrier defenses are problematic for an eB/L (Todd, 2019).

2.2 Civil law systems

In civil law systems, there are documents corresponding to documents of title, but a different approach is taken. The term "document of title" itself is alien to civil law systems, and it created serious difficulties as to how to translate this term into civil law systems (Pejović, 2020). The corresponding function of the B/L as a document of title in the civil law systems is the effect to property rights of the B/L, also known as the delivery effect of the B/L, which shows that the B/L is a document representing the right to request delivery of goods (Nakamura and Hakoi, 2013). For example, Article 524 of *German Commercial Code* provides that: "Provided the carrier is in possession of the goods, the transfer of a bill of lading to the consignee identified therein shall have the same effects, in terms of the acquisition of rights to the goods, as does the delivery of the goods for carriage." Similar provisions can also be found in Article 763 of *Japanese Commercial Code*, Article 133 of *Korean Commercial Code* and many other jurisdictions.

In most jurisdictions of civil law systems, transfer of property rights of goods as movable properties requires the delivery of goods. For example, Paragraph 1 of Article 188 of *Korean Civil Code* provides that: "The assignment of real rights over movables takes effect by delivery of the Article." Even the *Japanese Civil Code*, which adopts the principle of agreement, requires only the agreement between the transferor and transferee to transfer of property rights, also requires the delivery for the acquisition of movable property as a requirement without which the transferee shall not be able to assert a priority of his/her acquisition against a third party (Article 178) (Matsuo, 2021). However, if the goods in transit need to be resold, it is usually impossible to actually deliver them.

Possession at civil law systems means having actual control, and indirect possession is also recognized as possession (Chang et al., 2023). Based on the delivery effect of the B/L, possession of B/Ls is equivalent to indirect possession of goods, and delivery of B/Ls is also equivalent to symbolic delivery of goods, which can meet the delivery required in transfer of property rights of goods. This makes it possible to substitute delivery of goods with the delivery of B/Ls (Kobayashi et al., 2022). There are different theories on the delivery effect of B/Ls, such as Representation Theory, Strictly Relative Theory and Absolutely Theory. According to the Representation Theory as mainstream theory, possession of a B/L is also the basis for a B/L to have delivery effect. Therefore, there is no substantive difference between common law systems and civil law systems on this problem, and possession of B/Ls is the premise to play the value of negotiable cargo documents.

One of the legal difficulties of eB/Ls is that the traditional concept of possession requires actual control over the object. But the essence of an eB/L is information, and it does not have the physical form like a traditional paper B/L. For example, Article 2 of the *MLETR* provides that electronic record means information generated, communicated, received or stored by electronic means. Intangible objects are excluded from the scope of possession in most jurisdictions. This entails ensuring that the electronic document can embrace the notions of delivery and possession that are bound up in the paper version of B/Ls and which have established for centuries. Likewise, the use of B/Ls to transfer possession and pass property may be difficult to achieve electronically unless proper provision is made for this (Girvin, 2022). Functional equivalence is one of the basic principles of e-commerce legislation, and how to deal with the functional equivalence of possession is one of the key points of eB/Ls legislation.

3 Legislation on the international level

There are currently three international legislations closely related to eB/Ls, i.e. *CMI Rules for Electronic Bills of Lading* (hereinafter referred to as "*CMI Rules*"), *United Nations Convention on Contracts for the International Carriage of Goods Wholly or Partly by Sea*, (hereinafter referred to as "*Rotterdam Rules*") and the *MLETR*. Neither the *CMI Rules* nor the *MLETR* are mandatory rules. The former are voluntary and are effective only when the parties contractually incorporate then, and the latter is a

model law. The *Rotterdam Rules* have not yet come into effect. The concept that is functionally equivalent to possession in international legislations is usually "control".

3.1 The CMI rules

Under the *CMI rules*, a Holder means the party who is entitled to the rights described in Article 7(a) by virtue of its possession of a valid Private Key (Article 2). The control is used in the term "right of control", which includes a series of rights that the holder of a paper B/L has, including claim delivery of the goods, nominate the consignee or substitute a nominated consignee for any other party, transfer the right of control, instruct the carrier on any other subject concerning the goods in accordance with the contract of carriage [Article 7(a)]. In this sense, the "control" used by *CMI rules* refers to a substantive controlling rights over the goods (Jiang, 2023). Therefore, it is not or not only a functional equivalent concept to possession of B/Ls.

3.2 The Rotterdam Rules

The *Rotterdam Rules* were the first to create the concept of "electronic transport record" in the legislations on international transport of goods. Article 8(b) of the *Rotterdam Rules* sets out in terms the principle of equivalence, i.e. the principle that the "issuance, exclusive control or transfer of an electronic transport record has the same effect as the issuance, possession or transfer of a transport document". The phrase "exclusive control" is nowhere defined but is used in the definition of the word "issuance" at Article 1.21, where "issuance" is defined as the "issuance of the record in accordance with procedures that ensure that the record is subject to exclusive control from its creation until it ceases to have any effect or validity" (Baatz et al., 2009). Nevertheless, exclusive control should be considered as a functional equivalent of possession.

The main obstacle to the transfer of electronic transferable transport documents is the need to create a way for the holder of a legitimate transfer to feel assured that there is indeed a document, that there are no defects on the surface of the document, and that the signature or other substitute is genuine and that the document is transferable. This approach makes control of the electronic document equivalent to physical possession of the paper document in law. Whether it is possession or control, the purpose is to avoid conflicts of interest between parties over the same goods. Two people cannot own a certain product or hold a certain transport document at the same time. Possession or control ensures the orderliness of the chain of transfer of goods and documents. The purpose of the *Rotterdam Rules* is to replace this function by establishing an electronic system that ensures that at any given point in time, only one person can exercise exclusive control over a negotiable electronic transport record by linking the transferability of the electronic transport record to established procedures. However, since the *Rotterdam Rules* do not specifically define "exclusive control", they are unable to provide definitive guidance for commercial practices. In addition, the *Rotterdam Rules* have not yet come into effect, and the electronic transport record system established therein has also lacked the opportunity to be tested in practice.

In addition, the *Rotterdam Rules* also provide for a similar concept, i.e. the right of control of the goods, which consists of the right of disposal of the goods while in transit (Berlingieri, 2014). Although both contain the expression "control", the object of control of eB/Ls is eB/Ls as information, while the object of the right of control is goods. The right of control applies to both situations where a paper B/L or an electronic B/L is issued. Therefore, the right of control and the control of eB/Ls are two completely different concepts.

3.3 The MLETR

The *MLETR* is the latest legal instrument proposed internationally as a way of enabling the use of electronic functional equivalents to negotiable instruments and documents of title, including eB/Ls. There are three main functional equivalence provisions laid down by the MLETR designed to enable this transition. Article 11 is one of them, which is the requirement that exclusive control be given over the electronic substitute and that the person in control be identifiable (Goldby, 2019). The concept of "control" is also one of the core concepts of the *MLETR*. Article 11 provides a functional equivalence rule for the possession of a transferable document or instrument. Functional equivalence of possession is achieved when a reliable method is employed to establish control of that record by a person and to identify the person in control. The concept of "control" is not defined in the *MLETR* since it is the functional equivalent of possession, which, in turn, may vary in each jurisdiction (United Nations, 2018).

It can be seen that the approach taken by the *MLETR* to solve the "possession problem" of eB/Ls is to create a new concept as the functional equivalent of possession, so as not to affect the concept of possession that has been formed in various legal jurisdictions over a long period of time. This option is obviously more feasible for international legislation than expanding the concept of possession or its scope of application.

Paragraph 1 of Article 11 provides that: "Where the law requires or permits the possession of a transferable document or instrument, that requirement is met with respect to an electronic transferable record if a reliable method is used: (a) To establish exclusive control of that electronic transferable record by a person; and (b) To identify that person as the person in control." Paragraph 1(a) use the same expression "exclusive control" as the *Rotterdam Rules*, and the requirement for "exclusive" is obviously intended to correspond to the concept of possession. Paragraph 1(b) requires the person in control of the electronic transferable record to be reliably identified as such. The person in control of an electronic transferable record is in the same legal position as the possessor of an equivalent transferable document or instrument (United Nations, 2018), such as the B/L holder.

Paragraph 2 of Article 11 provides that: "Where the law requires or permits transfer of possession of a transferable document or instrument, that requirement is met with respect to an electronic transferable record through the transfer of control over the

electronic transferable record." Under this provision, transferring control of an eB/L will have the same effect as transferring possession of a paper B/L, which is also equivalent to symbolic delivery of goods. Therefore, the eB/L can have the function of the paper B/L as a document of title under the common law systems, as well as the delivery effect under the civil law systems.

In the current discussion, there is little criticism of the creation of the concept of possession, because from the perspective of the hypothetical effect, the concept of control is indeed an ideal choice and is also in line with the principle of functional equivalence in e-commerce legislation. This can be easily seen from the fact that many jurisdictions are currently following the *MLETR*. However, creating the concept of control is not difficult; all that is needed is a few lines of legislation. What is more important is how to implement control so that it can be effectively identified in practice and not apply overly cumbersome processes, because what international trade and shipping value most is transaction efficiency. It may be acceptable for the *MLETR* not to define controls, but the criteria for controls should be a key issue in ensuring that the control regime is effective. Although Article 12 of the *MLETR* has made some provisions on the general reliability standard, it is still only a principle provision in general, and its operability is still unknown. What is certain is that the identification of control, especially the implementation of the reliability standard, must be based on sufficient electronic information technology support, and the issues involved are probably far more complicated than the law.

4 Legislation on the national level

Among the jurisdictions that have completed or are in the process of enacting eB/Ls legislation, five jurisdictions deserve special attention. Firstly, South Korea was the first jurisdiction to enact domestic legislation on eB/L, and this was long before the *MLETR*, thus providing a perspective different from that of subsequent jurisdictions. Secondly, the United Kingdom and Singapore are typical common law jurisdictions. Thirdly, France is the only typical civil law jurisdiction among the countries that has enacted legislation based on the *MLETR*. Fourthly, as a typical civil law jurisdiction, Japan's interim draft provides multiple options for most provisions. Most of the other jurisdictions that have enacted legislation based on the *MLETR* are not shipping countries, so the reference value is relatively small.

4.1 The United Kingdom

The law of England and Wales – like that of many other significant trade jurisdictions around the world – does not recognize intangible things as being amenable to possession. This means that electronic documents, which are considered to be intangible, cannot be possessed and therefore cannot presently function in the same way as their paper counterparts (Law Commission, 2022).

The UK has enacted the *Electronic Trade Documents Act 2023* (hereinafter referred to as "*ETDA*") as a separate act to regulate electronic trade documents including bills of lading. The *ETDA* did not directly transplant the provisions of the *MLETR*, but rather redesigned some provisions based on the purpose of the *MLETR*. According to the *ETDA*, a paper trade document is a document of a type commonly used in connection with trade in or transport of goods, or financing such trade or transport, and possession of the document is required as a matter of law or commercial custom, usage or practice for a person to claim performance of an obligation [Article 1(1)]. It can be seen that the requirement for possession is also one of the basic characteristics of the paper trade document that the electronic trade document is used to replace.

Article 3 of the *ETDA* provides that a person may possess, indorse and part with possession of an electronic trade document, and an electronic trade document has the same effect as an equivalent paper trade document. Anything done in relation to an electronic trade document has the same effect in relation to the document as it would have in relation to an equivalent paper trade document. This section is intended to remove the legal blocker that historically has prevented trade documents in electronic form from being possessed. As a result of this section, electronic trade documents are capable of possession (Great Britain, 2023). Therefore, the approach of the *ETDA* to solving the "possession problem" is different from the *MLETR*, and it does not create a new concept such as control that is functionally equivalent to possession, but chooses to expand the concept of possession so that its object can cover electronic trade documents that are intangible objects, including eB/Ls.

As the *MLETR* and the *Rotterdam Rules* do not provide for a definition of control, the *ETDA* does not set out what constitutes possession of an electronic trade document. Since possession is a relative and fact-specific concept, what constitutes possession of an electronic trade document in any particular context will be assessed as a matter of common law. The common law approach to establishing possession as a matter of fact considers two elements: factual control and intention. Who has possession of something at any one time will therefore depend on the type of control they have in respect of it and their intentions in relation to it, assessed against the control and intentions of other people who may also have a claim. Although existing case law concerning possession relates to tangible assets, many of the principles are capable of application to electronic trade documents (Great Britain, 2023).

4.2 Singapore

Singapore enacted the *Electronic Transactions (Amendment) Act 2021* in February 2021, amending the *Electronic Transactions Act 2010* (hereinafter referred to as "*ETA*"). The latter thus was inserted a new Part 2A "Electronic Transferable Records". The *ETA* was first enacted in 1998 to provide legal certainty for digital transactions, which supports legal enforceability of electronic records and signatures, the *ETA* provides for the legal recognition of electronic records, and expressly allows for them to satisfy any requirement for writing in the written law (Hsu, 2021).

After the amendment, the ETA adopts most of the provisions of the MLETR, and the wording of most articles is basically consistent with the MLETR. According to Paragraph 2(a) of Article 16A of the

ETA, in the interpretation of any provision of Part 2A, regard is to be had to the international origin of the MLETR and the need to promote uniformity in its application. Article 16B also provides that: "(1) This Part adopts the Model Law in its application to an electronic transferable record in accordance with the provisions of this Part. (2) Unless otherwise provided, nothing in this Part affects the application to an electronic transferable record of any rule of law governing a transferable document or instrument."

Article 16I of the ETA basically transplants Article 11 of the MLETR, but an obvious difference is that it uses "Requirement for possession or transfer of possession" instead of "control" as the title. However, the actual term used in the article for ETRs is still "control". Therefore, the ETA essentially still creates a new concept of "control" for eB/Ls as the functional equivalent of possession. According to the explanation in the Explanatory Note to the MLETR, the title of article 11 refers to "control" and not to "possession", thus departing from the naming style of other articles of the MLETR, since the notion of "control" is particularly relevant in the MLETR. While a notion of "control" may exist in national legislation, the notion of "control" contained in article 11 needs to be interpreted autonomously in light of the international character of the MLETR (United Nations, 2018). Similar to MLETR, the ETA also does not specify the definition of control.

4.3 South Korea

After the revision of 2007, Article 862 of *Korean Commercial Code* is the provision on eB/Ls. Paragraph 1 provides that an eB/L shall have the same legal effect as a B/L. Paragraph 5 provides that: "Eligibility requirements for a designated registry agency of electronic bills of lading, electronic methods for the issuance and endorsement thereof, detailed procedures for receiving cargo, and other necessary matters shall be prescribed by *Presidential Decree*." Thus Korean law first stipulates the basic validity of eB/Ls, while other specific issues regarding eB/Ls will be stipulated by *Presidential Decree*. This model can take into account both the efficiency and flexibility of legislation.

The *Regulations on Implementation of the Provisions of The Commercial Code Regarding Electronic Bills of Lading* (hereinafter referred to as "*Presidential Decree*") took effect on August 4 2008, nearly a decade earlier than the *MLETR*, and has been amended for three times in May and November 2010 and March 2013. Based on the *Presidential Decree*, South Korea established a central registry system that is completely different from the *MLETR*. According to Article 3 to 5 of the *Presidential Decree*, the law recognizes only the registry method of granting exclusive control, because only eB/Ls managed in the electronic title registry set up by the law itself are granted functional equivalence. The operators of the system, Korea Trade Net (KTNET) and KL-Net, were selected by the Korean Ministry of Justice as the title registry in accordance with the *Presidential Decree*, under which the Ministry also has the authority to supervise the registry operator and audit its operations. Therefore, in order to be functionally equivalent to a paper B/L under Korean law, an eB/L must be registered in a quasi-public registry operated by a state-selected operator and supervised by the state (Goldby, 2019). When a carrier intends to issue an eB/L, he should transmit an application for issuance and registration by an electronic document, containing the required information, to a registry agency along with the carrier's certified digital signature affixed thereon and a document (including an electronic document) that certifies that the shipper has consented to the issuance of the eB/L (Paragraph 1 of Article 6).

This model of central registry removes the need to create a functional equivalent of possession so as to determine the priority of various rights and obligations that accompany the electronic alternative to the document of title; in effect, this model creates an independent system governing the electronic alternative, and neither need, nor attempt, to fit the electronic alternative into the existing legal framework (Goldby and Yang, 2022). At the same time, there is a problem that there is no mechanism to guarantee the international convertibility even in the *Presidential Decree*. If the eB/L is involved in international trade, a foreigner should record it as a party in the title registry (Kim, 2017). This is actually a traditional problem in the electronicization of B/Ls. According to an admittedly outdated survey report commissioned by the United Nations Conference on Trade and Development (UNCTAD) in 2003, the biggest obstacles to adoption included a need for more suitable infrastructure and market readiness, legal uncertainty, security concerns, high costs and confidentiality issues. In particular, the inability of users to trade with non-members, anyone who wants to use the eB/L must join a closed system and a group of participating members (Ioannou, 2023).

The advantage of the centralized registry system lies in fostering potential users' confidence in the emerging system through state support (Goldby, 2019). Taking the Korea Trade Network (KTNET), one of the electronic bill of lading registration agencies designated by the Minister of Justice of South Korea, as an example, the KTNET system records each step of the circulation of electronic bills of lading to ensure their secure transfer. The record of rights transfer on the electronic bill of lading register has the legal effect of transferring rights, thus establishing the proprietary nature of the electronic bill of lading. However, some scholars in South Korea have highlighted drawbacks in the current centralized registry system. Notably, the closed nature of the electronic bill of lading system is seen as conflicting with the principle of technological neutrality and lacking in the concept and requirements based on functional equivalence (Lee, 2023). Moreover, as mentioned previously, the law does not provide a conversion mechanism for domestic electronic bills of lading recognized internationally. Consequently, foreign parties using electronic bills of lading in international trade must also register with South Korea's centralized registry (Kim, 2017), creating inconvenience for international trade participants.

4.4 Japan

The transport and maritime sections of *Japanese Commercial Code* were revised in 2018, but eB/Ls are not included in the revision. The contents related to electronic transport documents focused on invoices and sea waybills. Paragraph 2 of Article 571 provides that: "In lieu of issuing an invoice, the shipper referred to in the preceding

paragraph may provide the information that is required to be contained in an invoice by electronic or magnetic means (meaning a means of using an electronic data processing system, or of otherwise employing information and communications technology, which is specified by Ministry of Justice Order; the same applies hereinafter), with the carrier's consent, pursuant to the provisions of Ministry of Justice Order. In this case, the shipper is deemed to have issued an invoice." And Paragraph 3 of Article 770 also allows for the issuance of sea waybills by electromagnetic means. But this provision does not apply to B/Ls. Although electronic services provided by Bolero International Ltd and essDOCS Exchange Ltd have recently seen some use in the Japanese market mainly due to demand from shippers, their legal position is unclear as there are no provisions in the *Japanese Commercial Code* or publicized court precedents dealing with the subject (Kobayashi et al., 2022).

Japan launched the legislation on eB/Ls in April 2022, with the goal of regulating eB/Ls by amending laws including *Japanese Commercial Code* and the *International Carriage of Goods by Sea Act*, and the *Interim Draft for Reviewing Regulations Related to Bills of Lading* (hereinafter referred to as "*Interim Draft*") was released in March 2023. Preparing an interim draft is a common legislative practice in Japan. The *Interim Draft* did not directly transplant the provisions of the *MLETR*, but instead amended the existing provisions of the *Japanese Commercial Code* and the *International Carriage of Goods by Sea Act* with reference to the *MLETR*, and added a few new provisions.

The formal name used in the *Interim Draft* for eB/Ls is "electronic bill of lading record". Similar to the *MLETR*, the *Interim Draft* creates the concept of "control" as the functional equivalent of possession. The reasons are mainly in four aspects: (1) electronic records cannot be recognized as "things", as defined as tangible things under the *Japanese Civil Code*, and therefore, they cannot be subject to possession; (2) it would be inappropriate to apply the concept of quasi-possession, such as for intangible property rights (bonds, patents, etc.), in governing the legal relationship involving electronic records, as it would complicate matters further; (3) it is necessary to conceptualize the state of exclusive control to recognize the functional equivalence between paper and electronic records; and (4) the adoption of the concept of control can be harmonized with the approach of the *MLETR* (Pejović and Lee, 2024).

The Interim Draft also creates the concept of control as a functional equivalent of possession, and provides two legislative options for the definition of control. According to the first option, control of an eB/L is defined as a state in which exclusive use can be made of the eB/L record. The second option does not set a legal definition for the control of eB/Ls, and the main considerations are three aspects: (1) The *MLETR* does not define "control". (2) Although there are currently no examples of the use of the concept of control in relation to electromagnetic records in Japanese law, there are concepts such as "control of operations", "control of activities" and "control of shipping" that are used to evaluate objects other than physical objects, and most of these laws do not define "control". For example, Paragraph 3 of Article 7 provides that: "To control or interfere with the formation or management of a labor union by workers or to give financial assistance in paying the labor union's operational expenditures;" (3) The term "exclusive right" is widely used in Japanese law for intellectual property rights such as patents and copyrights, which are intangible property rights. However, the law also does not define the concept of "exclusive right", but instead leaves it to legal interpretation (Counselor's Office et al., 2023).

4.5 France

Part II (Articles 14 to 17) of the *Law No.2024-537 of June 13, 2024 Aimed at Increasing Business Financing and the Attractiveness of France (1)* (hereinafter referred to as "*Law No.2024-537*") is "Facilitating the International Growth of French Companies Through the Dematerialization of Transferable Securities", which incorporates the main provisions of the *MLETR*. According to Article 14, a transferable security is a document that represents property or a right and that gives its bearer the right to demand performance of the obligation specified therein and to transfer this right, including B/Ls to order or to bearer governed by Section 2 of Chapter II of Title II of Book IV of Part V of the *French Transport Code*.

The Law No.2024-537 also created the concept of "control". The provisions of Article 11 of the *MLETR* are reflected in Paragraph 2 of Article 15 and Paragraph 1 of Article 16 of the *Law No.2024-537*. According to these provisions, the bearer of the electronic transferable title is the person who has, for himself or for a third party, exclusive control over it. This control allows him to exercise the rights conferred by this title, to modify it or have it modified and to transfer it, under the conditions provided for in this title. The electronic transferable title has the same effects as the transferable title established on paper when it contains the information required for a transferable title established on paper and a reliable method is used to: (1) Ensure the uniqueness of the electronic transferable title; (2) Identify the bearer as the person who has exclusive control over it; (3) Establish the bearer's exclusive control over this electronic transferable title; (4) Identify its signatories and successive bearers, from its creation until the time when it ceases to produce its effects or to be valid; (5) Preserve its integrity and attest to any modifications made to it, such as additions or deletions permitted by law, customs, usage or the agreement of the parties, from its creation until the time when it ceases to produce its effects or to be valid.

4.6 Other jurisdictions

Except for the United Kingdom, Singapore and France, the legislations on eB/Ls of other seven jurisdictions that have adopted the *MLETR* have all directly transplanted the provisions of Article 11 of the *MLETR*, and created the concept of control as the functional equivalent of possession.[1] For a comprehensive overview of the current legislative status of electronic bills of lading across various countries and the influence of the MLETR, please refer to Table 1.

5 The "possession problem" in China

The revision of *Chinese Maritime Code* of 1992 began in 2017, and four formal drafts have been formed so far. The three drafts in March 2018, November 2018 and May 2020 only added electronic transport records as a type of transport documents parallel to B/Ls, but did not provide for the possession or control of electronic transport records.

The *Revised Draft for Comments* of April 2024 added Section 5 "Electronic Transport Records" to Chapter IV "Contracts of Carriage of Goods by Sea", in which Article 85 provides that the electronic transport record issued by the carrier shall adopt a reliable method, and the fifth requirement of the reliable method is that the holder is able to prove his or her identity and have exclusive control over the electronic transport record. Apart from this, the *Revised Draft for Comments* does not define control or make other provisions for control. This provision is rather vague and does not seem to be sufficient to solve the "possession problem" of eB/Ls. Because under the *MLETR*, control is clearly defined as a functional equivalent to possession. Article 11, which specifically stipulates control, is also located in Chapter II "Provisions on functional equivalence". Although Article 11 does have provisions regarding to use a reliable method, the emphasis of these provisions is still on the control of ETRs, which can meet the legal requirements for possession of transferable documents. At the same time, the transfer of control is equivalent to meeting the requirement of transfer of possession. The provisions concerning control in Article 85 of the *Revised Draft for Comments* fail to reflect such functional equivalence. In summary, requiring the electronic transport record issued by the carrier to ensure that the holder has exclusive control over the electronic transport record does not mean that the law gives the control of the electronic transport record the same legal effect as possession of the B/Ls. The electronic transport record cannot therefore have the function as a document of title.

In short, the control of eB/Ls can serve as the basis for the transferability of eB/Ls only if the law makes the same evaluation on the control of eB/Ls and the possession of paper B/Ls. Without such functional equivalence, it is meaningless to simply create the concept of control. The result may be that in practice merchants still cannot trust that eB/Ls can represent the goods like paper B/Ls, nor can they believe that transferring control of eB/Ls can transfer the rights to the goods.

One of the reasons for this situation is that Chinese law currently has no provisions regarding whether a B/L is a document of title or the delivery effect of the B/L. According to Article 71 of *Chinese Maritime Code*, a B/L is a document based on which the carrier undertakes to deliver the goods against surrendering the same, but this does not mean that a B/L is recognized as a document of title. At the same time, there has always been great controversy in China's maritime law theory about the legal nature of B/Ls. Not only are there few discussions on the delivery effect of the B/L with reference to existing theories of the civil legal systems, but there is also no consensus on the corresponding meaning of document of lading in Chinese law. For example, in the famous Guiding Case No.111 of the Supreme People's Court of China, namely, Liwan Subbranch, Guangzhou Branch of China Construction Bank Co., Ltd. v. Guangdong Lanyue Energy Development Co., Ltd. et al. (dispute over issuance of a letter of credit), the bank held the B/L based on the issuance of the letter of credit, but there was a dispute as to whether the bank enjoyed the ownership of the goods recorded in the B/L. The Supreme People's Court held that a B/L had dual attributes including certificate of creditor's rights and certificate of ownership, but it did not mean that the holder of a B/L would necessarily enjoy the ownership of the goods under the B/L. As for the holder of the B/L, whether it could obtain the real right and which type of real right it could obtain depended on the contractual stipulations of the parties. When the issuing bank holds the B/L in accordance with the contractual stipulations between it and the applicant, the people's court should, in light of the characteristics of the letter of credit transactions, make reasonable interpretation of the contract involved and determine the true intentions of the issuing bank for holding the B/L.

Not stipulating the delivery effect or the nature as document of tile of the B/L would not have a significant impact on paper B/Ls. The reason is that the nature of bills of lading is the result of hundreds of years of international trade and shipping practices, and has a solid basis in merchant custom law. In practice, no one would deny that a bill of lading can represent the goods, whether the basis of this function is the effect of delivery or the document of title. However, eB/Ls are new things after all, and there is no such custom law basis. At this time, it is particularly important to find the basis for the transferability of paper B/Ls, because this is the object that the legislation of eB/Ls hopes to achieve functional equivalence.

Therefore, the significance of possession to the function of B/Ls is not clear under Chinese law, and the functional equivalence of possession will naturally not be taken seriously. It can even be said that the "possession problem" is still not a problem that has received sufficient attention under Chinese law. According to the first author's experience in participating in the legislative work as a member of the Working Group of Revision of *Chinese Maritime Code*, the legislators do not deny that *MLETR* provides a set of generally effective legislative rules on eB/Ls. Including *MLETR*, UNCITRAL's e-commerce legislations and the principles of non-discrimination against the use of electronic means, functional equivalence and technology neutrality established by UNCITRAL are indeed the most important reference blueprints for Chinese legislators. Unfortunately, the concept of the delivery effect of the B/L, which is common in the civil law system, is too unfamiliar to Chinese legislators and scholars, which has cut off the logical chain of directly transplanting the control regime stipulated in *MLETR* into Chinese law.

1 Including Article 7 of the *LAW No.(55) of 2018 with Respect to Electronic Transferable Records* of Bahrain, Article 34 of the *Electronic Transactions Act 2021* of Belize, Article 28 of the *Electronic Transactions Act 2021* of Kiribati, Article 35 of the *Electronic Transactions Act 2021* of Papua New Guinea, Article 86 of the *Law No.6822 on Services for Electronic Transactions, Electronic Documents and Electronic Transferable Documents* of Paraguay, Article 59 of the *Decree Law No.12/2024 General Legal Framework for Electronic Commerce and Electronic Signatures* of Timor Leste and Article 18 of the *Electronic Transactions Regulations 2021* of Abu Dhabi Global Market.

TABLE 1 Legislations on "possession problem" of eB/Ls in nation level.

Jurisdictions	Legislations	Articles	Approaches to solve the "possession problem"	Names of eB/Ls	Transplant of Article 11 of the MLETR
Bahrain	LAW No.(55) of 2018 with Respect to Electronic Transferable Records	7	create the concept of "control"	electronic transferable record	directly
Belize	Electronic Transactions Act 2021	34	create the concept of "control"	electronic transferable record	directly
France	Law No.2024-537 of June 13, 2024 Aimed at Increasing Business Financing and the Attractiveness of France (1)	15 & 16	create the concept of "control"	electronic transferable title	indirectly
Japan	Interim Draft for Reviewing Regulations Related to Bills of Lading	——	create the concept of "control"	electronic bill of lading record	indirectly
Kiribati	Electronic Transactions Act 2021	28	create the concept of "control"	electronic transferable record	directly
Papua New Guinea	Electronic Transactions Act 2021	35	create the concept of "control"	electronic transferable record	directly
Paraguay	Law No.6822 on Services for Electronic Transactions, Electronic Documents and Electronic Transferable Documents	86	create the concept of "control"	electronic transferable document	directly
Singapore	Electronic Transactions Act 2010	16i	create the concept of "control"	electronic transferable record	directly
South Korea	Regulations on Implementation of the Provisions of The Commercial Code Regarding Electronic Bills of Lading	3-5	central registry system	electronic bill of lading	——
Timor Leste	Decree Law No.12/2024 General Legal Framework for Electronic Commerce and Electronic Signatures	59	create the concept of "control"	electronic transferable record	directly
Abu Dhabi Global Market	Electronic Transactions Regulations 2021	18	create the concept of "control"	electronic transferable record	directly
United Kingdom	Electronic Trade Documents Act 2023	3	expand the scope of objects of possession	electronic trade document	indirectly

Based on the above situation, the revision of *Chinese Maritime Code* may need to first stipulate the delivery effect of B/Ls, and then provide a solution to the "possession problem" by expanding the object of possession to electronic transport records, or stipulating that control of electronic transport records is a functional equivalent of possession. The former is even more important than the latter. Regarding the former, it is recommended that the following provisions be made: "Delivery of a bill of lading for the purpose of transferring the ownership of the goods shall be deemed as delivery of the goods." The delivery effect of the B/L is limited to the ownership of the goods here, mainly considering that *Chinese Civil Code* has clearly defined the pledge of the B/L as a right pledge, avoiding system conflicts between the *Chinese Maritime Code* and *Chinese Civil Code*. The provision can be placed after the current Article 71, that is, following the function of the B/L to stipulate the delivery effect of the B/L. The latter can directly transplant the provisions of Article 11 of the *MLETR* and appropriately integrate them with other provisions on eB/Ls. The key point is to emphasize that controlling an eB/L has the same effect as possessing a paper B/L, that is, delivering the B/L is equivalent to delivering the goods, and controlling an eB/L is equivalent to possessing a paper B/L, thereby achieving the delivery effect of the eB/L by two sets of equivalence. As for the specific standards of control, they can be handed over to administrative regulations formulated by the State Council or departmental regulations formulated by the Ministry of Transport. Such normative documents have greater flexibility in modification and can better adapt to the evolving electronic information technology.

6 Conclusions

From the above analysis, the following conclusions may be drawn:

1. The possession of the paper B/Ls is the basis of the function of a B/L as a document of title in common law systems and the delivery effect of B/Ls in civil law systems. The "possession problem" of eB/Ls is how to ensure that eB/Ls, as intangible objects, continue to have this basis.
2. In the international level, the *MLETR* creates the concept of control of electronic transferable records as a functional equivalent to possession of paper B/Ls. Although the *CMI Rules* and the *Rotterdam Rules* involve control, neither of them makes specific provisions for control.

3. In the national level, there are three solutions to the "possession problem": (a) Expanding the objects of possession to cover eB/Ls, such as the United Kingdom. (b) Adopting the same approach as the *MLETR*, creating a concept of control as a functional equivalent of possession, such as Singapore and Japan, which is in the process of legislating, as well as Abu Dhabi Global Market and other 6 jurisdictions which have directly transplanted Article 11 of the *MLETR*. (c) Establishing a central registry system so that possession of eB/Ls does not have to be demonstrated. A typical example is South Korea, where the legislation on eB/Ls preceded the *MLETR*.
4. The revision of *Chinese Maritime Code* currently does not pay sufficient attention to the "possession problem" of eB/Ls. The countermeasure should be to first stipulate the delivery effect of paper B/Ls, and then provide a solution to the "possession problem" of eB/Ls.
5. According to the current legislative trends in major jurisdictions and the demonstration model established by *MLETR*, it can be foreseen that solving the possession problem of eB/Ls by creating the concept of control will become the mainstream legislative model in the future. Even in South Korea, which adopts a central registration system, theorists and practitioners generally propose that the concept of control should be introduced as a functional equivalent to possession. However, creating a concept is only the beginning of establishing an effective possession regime. What is more important is to clarify the identification criteria for exclusive control and enable it to be judged more conveniently in business practices that always pursue efficiency. Among these, the support of electronic information technology is probably far more important than the law.

Author contributions

SS: Formal analysis, Supervision, Visualization, Writing – original draft, Writing – review & editing. RH: Resources, Validation, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Aikens, R., Lord, R., Bools, M., Bolding, M., and Toh, K. S. (2021). *Bills of lading* Vol. 47 (London, UK: Informa Law from Routledge), 164.

Baatz, Y., Debattista, C., Lorenzon, F., Serdy, A., Staniland, H., Tsimplis, M., et al. (2009). *Rotterdam rules: A practical annotation* (London, UK: Informa Law from Routledge), 8–07.

Berlingieri, F. (2014). *International maritime conventions volume I: the carriage of goods and passengers by sea* (London, UK: Informa Law from Routledge), 205.

Bridge, M. (Ed.) (2010). *Benjamin's sale of goods* (Oxford, UK: Sweet & Maxwell), 18–007.

Bugden, P. M., and Lamont-Black, S. (2013). *Goods in transit and freight forwarding* (London, UK: Sweet & Maxwell), 133.

Chang, Y., Chen, W., and Wu, Y. (2023). *Property and trust law in Taiwan* (London, UK: Wolters Kluwer), 96.

Counselor's Office, Civil Affairs Bureau and Ministry of Justice (2023). *Supplementary instructions of the interim draft for reviewing regulations related to bills of lading*. (Tokyo, Japan: Shoji Homu), 20–21.

Dubovec, M. (2006). The problems and possibilities for using electronic bills of lading as collateral. *Arizona J. Int. Comp. Law* 23, 465.

Garner, B. A. (Ed.) (2019). *Black's law dictionary* (Toronto, Canada: Thomson Reuters), 1408.

Girvin, S. (2022). *Carriage of goods by sea* (Oxford, UK: Oxford University Press), 281.

Goldby, M. (2019). *Electronic documents in maritime trade: law and practice* Vol. 204 (Oxford, UK: Oxford University Press), 332–333.

Goldby, M., and Yang, W. (2022). Solving the possession problem: An examination of the Law Commission's proposal on electronic trade documents. *Lloyd's Maritime Commercial Law Q.* 605, 618.

Greenberg, D. (ed.) (2015). *Jowitt's Dictionary of English Law* (Sweet & Maxwell), 782.

Great Britain (2023). *Electronic trade documents act 2023 explanatory notes* (London, UK: The Stationery Office), 13.

Hsu, A. (2021). Amendments to the electronic transactions act. *NO&T Asia Legal Rev.* 34, 3.

Ioannou, I. (2023). *Is enabling legislation sufficient to promote the uptake of electronic paperless trading systems?* 5–6, NUS Law Working Paper, 2023/017. Available online at: https://law.nus.edu.sg/cml/wp-content/uploads/sites/8/2023/06/CML-WPS-2304.pdf (Accessed November 14, 2024).

Jiang, T. (2023). Regulating electronic bills of lading on a national level. *J. Business Law* 604, 610.

Kim, I. H. (2017). *Transport law in South Korea* (London, UK: Wolters Kluwer), 102.

Kobayashi, N., Hiratsuka, M., Yamashita, S., Miyazaki, Y., and Tadano, Y. (2022). *Transport law in Japan* Vol. 100 (Alphen aan den Rijn, Netherlands: Wolters Kluwer), 104.

Law Commission (2022). *Electronic trade documents: Report and Bill* (London, UK: Law Commission), 78.

Lee, U. (2023). Direction and analysis of electronic bill of lading legislation of major countries: focusing on the UK and Japan. *J. Korea Maritime Law Assoc.* 45, 171–221.

Matsuo, H. (2021). *Property and trust law in Japan* (Alphen aan den Rijn, Netherlands: Wolters Kluwer), 137.

Nakamura, M., and Hakoi, T. (2013). *Droit maritime* (Tokyo, Japan: Seibundoh), 167.

Pejović, ČCheckt. a. e. (2020). *Transport documents in carriage of goods by sea: international law and practice* (London, UK: Informa Law from Routledge), 113.

Pejović, Č., and Lee, U. (2024). Towards global legal recognition of electronic trade documents: control or possession? *Texas Int. Law J.* 59, 101.

Rose, F. D., and Reynolds, F. M. B. (2022). *Carver on bills of lading* (London, UK: Sweet & Maxwell), 331.

Todd, P. (2019). Electronic bills of lading, blockchains and smart contracts. *Int. J. Law Inf. Technol.* 27, 342. doi: 10.1093/ijlit/eaaa002

United Nations (2018). *UNCITRAL model law on electronic transferable records* Vol. 42 (New York, NY: United Nations), 43–44.

United Nations Commission on International Trade Law (2024). *Fact sheet: UNCITRAL project on negotiable cargo documents*. 102, A/CN.9/WG.VI/WP. Available online at: https://documents.un.org/doc/undoc/ltd/v23/101/20/pdf/v2310120.pdf (Accessed November 14, 2024)

Wilson, J. F. (2010). *Carriage of goods by sea* (Pearson Education Limited), 132–133.

Ziakas, V. (2018). Challenges regarding the electronic bill of lading (EBOL). *Int. J. Commerce Finance* 4, 42.

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 21 November 2024
DOI 10.3389/fmars.2024.1503259

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Maruf M,
Dalian Maritime University, China
Mehran Idris Khan,
University of International Business and Economics, China

*CORRESPONDENCE
Ming Jing
ming_jing@fudan.edu.cn

RECEIVED 28 September 2024
ACCEPTED 28 October 2024
PUBLISHED 21 November 2024

CITATION
Jing M (2024) How "unequal treaties" influenced commission competence: a new perspective on the United Nations Convention on the Law of the Sea (Part XV) in the Timor Sea Conciliation. *Front. Mar. Sci.* 11:1503259. doi: 10.3389/fmars.2024.1503259

COPYRIGHT
© 2024 Jing. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

How "unequal treaties" influenced commission competence: a new perspective on the United Nations Convention on the Law of the Sea (Part XV) in the Timor Sea Conciliation

Ming Jing*

Fudan Institute of Belt and Road & Global Governance, Fudan University, Shanghai, China

The United Nations Convention on the Law of the Sea (UNCLOS) is a widely ratified multilateral treaty that defines and codifies the standards and principles of international law for the governance and management of the oceans. One of its key features is the facilitation of the peaceful settlement of disputes on maritime affairs. Article 281 constitutes an equality test by which the courts or tribunals can distinguish voluntary procedures from compulsory proceedings. Existing cases under Part XV did not provide a clear routine what circumstances might make a treaty under Article 281 "unequal". Article 311 deals with the tension between prioritizing the regional arrangements and maintaining UNCLOS as a closed, self-contained system. This research aims to provide insights into the proper application of these two articles in future UNCLOS disputes, as the Timor Sea Conciliation (Timor-Leste v. Australia) is the first instance of the conciliation mechanism under UNCLOS. Through the methods of doctrinal research and comparing the different argumentations in previous cases, the research found that the recent Timor Sea Conciliation was decided on the basis of a controversial understanding of UNCLOS Articles 281 and 311; that a treaty featuring specific and feasible arrangements for dispute settlement would be easier in passing Article 281's test; and that Article 311 favors UNCLOS's integrity and considers the permitted derogations as exceptions. It is suggested that the courts or tribunals under UNCLOS Part XV interpret Articles 281 and 311 in a systematic manner, which is believed to benefit the development of voluntary dispute settlement mechanism under UNCLOS in the long run.

KEYWORDS

unequal (parallel) treaties, UNCLOS Part XV, Article 281, Article 331, Timor Sea Conciliation

1 Introduction

Treaties bind parties based on consent through signature and ratification and contains laboriously negotiated commitments (International Law Commission, 1980; Abbott and Snidal, 2000). In contrast to soft, non-binding international agreements, treaties represent hard rules and are less susceptible to self-serving interpretations by the parties involved. However, similar to agreements in private law (Lauterpacht, 1927), consent sometimes does not represent a true willingness. It can also happen that a party decides to withdraw from its existing treaty obligations even if its consent was true earlier. In these circumstances, the party must have a legitimate basis for terminating unwanted, unduly burdensome, but binding agreements (Craven, 2005). One direct way to opt out is to invalidate the treaty. A common way to achieve this is to claim that treaties are unequal (Denby, 1924; Fishel, 1952; Gong, 1984; Turner, 1929; Vincent, 1970; Woodhead, 1931). In bilateral treaties, the party that deems the treaty beneficial will support it and insist that the complaining party continue fulfilling its obligations. Different ways to interpret treaties as "unequal" cause confusion in legal scholarship and hinder peaceful dispute settlement. What types of treaties are unequal? Which party can declare this? Is the mere claim of inequality sufficient to constitute a legitimate basis for deviating from *pacta sunt servanda*, an ancient general principle recognized by civilized nations in international law by which a promise made by a party in an agreement must be maintained (Lauterpacht, 1927)? Is there a limitation on the scope (what is the extent of the required inequality)? What other options do the parties have? Is there something parties can do to avoid future disputes when negotiating a treaty?

The international disputes awaiting settlement highlight the need for further inquiry (Koskenniemi, 2006). One example of unequal treaties came into play in the law of the sea when the recent Timor Sea Commission moved to negate Timor-Leste's binding *of the Certain Maritime Arrangements in the Timor Sea* (CMATS) with Australia because of equality. The United Nations Convention on the Law of the Sea (UNCLOS) plays a significant role in this field. Its DSMs are the focus of this study. Part XV, "Settlement of Disputes," contains three sections, namely, general provisions (Articles 279 to 285), compulsory procedures entailing binding decisions (Articles 286 to 296), and limitations and exceptions to the applicability of section 2 (Articles 297 to 299). These Articles articulate both voluntary and compulsory proceedings and specify when each applies (I.C.J. Reports, 1985; Rosenne, 2006; Shihata, 1965; Tamada, 2019).

Article 281 is a crucial provision because it contains a law of conflict that addresses the order of the two categories of proceedings (Jia, 2015). If the parties fully satisfy the elements of Article 281, they will not have to bring their dispute to arbitration under the compulsory proceedings in section 2. The wording of the Article signals a preference for limiting the use of compulsory proceedings or at least a preference for the parties' "settlement of a dispute by a peaceful means of their own choice." Article 281 requires persuasive evidence to show that "the two parties have agreed" (Yee, 2014). This raises the question of the type of agreement that qualifies. Opinions in the literature vary regarding what Article 281(1) requires (Yee, 2013). In practice, language leaves a large margin of discretion for courts, tribunals, or commissions (Tanaka, 2019). Article 286 recognizes the seisin of these bodies, which, through treaties or special agreements, gives them certain jurisdictions to decide a dispute (Rosenne, 1989). This manifests as the doctrine of *la competence de la competence*, which is incidental to exercising substantive jurisdiction (Fitzmaurice, 1986). Whether the court, tribunal, or Commission regards Article 281(1) as satisfying the competence decision determines whether the disputants will invoke compulsory proceedings. Controversies over competence arise easily when one party submits a dispute to a compulsory proceeding unilaterally following the parties' previous attempts to reach a voluntary settlement. If the decision sustains the other party's objection that there was an agreement allegedly consistent with Article 281, it will not invoke compulsory proceedings. In turn, the initiating party might try to eliminate the existing treaty, either by invalidating it or changing its arrangements in front of the decision.

As the first well-known conciliation case under Annex V of UNCLOS, the Timor-Leste and Australia Conciliation has a unique bargaining history, including an exchange of letters between the parties and the signing of CMATS. The status of these documents is an essential point of disagreement. Some seemingly neutral arrangements that turned out to have a potentially oppressive effect in CMATS make the case ideal for exploring how unequal treaties and Part XV's compulsory proceedings under UNCLOS interact (leaving aside the question of whether CMATS itself is unequal). This case also evokes Article 311, which discusses the relationship between UNCLOS and other arrangements; that is, whether Article 311 could tolerate the CMATS including an article that precludes the application of UNCLOS Part XV.

The objective of this research is to draw a line on what kind of treaties may pass the Article 281 test and to sketch a benchmark of Article 311 through the reasonable interpretation of integrity and compatibility. To achieve this objective, the methods of doctrinal and comparative research are adopted through the whole research. In Section 2, the method of game theory is used to evaluate the three essential indicators' interaction in this case. The passage below will go into whether CMATS is an unequal treaty under UNCLOS Article 281 and its legal consequences if yes; also, it analyzes the elements of a so-called unequal treaty and summarizes the features of a treaty that easily pass the Article 281 test; last but not least, it observes how the previous cases apply Article 311 and give a reasonable interpretation of the compatibility under UNCLOS. For the development of passage, the research regards permanent or temporal bodies for solving disputes as Global Governance Bodies (GGBs) (Benvenisti, 2014). If not explicit otherwise, their role is presumed to contribute to the peaceful settlement of disputes and promote the rule of law in the international community. The study below will first look into the framework for evaluating the equality of a treaty, the Article 281 test, with the contents of the Conciliation (Section 2); second, compare the interpretation of Article 281 by the Conciliation Commission with that of other existing rulings and find the regularities in international judicial practice; third, analyze the Commission's interpretation of Article 311 and compare it with other GGBs' rulings. The conclusion will be summarized based on the findings of these sub-questions.

2 Framework for evaluating treaty inequality: how do "unequal treaties" coordinate with UNCLOS?

The existing literature on unequal treaties mainly focuses on the status of the parties (subjects), the contents of the provisions (the distribution of rights and obligations), and negotiation history (Detter, 1966). Positivist analyses frequently examine these three indicators separately to determine whether a treaty remains valid (Davis et al., 2012). However, whether a treaty is valid only touches the issue's surface. This study believes that a systematic framework for evaluating treaty inequality, a three-indicator pattern, can depict the scope of inequality (i.e., how unequal a treaty is). To increase clarity and maintain accuracy, this part adopts the traditional legal approach to interpretation when analyzing the content of provisions, as mentioned above in Section 1. To illustrate the dynamic, changeable, and somewhat mysterious interactions among the three indicators, it also employs game theory to analyze potential inequality in the status of parties and uses a sociological approach to examine the parties' negotiation history. The analysis below in this section shows a full picture of the Timor Sea Conciliation and the unique relation between the two parties.

2.1 Party status: role of game theory

The original status concern mainly refers to the inequality charge that a treaty might cement an inferior relationship between two parties; in other words, the establishment of extraterritorial jurisdiction (Willoughby, 1922). The rationale behind this concern is that territorial sovereignty entails exclusive jurisdiction over the people and property within a state (Wheaton, 1880; Piggott, 1907). Thus, it is unlikely that the two parties can reach an equal treaty if either party is not fully sovereign (De Jonge, 2014; Simpson, 2000). The condition of sovereignty is not comprehensive enough to cover all issues relevant to status, and inequality is broader than the context of colonization. The statuses of parties can be unbalanced in various ways, even if both have full sovereignty.

In international relationship studies, game theory is an ideal tool to identify the degree of balance between parties, one that comes into play before any treaty analysis. Several possible game theory scenarios are appropriate for different areas of international law, as parties face varying opportunity costs depending on the situation (Raustiala, 2005). In specialized areas of international law, such as the Law of the Sea, the status of each party in a dispute has considerable influence on the game they will play and how they will play it.

2.1.1 Instability of asymmetric bargaining in prisoners' dilemma

In theory, as a means of cooperation between two parties, a binding treaty deters cheating by increasing the cost of non-compliance. This makes it particularly advantageous in the Prisoners Dilemma (the "PD") situations (Abbott and Snidal, 2000). The prisoner's dilemma is a game theory thought experiment involving two rational agents, each of whom can either cooperate for mutual benefit or betray their partner ("defect") for individual gain. The dilemma arises from the fact that while defecting is rational for each agent, cooperation yields a higher payoff for each. In PD, the potential for costly opportunism is high and cheating is difficult to detect. When incentives to defect from agreed upon commitments are low, a binding treaty with enforceable commitments seems less valuable (Braford, 2010). This resembles a Coordination Game (a "CG") situation, where the parties are not motivated to deviate from their agreement once they have established the focal point of coordination (Abbott, 1989; Martin, 1993). Therefore, including a dispute settlement mechanism in their treaty might not be necessary. Soft law can work in a CG where the rules can be precise, giving parties confidence that they will not be sued (Abbott and Snidal, 2000).

A stable PD situation relies on the fact that the two parties, A and B, have a similar capacity to hurt each other once they are betrayed; therefore, it requires that A and B have equal, or at least balanced, bargaining powers. In a situation where A is disproportionally stronger than B, A will have less concern about B's betrayal since B cannot cause great harm. In addition, any defect in B's part is easily visible to A's more sophisticated monitoring techniques and strategies.

UNCLOS has dominated maritime law since 1994 (Adi, 2009). Although the signing parties recognize UNCLOS as a comprehensive regime, it cannot cover all specific maritime rules (Boyle, 2005). Sometimes, general provisions are not broad enough to resolve complicated disputes among the parties. This explains why parties to UNCLOS negotiate regional or bilateral agreements, including binding treaties and non-binding soft agreements. Parties to regional or bilateral agreements reached before and after the effective date of UNCLOS can consider these parallel agreements under Article 281. Australia and the Democratic Republic of Timor-Leste, for example, agreed that CMATS would be a binding treaty. This choice might represent a PD situation in which both parties wanted to enhance the results of their negotiations and prevent the other party from defecting. However, bargaining power between the two parties is far from balanced. Australia has long been a strong marine power, while Timor-Leste did not achieve independent status as a sovereign state until 2002. Their strengths of threat to each other's potential betrayal are unequal, making the PD situation unstable.

A PD situation usually remains stable when the two parties suffer from the same lack of information: A cannot know whether B will defect (or has defected) and vice versa. Australia ratified UNCLOS in 1994, whereas Timor-Leste did not become a party until 2013. In 2006, when the two reached the CMAT, it was fair to assume that Australia had a much more sophisticated understanding of the Law of the Sea regime and maritime arrangements than Timor-Leste.

2.1.2 UNCLOS's role in redressing the unbalanced regional agreement

When the contents of UNCLOS were settled in 1982, several regional maritime agreements existed among the parties

(Bateman, 2007). The incorporation of Article 311, dealing with UNCLOS's relationship with other conventions and international agreements, suggests that the framers recognized this situation and expected it to continue. Article 311(2) of UNCLOS explicitly maintains the rights and obligations of state parties arising from other agreements compatible with the Convention as long as they do not affect other parties' enjoyment of their rights or the performance of their obligations under the Convention. Article 311(3) of UNCLOS permits the parties to conclude agreements modifying or suspending the operation of the Convention, applicable solely to the relations between them, through the procedure of the depositary under Article 311(4), which calls for them to notify the other State parties of their intention to do so. However, this permission does not apply if (a) the agreements relate to a provisional derogation that is incompatible with the effective execution of the object and purpose of the Convention, (b) the agreements affect the application of the basic principles embodied in the Convention, or (c) the agreements affect other State parties' enjoyment of their rights or performance of their obligations under the Convention.

The second and third paragraphs of Article 311 are complementary. Article 311(2) deals with parties' relations to existing agreements before the Convention, and Article 311(3) focuses on newly negotiated agreements based on the Convention. The requirement of non-derogation from the object, purpose, and basic principles of Article 311 demonstrates the framers' intent to redress the imbalance that can arise from regional or bilateral agreements. By excluding arrangements that deviate from the object and purpose of the Convention, Article 311 takes the basic principles of UNCLOS as a benchmark from which "declares" an imbalance arising from parallel treaties.

2.1.3 Who will redress the imbalance in UNCLOS?

What if the benchmark were unbalanced? As the Third United Nations Conference negotiated the Law of the Sea, a huge gap in bargaining power among all UNCLOS parties became evident (Beesley, 1983). The parties that signed and ratified UNCLOS after it took effect in 1994 felt that the Convention did not adequately reflect their interests. This has made the overall status of UNCLOS parties even more unbalanced. Timor-Leste became a party to UNCLOS in 2013; it did not have a voice in 1982 when other parties negotiated the Convention's rules. However, this history has not excused any signing party from its obligations under UNCLOS. Many theories may justify this apparent inequality. There is an implied assumption that by joining the agreement, a new party accepts all the rights and obligations that it imposes by default (Weisburd, 1996), or, more aggressively, that the role of UNCLOS amounts to customs under the Law of the Sea and therefore binds even newly entering parties (Caminos and Molitor, 1985).

UNCLOS framers attempted to redress the regional or bilateral maritime agreements imbalance through the Convention (Boyle, 2005). However, the parties' unbalanced status affects their negotiation ability to enter UNCLOS. Some regard the voluntary dispute settlement procedures in Part XV as reserved for party autonomy to rebalance the imbalance from UNCLOS. This efficacy relies on properly interpreting the relevant provisions in the parallel treaty for voluntary settlements and essential articles in UNCLOS Part XV.

2.2 Contents of provisions: the pros and cons of interpretation

Interpretation is the most commonly used approach in dispute settlement analyses (Van Damme, 2010). When the bodies established (or authorized) in the dispute settlement arrangement turn to this method, at least one party has already defected. Interpretations of relevant articles in a competence decision are significant when weighing whether the challenge from the betraying party is reasonable and whether the changes this party seeks are worth considering. How GGBs interpret specific articles reflects their attitudes toward the equality (or inequality) of the content of provisions and their inclination to change or maintain the *status quo*.

2.2.1 What types of provisions are unequal?

The existing literature on unequal provisions is substantial (Ku, 1994; Trinity College Library, 1927; Wong, 2003). Unequal treaties usually fall into one of three categories: (a) treaties containing formally unequal obligations, regardless of their actual effect; (b) treaties with formally equal provisions that impose unequal obligations in reality; and (c) treaties in scenario (b), the unequal obligations that occur as a result of unforeseen developments (Malawer, 1977). However, most existing analyses of these categories focus on the parties' bad faith rather than on the influence of the provisions (Craven, 2005). This study posits that the latter aspect deserves attention.

Of the three categories, scenario (a) presents the most apparent circumstance of inequality because it can contain extreme, non-reciprocal arrangements of duties and rights. When a treaty confers almost all rights to one party and imposes all corresponding duties on the other, its inequality is self-evident. In scenario (b), the parties may or may not have been aware of the inequality. In evaluating this category of articles, we must examine the extent to which the vulnerable party's enjoyment of its equal rights speaks louder than whether bad incentives exist under the cover of apparently equal provisions. Scenario (c) makes it difficult to prove the incentive to create or even the foreseeability of inequality. However, some adjustments are necessary if one party has unequal obligations.

Few treaties in the UNCLOS era (since it entered into force in 1994) have contained nonreciprocal distributions of rights and duties. Most circumstances that GGBs have confronted resemble scenarios (b) and (c), so they require careful interpretation. GGBs with jurisdiction under Section 2 must apply the Convention and other international law rules in ways compatible with the Convention. Article 31 of the Vienna Convention, recognized as the customary standard in treaty interpretation, also binds to GGBs (Merkouris, 2017).

Therefore, a GGB is expected to perform its interpretation using the applicable laws of UNCLOS, the framework of the Vienna Convention's interpretation rules, and good faith (Villiger, 2011).

2.2.2 Interpretation of treaty provisions in the context of UNCLOS Article 281

Timor-Leste commenced its conciliation with Australia through a notification under Section 2 of Annex V, announcing that it sought to solve a dispute concerning "the interpretation and application of Articles 74 and 83 of UNCLOS for the determination of the exclusive economic zone and the continental shelf between Timor-Leste and Australia including the establishment of the permanent maritime boundaries between the two States" (Notification instituting Conciliation, 2016). The Conciliation Commission was established under Article 298(1)(a)(i). Australia did not object, although it did object to six other areas. The first, second, and third objections relate to the status of CMATS and the exchange of letters in the context of Article 281, namely, whether their contents and negotiation history consisted of an agreement for the purpose of Article 281(1). On September 19, 2016, the Commission issued its "Decision on Australia's Objections to Competence," in which its members unanimously rejected all of Australia's objections, although to different extents. This section examines the Commission's analysis of how the unequal properties of the CMATS negated voluntary settlements.

2.2.2.1 How did the Commission interpret the CMAT provisions and Article 281?

Australia's third objection suggests that exchanging letters constituted an agreement to resolve delimitations through negotiations within Article 281 (Alkatiri, 2003; Howard, 2003). The Commission interpreted Article 281 as requiring a legally binding agreement and rejected this suggestion, stating that letters on the subject did not reflect a binding agreement (the Commission). This interpretation relied mainly on the Commission's perception that Article 281 was parallel to Article 282 and that Article 282 required a binding agreement. Under Article 282, parties that agree to a general, regional, or bilateral agreement to submit their dispute to a procedure entailing a binding decision are explicitly permitted to opt out of the UNCLOS DSM. According to the Commission, allowing a nonbinding agreement to create the same opting-out effect would be logically inconsistent.

Australia based its first and second objections on the moratorium provisions in the CMATS. It claimed that Article 4 of this treaty was consistent with Article 281(1) of UNCLOS and thus should exclude the parties from compulsory proceedings (Australia). CMATS is a binding treaty in which Article 4, entitled "moratorium," provides that "neither Australia nor Timor-Leste shall assert, pursue or further by any means in relation to the other Party its claims to sovereign rights and jurisdiction and maritime boundaries for the period of this Treaty," and that "neither Party shall commence or pursue any proceedings against the other Party before any court, tribunal or other dispute settlement mechanism that would raise or result in, either directly or indirectly, issues or findings of relevance to maritime boundaries or delimitation in the Timor Sea (CMATS)." The Commission regarded the contents of that article as "not to seek settlement of the Parties' dispute over maritime boundaries for the duration of moratorium," and rejected these two objections for that reason (the Commission).

2.2.2.2 Was there any problem with the Commission's word game analysis?

There were some problems with the Commission's word game analysis. First, the Commission did not explain what "parallel" means in this context, nor did it offer its reasons for interpreting the two articles as parallel. As Article 282 clarifies that it deals with situations in which there are binding agreements between parties, Article 281 might have been designed exactly for situations requiring voluntary dispute settlement in which there are no binding agreements. This is also consistent with the purpose of Article 280, which emphasizes that the parties' right to settle a dispute between them "by any peaceful means of their own choice" should not be impaired. However, adjacent articles do not necessarily have the same meaning. They serve similar purposes from different perspectives. The requirement of "binding" in Article 282 mainly focuses on the procedural dimension, such as the signature and ratification of the general, regional, or bilateral agreement. Without such a formal procedure, if an agreement contained specific language about how the parties would voluntarily settle a dispute, it would seem to qualify under Article 281(1).

Second, why can a binding convention not tolerate some nonbinding arrangements as long as they are compatible with the convention? Several binding conventions include voluntary multilateral arrangements (WTO Ministerial Conferences, 2019). Soft rules should not be excluded from the Convention because they are nonbinding. In reality, the degree to which hard provisions can bind parties varies. Articles 281 and 282 constitute the coordination of international legalization in which hard and soft rules have complementary roles. Soft rules are advantageous in terms of their precision (Abbott and Snidal, 2000). Permitting parties to opt out of a binding convention through a soft arrangement does not create logical inconsistency as long as the arrangement does not contradict the Convention. Additionally, if the arrangement in soft form incorporates the "close-to-binding" contents in substance, this resolves the logical inconsistency.

The Commission was silent on whether to interpret Article 4 of the CMATS as an unequal provision. Negating this for voluntary settlement under UNCLOS Article 281(1) does not amount to a declaration of inequality. GGBs use extreme caution and never speak of this point. However, in strict compliance with the textualism of the Vienna Convention, the literal meaning of CMATS Article 4 merely implies the intention to enhance existing treaty remedies and avoid further disputes. Evaluating whether this provision is unequal requires weighing whether an overconfident assumption that there will not be any dispute in the future can create the effect of oppressing either party and disproportionally balance the contents of the treaty. Same or similar rights and obligations can mean considerably different

things for the two parties in asymmetric bargaining. The contents of Article 4 appear to bind parties with the same obligation, that is, to refrain from submitting their disputes to GGBs outside the CMATS. In this instance, the seemingly identical obligations in this article would have had a different effect on each party; they might have deprived Timor-Leste of its core interests. This reasoning emphasizes unequal influence, but the evidence is not strong enough to imply that one party had such bad faith that it was willing to deprive the other party of the chance to seek external judicial or arbitral remedies. Therefore, a combined influence-incentive analysis outperforms Malawer's classic incentive-oriented view of feasibility. The question of whether negative incentives exist goes beyond mere interpretation. A sociological approach to deepening the background will help us better understand the incentive aspect of this matter.

2.3 Negotiation history: a deep sociological analysis of the treaty's background

Among the three indicators of unequal treaties – the status of parties, the contents of provisions, and negotiation history – the history of bargaining is the most dynamic. Unique stories in the negotiation history (the "NH") might also reflect the unbalanced status of the parties and even affect what information they choose to include in their draft complaint. NH is the basis of the three-indicator pattern, which maps a general model of their interaction. Much scholarship has focused on the NH, especially examining the number of invalidated treaties after the end of the colonial period, but some questions remain unanswered.

2.3.1 Existing international law governing NH of treaties

The contemporary rules governing the NH of treaties describe a ray of the matrix (Figure 1) (Crawford, 2006; Kritsiotis, 1998). One end (point A) was fixed by preventing the use of force (Dinstein, 2005; Frowein and Cogens, 2009). To different extents, Articles 51 and 52 of the Vienna Convention invalidate treaties procured through the unlawful use of force. The species was established as *jus cogens*. The justification for invalidating a treaty that a party procures in this manner lies in the lack of free consent and the behavior of the party that, under duress, cannot express its true preference (Lauterpacht, 1927). This implies an imbalance in the bargaining positions of the two parties when a treaty is concluded (Craven, 2005). The unequal status of the parties does not necessarily result in an unbalanced treaty. However, an extreme disparity in their NH automatically makes a treaty unequal (and even invalid) based on the *jus cogens* violation.

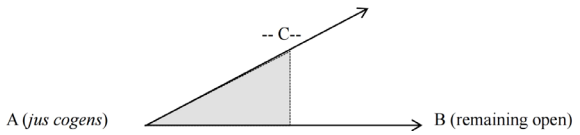


FIGURE 1
One end (point A) was fixed by preventing the use of force. To different extents, Articles 51 and 52 of the Vienna Convention invalidate treaties procured through the unlawful use of force. The species was established as *jus cogens*. Treaties within the shaded zone might be unequal treaties, or they might merely be asymmetric bargained agreements. This depends on how line C (representing the degree to which the parties are unbalanced in bargaining) moves along the ray. The indicator NH provides a playing field in which the status of parties can change and, in so doing, can bring about a change in the content of provisions. This happens when a strong power incidentally suffers from an unexpected development that decreases its bargaining strength and increases its willingness to accept less beneficial arrangements than those it had once hoped for. This change may have saved the treaty from potential charges of inequality.

Therefore, NH is a decisive indicator. A history of negotiations without extreme oppression is a prerequisite for an equal treaty.

What was the other end of the ray? This is merely asymmetric bargaining, which can describe a variety of treaties in the contemporary, unbalanced international community. Model Bilateral Investment Treaties (BITs) in the investment regime provide a good comparison (Bedrosyan, 2018). This asymmetry cannot be automatically defined as equivalent to inequality. Treaties within the shaded zone (Figure 1) might be unequal treaties, or they might merely be asymmetric bargained agreements. This depends on how line C (representing the degree to which the parties are unbalanced in bargaining) moves along the ray. The indicator NH provides a playing field in which the status of parties can change and, in so doing, can bring about a change in the content of provisions. This happens when a strong power incidentally suffers from an unexpected development that decreases its bargaining strength and increases its willingness to accept less beneficial arrangements than those it had once hoped for. This change may have saved the treaty from potential charges of inequality.

The indicator NH can depict how unique stories influence the positions of the parties and might cause further differences in the content of treaty provisions.

2.3.2 What happened in the negotiation history of CMATS?

This section briefly introduces the notorious spying scandal and analyzes how it relates to the imbalance between the two parties, the contents of the treaty, and Australia's bad faith. It began in 2004 when the Australian Secret Intelligence Service ("ASIS") clandestinely planted covert listening devices in a room adjacent to the Timor-Leste Prime Minister's Office in Dili, the country's capital, to obtain information that would ensure that Australia held the upper hand in its negotiations with Timor-Leste over the rich oil and gas fields in the Timor Gap (Collaery, 2013). Although the Timor-Leste government was unaware of Australia's espionage operations, negotiations were hostile. The first Prime Minister of Timor-Leste, Mari Alkatiri, bluntly accused Australia's Prime Minister, John Howard, of plundering the oil and gas in the Timor Sea, stating: "Timor-Leste loses $1 million a day due to Australia's unlawful exploitation of resources in the disputed area. Timor-Leste cannot be deprived of its rights or territory due to crime (Marian and Cronau, 2014)." Ironically, Australian Foreign Minister Alexander Downer responded, "I think they've made a very big mistake thinking that the best way to handle this negotiation is trying to shame Australia, is mounting abuse on

our country and accusing us of being bullying and rich and so on, when you consider all that we are done for East Timor (Marian and Cronau, 2014)."

Witness K, a former senior ASIS intelligence officer who led the bugging operation, confidentially noted that in 2012, the Australian Government had accessed top-secret, high-level discussions in Dili and exploited these during negotiations over the Timor Sea Treaty (Steve, 2016), which CMATS later superseded. Timor's Prime Minister, Xanana Gusmao, discovered the bugging and, in December 2012, told the Australian Prime Minister, Julia Gillard, that he knew of the operation and wanted the treaty to be invalidated, as a breach of good faith had occurred during the treaty negotiations (Marian and Cronau, 2014). Prime Minister Gillard did not agree with the invalidation of the treaty. The first public revelation of an allegation of the 2004 espionage in Timor-Leste appeared in 2013 in an official Australian government press release. Interviews with Australian Foreign Minister Bob Carr and Attorney-General Mark Dreyfus detailed the alleged espionage and several subsequent media reports (Marian and Cronau, 2014). The knowledge of the espionage led Timor-Leste to reject the treaty on the Timor Sea and refer the matter to the International Court of Justice (the "ICJ") in The Hague (Allard, 2014). Timor's lawyers, including Bernard Collaery, intended to call Witness K as a confidential witness in an "in camera" hearing in March 2014. However, in December 2013, the ASIO and the Australian Federal Police raided the homes and offices of both Bernard Collaery and K, confiscating many legal documents. Timor-Leste immediately sought an order from the ICJ to seal and return documents (Allard, 2014). In March 2014, the ICJ ordered Australia to stop spying on Timor-Leste and not interfere with the communication between East Timor and its legal advisors in arbitral proceedings and related matters (Allard, 2014; Allard, 2016).

In April 2013, Timor-Leste launched a case in the Permanent Court of Arbitration in the Hague to pull out a gas treaty that it had signed with Australia, accusing the latter of having had an ASIS bug in the East Timorese cabinet room in Dili in 2004 (I.C.J, 2015; International Court of Justice, 2015). Timor-Leste initiated a conciliation case over the sea border shared with Australia in April 2016. Timor-Leste believes that much of the Greater Sunrise oilfield falls under its jurisdiction, and that it has lost $US5 billion to Australian companies as a result of the treaty that it now disputes (Allard, 2014; Gusmao et al., 2013).

The imbalance of their bargaining status is obvious from this story. Australia's spying thoroughly and flagrantly took advantage of Timor-Leste's weaknesses in strength, techniques, and information. Subsequent attempts to hide evidence and punish whistleblowers further proved the government's willingness to use its superior position. The ICJ's order to stop spying had the effect of declaring it illegal.

2.3.2.1 Did Australia's spying in NH constitute coercion?

Article 51 of the Vienna Convention prohibits the coercion of representatives of other negotiating states. If one party procured the State's consent through an act or threat directed against the State's representative, that consent would not have any legal effect. Is spying on a representative act or a threat to him? The negotiations were hostile, but the Prime Minister of Timor-Leste did not feel threatened during the bargaining. The spying process is secret, and it is difficult to argue that a given act imposes a threat on someone who has no knowledge of it.

Article 52 voids any treaty concluded through a threat or the use of force in violation of the principles of international law embodied by the UN Charter (International Court of Justice, 1986). Is espionage the use of force in violation of UN principles? The UN has never explicitly addressed this issue outside the context of war (Chesterman, 2006; Demarest, 1996). The convergence of international law and peacetime espionage is highly controversial (Prochko, 2018).

The ICJ officially removed the case, "Questions relating to the Seizure and Detention of Certain Documents and Data," from its to-do list on June 12, 2015, after Timor-Leste confirmed that Australia had handed back the relevant papers (I.C.J, 2015). Timor-Leste's agent explained that "following the return of the seized documents and data by Australia on May 12, 2015, Timor-Leste has successfully achieved the purpose of its Application to the Court, namely the return of Timor-Leste's rightful property, and therefore implicit recognition by Australia that its actions were in violation of Timor-Leste's sovereign rights." Leaving aside the question of whether Australia had confirmed a violation of sovereignty, there was no use of force.

Therefore, the existing law governing NH did not apply to Australia's spying activities.

2.3.2.2 What was Australia's real incentive behind Article 4 of CMATS?

Seemingly balanced provisions can impose unequal effects on the parties [see Scenario (b)]. Evaluating such circumstances requires us to consider both the incentives and influences.

Peter Galbraith, the lead negotiator for Timor-Leste, laid out the motives behind ASIS's espionage, "What would be the most valuable thing for Australia to learn is what our bottom line is, what we were prepared to settle for. There's another thing that gives you an advantage, you know what the instructions the prime minister has given to the lead negotiator. And finally, if you're able to eavesdrop you'll know about the divisions within the East Timor delegation and there certainly were divisions, different advice being given, so you might be able to lean on one way or another during the negotiations (Marian and Cronau, 2014)." A statement from a victim's agent may be vulnerable to claims that it lacks objectivity. Nevertheless, there is a gap between seeking advantageous bargaining status by exploring the counterpart's information and the incentive to oppress that party. Australia's spying exacerbated its already unbalanced status and widened the gaps in techniques, intelligence, and negotiation strategies between the two powers. Article 4 of CMATS restricts further sea claims by Timor-Leste until 2057, which may lead to a continuing or even expanding imbalance between the two parties. This is consistent with the suggestion that the status of the parties was "unequal."

Australia's spying intensified its superior bargaining position, aggravated the existing imbalance, and exposed its bad faith, which affected the parties' NH. CMATS enhanced the unbalanced results of the negotiations, which might have had an unfair effect on

Timor-Leste. Such an influence, together with the bad incentives of the superior party, makes the apparently neutral Article 4 of CMATS an unequal provision. This part believes that the Commission implicitly relied on this analysis to negate the treaty for the purposes of Article 281(1). The three-indicator pattern shows how the concept and analysis of unequal treaties coordinates with UNCLOS Part XV.

2.4 Further implications: how would the Commission's interpretations influence future treaty negotiations and international law practices?

The influence on future negotiations and international law practices could not be ignored by GGBs, though a case ruling is not binding in the international community. Coherence in homogeneous or similar issues is always a pursuit of international judicial decision making. This influence does only affect the future interpretations of the articles concerned, but also the enforcement mechanism of a convention as a whole, especially when a convention dominates a field of rules in a systematic manner. UNCLOS is regarded as a Charter in the law of the sea, which provides an apparent necessity to look into its enforcement mechanisms when we discuss its articles' interpretations.

2.4.1 The harms of a defective interpretation on the predictability of international law development

It is difficult to recognize the Timor Sea Conciliation competence decision without defects. In sum, the interpretation approach excels in identifying the primary evidence of the parties' intentions (preventing future disputes) through the terms adopted in the provision. However, textualism cannot locate the exact incentives for any party without going deeper into the negotiation history behind a treaty. The frequent ambiguity in treaty terms contributes to this difficulty. This research analyzes the logic of this ruling from the perspective of unequal treaties and finds that CMATS, the parallel treaty between Timor-Leste and Australia, embodies some inequality characteristics that might have justified the Commission's expansion of jurisdiction. The Commission's word game analysis of Article 281 reveals that GGBs are willing to be selective when they interpret UNCLOS articles at the jurisdictional stage. The Commission's interpretation of the explicit exclusion of further procedures as "not to seek settlement" damages the predictability of international judicial making, which, according to some scholars, caused an apparent expansion of the Commission's competence.

2.4.2 The interpretation between the equality test and the enforcement mechanism under UNCLOS

The life of a legal rule lies in its enforcement. The probable hardship in enforcing a ruling would to a large extent affect the dignity or the authority of the GGB that made the ruling. The overreaching statement of the Commission on the equality test was intended to achieve *effectiveness*, meaning that GGBs should consider the consequences of their decisions (on whether the dispute could be settled after decision-making) in their ruling process in dispute settlement (as is further implied in Section 3.3 below), would increase the obstacles in enforcing the ruling, lower the feasibility in fulfilling the contents in the decision, and in turn harm the objective of *effectiveness*. However, the Annex V Conciliation is located by UNCLOS Part XV as a voluntary, non-compulsory proceedings, which is not as binding as the other proceedings, such as the ITLOS litigations in Annex VI and the arbitrations in Annex VII.

The GGB aims to adjust the unbalanced situation in international treaty negotiation through setting a strict standard while making voice on the equality test. This action does not contribute to the solution, while it even adds the difficulties in realizing the contents in a non-compulsory conciliation decision from the beginning. In the context of enforcement and effectiveness, the previous cases under the compulsory proceedings of UNCLOS deserve more attention, as we would look into in Section 3 below.

3 Paradox of jurisdiction: the equality test of Article 281 in conjunction with merits

Section 2 above discussed the Timor Sea case as the first Conciliation under UNCLOS in detail, showing how the Commission interpreted Article 281. However, existing rulings made by other courts or tribunals under UNCLOS did not always consist with the Timor Sea Commission. Scholars have examined Article 281 in previous competence decisions, seeking to analyze various parties' attempts to solve disputes voluntarily. They used four criteria relevant to this article: whether the agreement between the parties for voluntary settlement needs to be a binding treaty; whether the agreement substantially covers the issues under dispute; whether the agreed means in the parallel treaty need to be exhausted; and whether its provisions need to contain an explicit exclusion of the compulsory proceedings in UNCLOS. This section goes into how the existing rulings interpret Article 281 by answering these four questions one by one and make comparisons with that of the Commission when necessary. Some previous cases made obvious counterarguments against our Timor Sea Conciliation, which in turn outstands the value in conducting comparative studies.

3.1 Existing rulings on Article 281

In various cases, the defendant parties quoted Article 281 to object to the jurisdiction of GGBs based on evidence of their previous attempts to reach a voluntary settlement. Broadly, the GGBs deciding the cases below agree that indefinite negotiation is unnecessary, but the agreement must cover the substantive issues in dispute. However, the GGBs' opinions differ regarding what the Article requires to avoid triggering compulsory proceedings.

3.1.1 The Southern Bluefin Tuna Case (Australia and New Zealand v. Japan), 2000

One issue in the Southern Bluefin Tuna Case was how the two treaties with parallel articles bore upon a particular dispute. The "Award on Jurisdiction and Admissibility of Southern Bluefin Tuna Case" in 2000 determined that the rights and duties under the two treaties were inextricably linked, "for the reason that the Convention for the Conservation of Southern Bluefin Tuna (CCSBT) was designed to implement broad principles set out in UNCLOS" (Southern Bluefin Tuna Case, 2000). Although the court declared that Japan's reliance on *the lex specialis* (a legal principle prioritizing the rules in a special field against others in general fields when they contradict) was erroneous, the tribunal held that the parties had addressed all the main elements of the dispute under the CCSBT framework. Even if Article 281(1) did not require the parties to "negotiate indefinitely," the tribunal found that the parties had not exhausted the options in Article 16(1) of CCSBT and that their failure to reach an agreement for referral of the dispute did not absolve them of the responsibility to continue to seek its resolution by the peaceful means that the Article provides. Since the 1993 CCSBT was a binding treaty, the tribunal did not shed light on whether the ruling would have changed, and there was no binding agreement. Instead, the ruling focused on whether the explicit exclusion of other dispute settlement procedures was necessary for the purpose of Article 281. As the applicant parties, Australia and New Zealand, argued, the contents of Article 16(2) of the CCSBT did not expressly exclude further dispute settlement procedures. Finally, the tribunal determined that the implicit exclusion was sufficient.

3.1.2 MOX Plant Case (Ireland v. United Kingdom), 2003

In the "Order on Suspension of Proceedings on Jurisdiction and Merits" and the "Request for Further Provisional Measures of MOX Plant Case" in 2003, the focus was on whether the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) substantially covered the field of the dispute (MOX Plant Case, 2000). ITLOS believes that OSPAR did not pass the substantive coverage test to an extent that would trigger the application of UNCLOS Articles 281 and 282.

3.1.3 Land reclamation case (Malaysia v. Singapore), 2003

In the "Order of Provisional Measures on the Case concerning Land Reclamation by Singapore in and around the Straits of Johor" in 2003 (Pinto et al., 2003), ITLOS determined that Article 281 was inapplicable since both Malaysia and Singapore agreed that their meetings would be without prejudice to Malaysia's right to proceed with the arbitration, according to Annex VII to the Convention, or to its right to request the Tribunal to prescribe provisional measures (Pinto, 2003). ITLOS based its jurisdiction on the agreement between the parties that meetings would not affect Malaysia's right to seek remedies through UNCLOS compulsory proceedings. This ruling promoted the non-exclusion of Article 281 over its other elements. Effectively, the tribunal determined that it has jurisdiction as long as the parties explicitly permit compulsory procedures in their agreement, regardless of whether the agreement is binding, what it covers, or whether the parties have reached a settlement by the agreed means.

3.1.4 Maritime delimitation case (Barbados v. Trinidad and Tobago), 2006

The "Award of the Arbitral Tribunal concerning the Maritime Boundary between Barbados and the Republic of Trinidad and Tobago" in 2006 made an unprecedented pronouncement concerning the relationship between Articles 281 and 282. The tribunal noted that Article 282, which covers bilateral or multilateral treaties that provide for a resort to compulsory procedures that can be applied in lieu of Section 2 procedures, was inapplicable to the dispute (Schwebel et al., 2006). Its sister Article 281 the dispute, however, "is intended primarily to cover the situation where the Parties come to an *ad hoc* agreement as to the means to be adopted to settle the particular dispute which has arisen." This interpretation is the opposite of the Timor Sea Conciliation Commission's view of parallel structures. The tribunal admitted that the parties had agreed in practice, although not by any formal agreement, to settle their disputes through negotiation, which was in any event that Articles 74(1) and 83(1) imposed on them. This amounts to the admission that an agreement with no binding form can pass the threshold of Article 281(1) as long as it covers the issues in dispute. The tribunal concluded that it had jurisdiction over the merits since the parties' *de facto* agreement did not exclude any further procedures under Article 281(1) and because their chosen peaceful procedure settlement procedure – negotiation – had failed to result in a settlement of their dispute.

3.1.5 South China Sea case (The Philippines v. China), 2015

The "Award on Jurisdiction and Admissibility of South China Sea Arbitration" in 2015 presented an extremely strict interpretation of Article 281. The tribunal generated three elements that form the basis of this article (overlapping three of the four focal points: whether the agreement between the parties for voluntary settlement needs to be a binding treaty, whether the agreement substantially covers the issues under dispute, whether the agreed means in the parallel treaty need to be exhausted, and whether its provisions need to contain an explicit exclusion of the compulsory proceedings in UNCLOS, regarding all of them as necessary) (Yee, 2014).

The tribunal determined that the parties did not intend the "Declaration on the Conduct of Parties in the South China Sea" (DOC) to be a legally binding agreement; this finding would have been sufficient to dispose of this issue for purposes of Article 281. According to the tribunal, the terms of the DOC reaffirmed existing obligations rather than reflecting a clear intention to establish rights and obligations between the parties, irrespective of the form or name of a document. The tribunal did not delve into the question of whether the contents of the DOC covered the dispute since its form did not conform to Article 281(1)'s requirement for a binding agreement.

The tribunal ruled that neither of the other two elements – whether the parties reached a settlement by recourse to the agreed means or whether the agreement excluded any further procedures – had been satisfied. It noted that Article 281 did not require the parties to pursue any agreed means of settlement indefinitely but said that they should abide by any limit that their agreement laid out. The lack of a time limit for the DOC and many years of futile discussions between the Philippines and China led the Tribunal to conclude that the parties had not reached a settlement.

Regarding the exclusion of Part XV procedures, the Tribunal considered both views in Southern Bluefin Tuna and adopted the dissenting view of Judge Kenneth Keith that explicit exclusion was required. By concluding that "the better view is that Article 281 requires some clear statement of exclusion of further procedures," the tribunal broadened the availability and scope of compulsory jurisdiction under UNCLOS. It examined the "Treaty of Amity and Cooperation in Southeast Asia" (the Treaty of Amity) and other bilateral statements using the same benchmark and disqualified them under Article 281(1).

3.2 The approach in rulings on Article 281: a treaty with a specific DSM

From the start of Timor Sea Conciliation to existing rulings, opinions of the UNCLOS courts or tribunals regarding Article 281 demonstrate no consistency regarding whether it requires a binding agreement and whether it needs to be explicit about excluding further procedures to avoid the jurisdiction of the GGBs. However, based on these rulings, it is possible to roughly determine the kind of treaty that would pass the Article 281 test. The capacity of a parallel treaty to contribute to voluntary settlements, according to the GGBs' previous decisions, is an approach in coordination with the equality test, although not readily apparent.

3.2.1 What is special about the CCSBT in the Southern Bluefin Tuna Case?

The CCSBT in the Southern Bluefin Tuna case contained a list of means for dispute settlement, including negotiation, inquiry, mediation, conciliation, arbitration, and judicial settlement. These are all routes through which future parties can reach peaceful settlements without the tribunal's involvement. Some procedures on the list, such as arbitration and judicial settlement, can lead to a binding decision, creating an enforceable remedy similar to compulsory proceedings under Part XV. The Southern Bluefin Tuna case is the only one thus far that has been concluded with no jurisdiction. It seems far-fetched to imply that the tribunal made this decision because it thought that the parties were likely to resolve the matter on their own using the dispute settlement options in the CCSBT. However, the apparently balanced arrangements in the CCSBT may have led the tribunal to rely on the treaty's capacity to contribute to settling disputes. Similarly, the MOX Plant tribunal suspended its jurisdiction on the merits, noting that "the essentially internal problems within the European Community legal order may involve decisions that are final and binding." A procedure that could result in two conflicting decisions would not be helpful in resolving the dispute, and this understanding motivated the MOX tribunal to wait rather than proceed.

3.2.2 Common features of the treaties that failed the Article 281 test

The Timor Sea Conciliation is not a classic case that failed the Article 281 test. Parallel treaties concerning jurisdiction in other cases that failed Article 281 had much in common. The dispute settlement procedures in the DOC before the South China Sea Tribunal allowed only the option of negotiation, which was not a procedure that led to a binding decision. Negotiations, as the most flexible means of dispute settlement, cannot guarantee peaceful settlement within a specified period. This arrangement in the parallel treaty could easily lead a GGB to assume that a given dispute will continue or even intensify despite years of negotiation if left unsupervised. The South China Sea Tribunal interpreted Article 281 as requiring a binding treaty, namely an agreement intended to establish rights or obligations. It disqualified the DOC for the purpose of Article 281 primarily because the agreement repeated the existing arrangements without establishing any new rights or obligations. It was its dissatisfaction with the efficacy of the existing arrangements or, more directly, the risk of unending negotiations which made the tribunal unwilling to rely on this document. Of all the decisions, the Barbados/Trinidad and Tobago Tribunals made the most flexible interpretation of this form of agreement by ruling that an *ad hoc* agreement was sufficient.

Nevertheless, it still found jurisdiction since the parties had not managed to settle their disputes through negotiation, as they had agreed, and it was determined that their agreement contained no exclusion of further procedures. Similar to the South China Sea case, this tribunal's analysis partly relied on the limitations of the negotiations. Without the tribunal's intervention, it would have been almost impossible for the parties to reach a settlement merely through negotiations.

The Barbados/Trinidad and Tobago Tribunal ruled against the Timor Sea Commission on the relationship between Articles 281 and 282 and whether Article 281 requires a binding treaty. However, the root of the parties' disagreement was the form of the parallel treaty and not its content. The Commission's expectations of the content of a parallel treaty were similar. Specific arrangements determining the means of settlement led GGBs to believe that the parties could and would settle their disputes voluntarily, equally, and peacefully. An agreement without these would represent inequality between the parties and could contribute to a settlement. Allowing the substance of an act (especially the intention behind it) to prevail over its form is a classic tendency in international judicial rule (Acharya, 1994). The fact that the South China Sea Tribunal and the Timor Sea Commission focused on the binding form of relevant parallel agreements without examining their contents is unusual.

A preliminary conclusion is that Article 281 might not require a formally binding agreement, as Article 282 does in the procedural

dimension, but that an agreement "to seek settlement of the dispute by a peaceful means of their own choice" should contain some workable arrangements by which to solve the dispute. When a parallel treaty confines the dispute to the parties without providing any feasible means of settlement, it conveys a signal of inequality and little likelihood of voluntary settlement. GGBs tend to interfere in this kind of dispute to adjust the unbalanced situation and assist the parties in reaching a settlement. Article 281 provides the equality test. While examining the equality (or inequality) of parallel treaties, the GGBs follow the following approach: whether parallel treaties between parties can come to a voluntary settlement.

3.3 The expansion of jurisdiction: judicial enthusiasm or a last resort?

Despite the lack of consistency in the existing rulings regarding the elements of Article 281, the relevant tribunals established jurisdiction for all of the above cases except for the Southern Bluefin Tuna case. The GGBs since the Southern Bluefin Tuna have all headed toward the same destination, although by divergent routes. One well-recognized justification for the expansion of jurisdiction is the principle of *effectiveness*, as is mentioned above in Section 2.4. This section explores the second justification for this expansion: necessity. When GGBs conduct equality tests on parallel treaties, the elements they need to observe are generally linked to the merits of the case.

3.3.1 Two principles in tension: effectiveness v. consent

Interpretations of Article 281 provide an insight into the casualty of GGBs on their own jurisdictions. Many foresaw the potential expansion of jurisdiction from the start of the UNCLOS. "It is most unlikely that a dynamic court exercising its powers will have much difficulty, both in finding that it possesses jurisdiction in a particular case and in finding that the Convention contains rules appropriate for the resolution of virtually all disputes arising under it (de Mestral, 1984)." Some regard this as judicial activism, which is not merely valuable but sometimes even necessary (Lowe, 2005). The principle of *effectiveness*, which allows GGBs to fulfill their judicial function, provides one justification for the judicial activism we saw above (Wolfrum, 2006; Buga, 2012). However, there is some tension between this principle and that of *consent*, which refers to sovereign states' willingness to be bound by GGBs' decisions as the foundation of jurisdiction (Permanent Court of International Justice, PCIJ, 1923). We cannot overemphasize the importance of a reasonable balance between these two principles in dispute settlement.

3.3.2 Necessity in expansion: issues not of exclusively preliminary character

It seems that expansion of jurisdiction is sometimes necessary. When the defendant party objects to jurisdiction relying on an agreement to which it is bound, initiating compulsory proceedings in UNCLOS could violate obligations under that parallel treaty. No GGB has ruled on the nature or consequences of such breaches. GGBs dealing with a binding treaty face the potential risk of challenging *pacta sunt servanda*. Establishing a degree of inequality that might invalidate a parallel treaty could be a persuasive justification for this deviation. The equality test of Article 281 regarding a parallel treaty involves determining whether the status of the parties is unbalanced, whether the distribution of rights and obligations in the treaty's contents is unfair, and whether there are any coercive factors in negotiating history. These details, however, easily penetrate the substance of the case, and according to the procedural rules of UNCLOS, they are not exclusively preliminary characters.

This paradox demonstrates the necessity of GGBs' broadening the availability and scope of compulsory jurisdiction under UNCLOS and provides another justification, or at least an explanation, for the GGBs' keenness to expand their competence. Without the capacity to look into the substantive issues, they cannot determine whether they have jurisdiction on issues "not of an exclusively preliminary character" in a competence decision for a given dispute. In the "Jurisdiction and Admissibility Award of Guyana/Suriname Arbitration" in 2007, the tribunal considered it appropriate to rule on the Preliminary Objections in its final award. Suriname's objections were not exclusively preliminary since "the facts and arguments are in significant measure the same as the facts and arguments on which the merits of the case depend" (Judge et al., 2007). The 2015 South China Sea award left jurisdiction over certain submissions to a substantive award for the same reason.

3.3.3 How would inconsistencies between the conciliation and former rulings on Article 281 influence the future of UNCLOS dispute settlement?

As is the case in our Timor Sea Conciliation, designing decisions regarding competence as a prerequisite involves an inherent paradox. The equality test in Article 281 touches on substantive issues, sometimes making an expansion of GGBs' competence unavoidable. This paradox provides a second justification for expanding jurisdiction, apart from *effectiveness*.

According to the GGBs, the equality test in Article 281 blocks unequal parallel treaties and contributes to the peaceful settlement of disputes in the long run. Parties seeking to avoid Part XV proceedings in the future may consider attaching more importance to the agreed means of settlement in their bilateral or regional treaty negotiations, which, according to the GGBs, may increase the likelihood of reaching a peaceful settlement. These findings may inform future treaty negotiations and dispute resolutions under UNCLOS in such a manner: the parties seeking to avoid Part XV proceedings may attach more importance to the agreed means of settlement. This would in turn influence the future interpretations of Article 281, such as promoting the benchmarks again and again, influencing the predictability in UNCLOS dispute resolution mechanisms and international law practices in future.

4 The dilemma of compatibility: Article 311's lack of clarity regarding benchmarks in UNCLOS

Section 3 above discusses the existing rulings on Article 281, which focuses on whether a parallel agreement under UNCLOS is an unequal treaty. Apart from the equality test, the compatibility benchmark under Article 311 is another controversial point in this case. Most state parties choose binding agreements when negotiating regional or bilateral marine rights and obligations; however, asymmetric bargaining easily makes agreements unbalanced. UNCLOS framers intended to redress regional or bilateral bargaining imbalance by imposing a uniform regime. However, UNCLOS resulted from asymmetric multilateral negotiations, so it had to leave space for voluntary arrangements between specific parties to remedy this issue. The benchmark regarding which regional or bilateral agreements the UNCLOS respects lies in Article 311, in which the GGBs' decisions have rarely been discussed. This section posits that the compatibility requirement in Article 311 is as important as that in Article 281 and, therefore, deserves more attention than it has received. It can be difficult, however, to determine what "compatible" means. This section compares the Commission's answer to those of other GGBs under UNCLOS and explores how they interpret compatibility under Article 311.

4.1 The Commission's Understanding: a unidirectional compatibility

The Commission did not examine CMATS through the lens of Article 311 because, in its view, CMATS is not a treaty that derogates from the terms of the Convention. First, CMATS is the first of the two treaties. Second, Australia and Timor-Leste did not notify any other UNCLOS parties, as Article 311(4) requires. Third, Article 4 of CMATS did not state that the parties must be willing to modify or suspend any obligations under the Convention (the Commission). However, these reasons for ignoring Article 311 reflect the Commission's limited assessment of its value.

Article 311 governs both the existing and later agreements through various sub-articles. Article 311(2) expressly applies to agreements that parties made before the UNCLOS came into effect. The notification requirement in Article 311(4) applies only under the circumstances of Article 311(3), which permits two or more parties to conclude agreements by modifying or suspending the operations of some UNCLOS provisions. In the existing agreements to which Article 311(2) applies, the intent to derogate from UNCLOS' Articles need not necessarily be explicit; when parties negotiated a regional or bilateral agreement before UNCLOS, they would have had no way of knowing which articles to modify or suspend.

The Commission implicitly ruled on the meaning of "compatible," even though it did not see Article 311 as relevant to the case. When examining CMATS Article 4 in the context of Article 281(1), it was stated that all discussions on competence must start from the Convention rather than from the CMATS (the Commission). This statement implies that all external agreements must be compatible with UNCLOS, not *vice versa*. The Commission did not consider the need to rebalance the inequalities inherent in the UNCLOS negotiations through regional or bilateral arrangements. This amounts to the rule that there is no basis for permitting derogation. The latter will always prevail whenever there is a controversy between other agreements and UNCLOS. This renders Article 311's permitted derogation meaningless.

Sections (2) and (3) of Article 311 are phrased in the exception-in-exception mode. They appear in UNCLOS, where exceptions can derogate some UNCLOS articles. The second exception is to prevent that derogation from affecting the purpose, object, or basic principles of the convention. What derogation means in theory, as Figure 2 shows, is that some part of circle B (the relevant agreement for Article 281) may move out of circle A (the Convention) and that this partial exception is acceptable as long as it does not fall into the second exception (the smallest circle SC, representing the provisions against the object and purpose). C is the point at which Article 311 came into play.

Imagine reasoning starting with a parallel treaty. The exception-in-exception mode becomes an exception-to-principles mode when parties incorporate a regional or bilateral agreement compatible

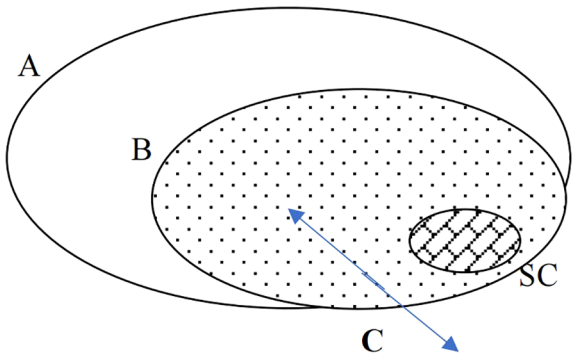


FIGURE 2
Sections (2) and (3) of Article 311 are phrased in the exception-in-exception mode. They appear in UNCLOS, where exceptions can derogate some UNCLOS articles. The second exception is to prevent that derogation from affecting the purpose, object, or basic principles of the convention. What derogation means in theory, as Figure 3 shows, is that some part of circle **(B)** (the relevant agreement for Article 281) may move out of circle **(A)** (the Convention) and that this partial exception is acceptable as long as it does not fall into the second exception (the smallest circle SC, representing the provisions against the object and purpose). **(C)** is the point at which Article 311 came into play. Imagine reasoning starting with a parallel treaty. The exception-in-exception mode becomes an exception-to-principles mode when parties incorporate a regional or bilateral agreement compatible with UNCLOS Articles into the UNCLOS framework. This parallel treaty will remain compatible with UNCLOS if it does not contradict its object and purpose. This compatibility (Figure 3) works in two ways. According to the Commission, any voluntary arrangement chosen by the parties (circle B) must remain completely within the framework of UNCLOS (circle A). The smallest circle will disappear, as nothing in circle B will contradict UNCLOS's object or purpose. This understanding largely restricts the function of Article 281(1) and further limits the potential for voluntary dispute settlement under Article XV. Ultimately, this makes the so-called compatibility unidirectional, as the arrow in Figure 2 points outward.

with UNCLOS Articles into the UNCLOS framework. This parallel treaty will remain compatible with UNCLOS if it does not contradict its object and purpose. This compatibility (Figure 2) works in two ways. According to the Commission, any voluntary arrangement chosen by the parties (circle B) must remain completely within the framework of UNCLOS (circle A). The smallest circle will disappear, as nothing in circle B will contradict UNCLOS's object or purpose. This understanding largely restricts the function of Article 281(1) and further limits the potential for voluntary dispute settlement under Article XV. Ultimately, this makes the so-called compatibility unidirectional, as the arrow in Figure 3 points outward.

What are the objectives and purposes of UNCLOS as a benchmark? For instance, it is easy to imagine a circumstance in which parties with geo-economic relationships agree to exploit the marine resources of adjacent marine areas in a manner different from the relevant regimes in UNCLOS, and it is difficult to imagine a scenario in which one State party gives up almost all of its essential interests in a submissive gesture. Nevertheless, parties cannot use Article 311 to justify unequal treaties, as they would easily fall into the second exception. Unequal provisions go against "the maintenance of peace, justice and progress of all" and the basic principles of "strengthening security, cooperation and friendly relations" in UNCLOS's Preamble. The significance of the non-derogation requirement lies in maintaining regional and bilateral agreements, including unequal provisions. In Article 311, unequal treaties derogate protected non-derogatory values. Compatibility complements the equality tests for voluntary settlements in Article 281.

4.2 A divergent "voice" from other GGBs: possibly dual-directional

In contrast to Article 281, few decisions have discussed Article 311, as noted above, but these limited rulings also represent a strong value in making comparisons, comparing the similar rulings to the potential counterarguments. This part goes into other opinions on Article 311, as it was conducted above on Article 281 in Section 3 above. The Southern Bluefin Tuna case is the only one that has analyzed a parallel agreement in the context of Article 311, and the tribunal drew its conclusions based partly on that analysis. At least one other case addressed issues concerning the relationship between the Convention and other sources of international law, such as whether historical rights were compatible with the UNCLOS regime. Regarding the relationship between Articles 281 and 311, the history of judicial decision-making under UNCLOS's compulsory proceedings is almost blank. Some cases did not involve parallel treaties or raise issues relevant to compatibility; in others, the GGBs were reluctant to speak to the subtle and complicated link between the two articles, even when voluntary settlement and compatibility were directly at issue. Nonetheless, we can extrapolate the tribunals' positions from their rulings without explicit statements. This section analyzes previous Article 311 decisions, especially regarding compatibility, to understand the GGBs' view of the relationship between Articles 281 and 311.

4.2.1 Existing ruling on Article 311

Article 311 defines how a treaty derogates UNCLOS's terms and the extent to which a derogation is compatible with UNCLOS. Of the existing rulings concerning jurisdiction and admissibility, the Southern Bluefin Tuna case offers only an analysis of Article 311. Japan, Australia, and New Zealand agreed that the 1993 CCSBT was compatible with UNCLOS. However, they disputed whether the CCSBT was a treaty derogated from UNCLOS. To some extent, this disagreement represents a divergence in their interpretations of "compatible" in Article 311. Japan believed that the CCSBT should prevail as *a lex specialis* and regarded the compatibility requirement in Article 311 as evidence supporting this analysis. In Japan's view, the list of procedures in Article 16 of the CCSBT constitutes a derogation with no detraction of other parties' enjoyment of rights under UNCLOS. According to Australia and New Zealand, the CCSBT is compatible with UNCLOS. Still, there is no indication in *travaux* (the materials regarding the parties' preparation when they negotiate a treaty) that Japan intended to opt out of the UNCLOS dispute settlement.

The focal point of the parties' controversy was whether a parallel treaty "compatible" with UNCLOS could justify a derogation from the compulsory proceedings. Australia and New Zealand emphasized that the CCSBT is compatible but not a treaty derogating from UNCLOS since they did not agree with those in negotiations. Japan claimed that as long as the CCSBT is compatible with Article 311, derogation is automatically permitted based on the parallelism of jurisdiction. The arguments of Australia and New

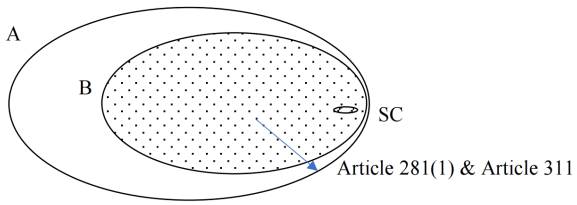


FIGURE 3
Sections (2) and (3) of Article 311 are phrased in the exception-in-exception mode. They appear in UNCLOS, where exceptions can derogate some UNCLOS articles. The second exception is to prevent that derogation from affecting the purpose, object, or basic principles of the convention. What derogation means in theory, as Figure 2 shows, is that some part of circle **(B)** (the relevant agreement for Article 281) may move out of circle **(A)** (the Convention) and that this partial exception is acceptable as long as it does not fall into the second exception (the smallest circle SC, representing the provisions against the object and purpose). **(C)** is the point at which Article 311 came into play. Imagine reasoning starting with a parallel treaty. The exception-in-exception mode becomes an exception-to-principles mode when parties incorporate a regional or bilateral agreement compatible with UNCLOS Articles into the UNCLOS framework. This parallel treaty will remain compatible with UNCLOS if it does not contradict its object and purpose. This compatibility (Figure 2) works in two ways. According to the Commission, any voluntary arrangement chosen by the parties (circle B) must remain completely within the framework of UNCLOS (circle A). The smallest circle will disappear, as nothing in circle B will contradict UNCLOS's object or purpose. This understanding largely restricts the function of Article 281(1) and further limits the potential for voluntary dispute settlement under Article XV. Ultimately, this makes the so-called compatibility unidirectional, as the arrow in Figure 2 points outward.

Zealand imply that the explicit exclusion of further procedures is proof of agreement on derogation in negotiations. Articles 281 and 311 are linked because the terms of exclusion in the former might serve as evidence of an agreement on derogation in the latter. Japan's argument that an agreement on derogation can be presumed based on the parallelism of jurisdictions amounts to saying that an implicit exclusion of the compulsory proceedings in UNCLOS in its parallel treaty is enough to prove its agreement on derogation.

When the Southern Bluefin Tuna Tribunal interpreted Article 281, it was found in favor of Japan that implicit exclusion was sufficient. However, when interpreting Article 311, the tribunal confusingly compared articles in CCSBT and UNCLOS relevant to coverage. The dispute over Japan's role in managing Southern Bluefin Tuna stocks, particularly its unilateral experimental fishing program, stemmed from the 1993 CCSBT, which, according to the tribunal, also fell under UNCLOS. According to the tribunal, this conclusion is consistent with Articles 311(2) and (5); therefore, it does not contradict the required compatibility. The Tribunal's interpretation of Article 311 links the compatibility issue to the coverage element in Article 281 rather than to the exclusion element disputed by the parties. The conclusion did not address the core of this disagreement.

The Southern Bluefin Tuna Tribunal's interpretation of Article 311 started in the 1993 CCSBT and diverged from the commission's unidirectional compatibility interpretation. Because a parallel treaty was designed to implement the broad principles of UNCLOS, a dispute concerning the CCBST would not be completely alien to the interpretation and application of UNCLOS. This interpretation admits dual-directional compatibility (Figure 2).

4.3 Regional arrangements v. UNCLOS: difficulties in interpreting Article 311

The parallelism of jurisdictions highlights the complexity of compatibility issues. This parallelism involves the possibility of two conflicting decisions and the potential conflict between regional arrangements and UNCLOS's comprehensive regime. Regarding compatibility, it remains unclear whether parallel treaties containing regional or bilateral arrangements for the purpose of Article 281 will derogate the rights and obligations that UNCLOS defines, and if so, what kind of derogation Article 311 permits. This ambiguity makes it more difficult for GGBs to deal with such circumstances when deciding on competence.

4.3.1 The influence of ambiguity on practice

GGBs' opinions give a notice to other parties under UNCLOS and may influence their choice of dispute settlement in future. The practical implications of some rulings are deep, profound and long-lasting. Ambiguity in terms of rules creates difficulties in interpretation and almost inevitably results in inconsistent practice. The Commission's unidirectional compatibility view and dual-directional understanding of the Southern Bluefin Tuna tribunal reflected the confusion of the GGBs when confronted with regional arrangements vis-à-vis UNCLOS's comprehensive regimes. Another approach in practice is to set the dispute aside and wait instead of making a ruling that is less likely to hold up.

Some commentators thought that this Order of Suspension in the MOX Plant case illustrated an obvious attempt to avoid repeating the fallacy of Southern Bluefin Tuna (Roben, 2004). The MOX Plant Tribunal suspended the case to avoid the risk of two conflicting decisions. This self-restraint demonstrates the judicial institution's values of mutual respect and conformity. However, by yielding to the European Community's legal order, the tribunal also provoked critique that it favored a regional arrangement over a comprehensive regime. The tribunal noted the likelihood that the European Court of Justice would make a binding decision in the conflict but did not express concern that the European Community's legal order might derogate the DSM under Part XV of the UNCLOS. Nevertheless, the tribunal did not take for granted that the European Community law should prevail and remained seized of the dispute until "a clearer picture" developed.

4.3.2 The embarrassing role of parallel treaties in UNCLOS

The relationship between the two important Articles 281 and 311, as discussed above, is ambiguous in UNCLOS. Thus, the kind of parallel treaty, either bilateral or regional, that both the equality test in Article 281 and the non-derogation test in Article 311 would permit is unclear. This ambiguity highlights the dilemma of "compatibility" in UNCLOS. There are no clear instructions to guide GGBs between prioritizing regional arrangements as exceptions and maintaining the DSM in UNCLOS as a closed, self-contained system. The literal meaning of Article 311 favors the latter, in which case, UNCLOS would prevail over both earlier and later treaties in the case of any inconsistency (Boyle, 2005). Article 311 states that because UNCLOS is an integral agreement, only a parallel treaty between parties compatible with UNCLOS can derogate its provisions. However, the scope of permitted derogation in any given case is subject to interpretation.

Similar circumstances exist in other areas of international law within a comprehensive framework, such as trade law. In the late 1940s, the World Trade Organization (WTO) provided a package of rules and regulations under the General Agreement on Tariffs and Trade (GATT) chapeau. These generally gave parties that joined the agreement after it came into force rights and obligations that differed from those of the initiating parties. The commonly used protocol commitments that the GATT imposes on these later-signing parties will likely exacerbate an already unbalanced situation.

How did the WTO respond to the problem? First, it allows these parties to participate in various benefits from joining the global market. They reap almost all the fruit of the founding parties' negotiations. The promise of non-discriminatory treatment is especially significant for newly emerging economies. Second, the GATT permits these countries to use various Free Trade Agreements (FTAs) to supplement GATT articles. As explicitly allowed exceptions within the WTO framework, FTAs provide a channel to redress the imbalance between parties in GATT

arrangements. The privileged status of FTAs in the WTO grants automatically stands in stark comparison to the regional arrangements established by parallel treaties in UNCLOS. These arrangements must be compatible with Article 311 to become permitted exceptions. For dispute settlement purposes, the arrangements must first pass the equality test of Article 281 before the compatibility test can be applied.

The terms for excluding compulsory proceedings in a parallel treaty for the purposes of Article 281 can serve as evidence of the parties' agreement on derogation under Article 311: When the object of derogation refers to DSMs, it remains unclear whether the derogation–namely, opting out of a particular DSM–needs to be explicit. Article 311 establishes the integrity of UNCLOS as a principle and designs a compatibility test to examine exceptions. Determining which bilateral or regional arrangements permit derogation remains a significant challenge for the GGBs.

4.3.3 How would the Conciliation's interpretation of Article 311 influence the future?

The Commission's understanding of Article 311 is controversial. Its view of compatibility is too conservative compared to the Southern Bluefin Tuna Tribunal. Although no clear benchmarks clarify what type of derogation will be compatible, the conclusion that CMATS is not a treaty derogating UNCLOS seems arbitrary. The Commission did not consider the relationship between CMATS and Article 281. Apart from unidirectional compatibility, the Commission tried to use Articles 311(2) and (3) to differentiate between earlier and later treaties. The terms in this Article suggest that UNCLOS is more tolerant of earlier agreements, as the limitations on future agreement negotiations in Article 311(3) appear stricter. However, both sections emphasize "compatibility" with UNCLOS and diverge only in describing the term. Another interpretation seems reasonable. Only the burden of proof differs if a party quotes the two paragraphs in any proceedings.

Article 311 was essential. It emphasizes the integrity of UNCLOS while leaving some space for the possible priority of regional arrangements. These exceptions may not have had the effect of making treaties unequal. Above the bottom line of non-inequality, determining the extent to which a tribunal will consider derogation compatible deserves more attention in the GGBs' rulings and from academics.

5 Conclusion

Article 281 provides an equality test by which GGBs distinguish between voluntary and compulsory proceedings. The research found that, though not perfectly consistent, existing GGB rulings on Article 281 have paid more attention to the *contents* of the parallel treaty–more specifically, to the specific arrangements for dispute settlement–than the treaty's *form*. In coordination with this equality test, GGBs also follow an approach when examining parallel treaties: the capacity of treaties to contribute to voluntary settlements. A parallel treaty between parties of balanced status with fairly distributed rights and obligations and a non-dominated negotiation history makes it easier for GGBs to assume that the parties will reach a peaceful settlement without interference.

The findings include the elements of the equality test: When GGBs examine whether a parallel treaty between the parties at issue is unequal, they mainly analyze the status of the parties, the contents of the provisions, and the negotiation history of the treaty. An accidental finding is that the analysis of these elements of unequal treaties easily touches on the substance of the case, making it difficult for the GGBs to make clear decisions on their own competence at the jurisdiction stage. This study thus also finds that necessity as a justification for expanding GGBs' jurisdiction under UNCLOS because the equality test of Article 281 is not exclusively preliminary. This constitutes an inner conflict within UNCLOS Part XV that remains unsettled until a thoroughly improved design for dispute settlement arrangements emerges. Presently, the GGBs can hardly determine their competence at the jurisdictional stage, so their attitudes toward competence rulings are comparatively indifferent. In the rulings discussed above, these GGBs based many arguments on convenience and left the core issues to a substantive stage. As to the findings on Article 311, the research finds the Conciliation's opinion on the compatibility test unidirectional, which does not represent the majority in the existing rulings, even if the comparable cases are actually limited in number.

The future implication of this research is long-lasting, since this case is predicted to have a profound influence on future UNCLOS dispute settlement. The GGBs' inconsistent interpretations of Articles 281 and 311 demonstrate a considerable range of ways in which parties can settle disputes. Their selectivity not only reduces predictability but also ensures the ongoing feasibility of the UNCLOS DSM. The shifting competence of the DSM is a product of the "living constitution," which we can reasonably expect to evolve (Klein, 2017). The responsibility of GGBs within this dynamic evolution is significant, as their rulings constitute a subsidiary source of international law through judicial creation. Their decisions on competence in compulsory proceedings contributed to the evolution of UNCLOS regimes and shaped the scope of global administrative laws.

To gain an increase in predictability in future international law and dispute settlement, it is recommended that the courts or tribunals under UNCLOS Part XV interpret Articles 281 and 311 in a systematic manner, consider the parties' statuses and their negotiating history while conducting the equality test. The contents of the provisions in Article 281 remain ambiguous without the necessary interpretation, and the traditional textualism is no longer omnipotent in the complicated practices of dispute settlement under UNCLOS. Therefore, it is also suggested that the background of a treaty in a timeline (from its negotiation till the occurrence of dispute) would help explain the contents in Article 281 when the courts or tribunals apply this article and therefore contribute to the dispute settlement. Last but not least, another recommendation is complemented that the compatibility test in Article 311 be considered in a more tolerant manner. The role of Article 311 is a bottom-line test to prevent the treaties under Article 281 from contradicting the framework of UNCLOS and derogating the integrity of the Convention. A more tolerant manner in

interpreting Article 311 would let more treaties in, which would benefit the voluntary dispute settlement mechanism under UNCLOS in a long run.

An offscreen voice is that the subsequent progress of the Timor Sea Conciliation has been encouraging. In 2018, the parties signed the 2018 Maritime Boundary Treaty, which, for the first time, demarcated maritime boundaries between the two parties and increased the revenue-sharing ratio of gas reserves in favor of Timor-Leste. The Commission delicately made its recommendations at the substantive stage, balancing the rights and obligations of the two parties. It adjusted inequality in the CMATS to some extent, ensuring that Australia did not lose too much. Some commentators regard adjustment as a model for settling future maritime claims (Schleich, 2018). However, it is still suggested that the equality test and the compatibility test be better to be dealt with in the competence decision stage, that be left to the substantive stage. After all, it is difficult to regard the late justice as justice.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

MJ: Conceptualization, Data curation, Methodology, Software, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. National Social Science Fund "Research on improving the judicial system and legal system of the Special Administrative Region" (23ZDA121).

Acknowledgments

The author thanks Prof. Wang Xing in Anhui University, Prof. Qi Xu in Jinan University and Prof. Qiuwen Wang for their inspirations and suggestions to the article.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2024.1503259/full#supplementary-material

References

Abbott, K. W. (1989). Modern international relations theory: A prospectus for international lawyers. *Yale J. Int. Law* 14, 327–364, at 359. doi: 10.1017/S0260210500113026

Abbott, K. W., and Snidal, D. (2000). *Hard and Soft Law in International Agreements* Vol. 54 (INT'L ORG), (Cambridge: International Organization), 421–427.

Acharya, S. (1994). *Maritime Delimitation and Territorial Questions between Qatar and Bahrain, Jurisdiction and Admissibility Judgment*, para 21-29. (Cham, Switzerland: Springer Press).

Adi, M. (2009). *The Application of the Law of the Sea and the Convention on Mediterranean Sea, Division for Ocean Affairs and the Law of the Sea* (New York, UN: Office of Legal Affairs Working Paper), 6.

Alkatiri, M. (2003). *Letter from Prime Minister Alkatiri to Prime Minister Howard, Annex AU-006.* (Dili, East Timor: Government of East Timor).

Allard, T. (2014). *Australia ordered to cease spying on East Timor by International Court of Justice* (Brisbane, Australia: Brisbane Times).

Allard, T. (2016). *East Timor takes Australia to UN over sea border* (Sydney, Australia: Sydney Morning Herald).

Bateman, S. (2007). UNCLOS and its limitations as the foundation for a regional maritime security regime. *KOR. J. DEFENSE ANALY* 19, 27–56, at 31. doi: 10.1080/10163270709464140

Bedrosyan, A. (2018). *The Asymmetrical Fork-in-the-Road Clause in the USMCA: Helpful and Unique.* Available online at: http://arbitrationblog.kluwerarbitration.com/2018/10/29/usmca (accessed February 23, 2020).

Beesley, A. (1983). *The Negotiating Strategy of UNCLOS III: Developed and Developing Countries as Partners: A Pattern for Future Multilateral International Conferences?* (Durham, United States: Duke University School of Law, 1983) 46 L. & CON. PROBLEMS. 183–194, at 189.

Benvenisti, E. (2014). *The Law of Global Governance* (Cambridge, UK: Cambridge University Press), 103–120.

Boyle, A. (2005). *Further Development of the Law of the Sea Convention: Mechanisms for Change* (Cambridge, UK: Cambridge University Press, 2005) 54(3) INT'L L. & COM L. QUAR. 353–384, at 369&582.

Braford, A. (2010). *When the WTO Works, and How It Fails* (Chicago: University of Chicago Public Law & Legal Theory Working Paper No. 300).

Buga, (2012). Territorial sovereignty issues in maritime disputes: A jurisdiction dilemma for law of the sea tribunals. *27 INT'L J. MARINE & COASTAL L. 59-95. citing R Wolfrum, Statement to the Informal Meeting of Legal Advisors of Ministries of Foreign Affairs (Oct. 23, 2006)*. Available at: http://www.itlos.org/fileadmin/itlos/documents/statements_of_president_/wolfrum/legal_advisors_231006_eng.pdf (accessed February 21, 2024).

Caminos, H., and Molitor, M. R. (1985). Progressive development of international law and the package deal. *AME. J. INT'L L* 79, 871–890, at 881. doi: 10.2307/2201830

Chesterman, (2006). The spy who came in from the cold war: intelligence and international law. *MICH J. INT'L L.* 27, 1071–1130, at 1072. doi: 10.2307/25059389

Collaery, B. (2013). *Australia Defends on East Timor Spy Row Raid*. (The Hague, Netherlands: Associated Press).

Craven, M. (2005). What happened to unequal treaties? The continuities of informal empire. *NORDIC J. INT'L L* 74, 335–382, at 335. doi: 10.1163/157181005774939896

Crawford, J. (2006). *The Creation of States in International Law. 2d ed*. (Oxford University Press, 2006), at 146. Yoram Dinstein. War, Aggression and Self-defense. 4th. ed. (Cambridge, UK: Cambridge University Press, 2005), 99, 104.

Davis, K. E., Fisher, A., Kingsbury, B., and Merry, S. E. (2012). *Governance by Indicators: Global Power through Quantification and Rankings* (Oxford: Oxford University Press).

De Jonge, A. (2014). From unequal treaties to differential treatment: is there a role for equality in treaty relations. *Asian J. INT'L L* 4, 125–151. doi: 10.1017/S2044251313000258

Demarest, G. B. (1996). Espionage in international law. *DEN. J. INT'L L. POL'Y* 24, 321–348, at 339.

Denby, C. (1924). *Extraterritoriality in China*. AME J. INT'L L. 18, 667. doi: 10.2307/2188842

Detter, (1966). *The Problems of Unequal Treaties* (Oxford, UK: International and Comparative Law Quarterly) INT'L L & COM. L. QUAR. 15, 1069–1084, at 1081.

Dinstein, Y. (2005). *War, Aggression and Self-defense. 4th. ed* Vol. 99 (Cambridge University Press), 104.

Fishel, W. (1952). *The End of Extraterritoriality in China* (New York: Octagon).

Fitzmaurice, G. (1986). *The Law and Procedure of the International Court of Justice* (Grotius Publications Ltd.), 441.

Frowein, J. A., and Cogens, L. (2009). *Max Planck Encyclopedia of Public International Law*. Available online at: http://www.mpepil.com (accessed February 21, 2004).

Gong, G. (1984). *The Standard of Civilization in International Society* (Oxford, UK: Clarendon Press).

Gusmao, X., Collaery, B., and Brennan, F. (2013). Case concerning East Timor Spying: *PM Xanana Gusmao calls for Australia to explain itself over ASIO raids* (The Hague, Netherlands: ABC Radio Australia Press).

Howard, J. (2003). *Letter from Prime Minister Howard to Prime Minister Alkatiri, Annex AU-007*. (Australia: John Howard Prime Ministerial Library Press).

I.C.J (2015). *Questions relating to the Seizure and Detention of Certain Documents and Data* (Netherlands: I.C.J. Press). Available at: https://www.icj-cij.org/files/case-related/156/18692.pdf.

I.C.J. Reports (1985). *Application for Revision and Interpretation of the Judgment of 24 Feb. 1982 in the Case concerning the Continental Shelf (Tunisia v. Libyan Arab Jamahiriya)*, Vol. 192, para 43.

International Court of Justice. (1986). *Military and Paramilitary Activities in and against Nicaragua (Nicar. V. U.S.)*. (The Hague, Netherlands: International Court of Justice). Judgment, 1986 I.C.J. Rep. 14 (June 27).

International Court of Justice. (2015). *Questions Relating to the Seizure and Detention of Certain Documents and Data (Timor Leste v. Austl.). Request for the Indication of Provisional Measures*, I.C.J. Rep. 18 (Mar. 3).

International Law Commission. (1980). *Vienna Convention on the Law of Treaties* (New York: United Nations).

Jia, B. (2015). *The Curious Case of Article 281: A "Super" Provision within UNCLOS?* Vol. 46 (England: Taylor & Francis Group Press, OCEAN DEVELOPMENT & INT'L L), 266–280, at 266.

Judge, I. E., Nelson, D. M., Franck, T. M., Hossain, K., Shearer, I., and Smir, H. (2007). *In the Matter of an Arbitration between Guyana and Suriname, Arbitral Tribunal Constituted Pursuant to Article 287, and in Accordance with Annex VII of the UNCLOS, para 48*.

Klein, N. (2017). The vicissitudes of dispute settlement under the law of the sea convention. *INT'L J. Mar. Coast. L* 32, 332–363, at 362. doi: 10.1163/15718085-12322045

Koskenniemi, M. (2006). *Fragmentation of International Law: Difficulties Arising from the Diversification and Expansion of International Law*. 5–14, Report of the Study Group of the International Law Commission. A/CN.4/L.682. (Helsinki, Finland: Erik Castren Institute) 5–14.

Kritsiotis, D. (1998). Reappraising policy objections to humanitarian intervention. *MICH. J. INT'L L* 19, 1005–1043, at 1041. doi: 10.2307/25059389

Ku, C. (1994). *Abolition of China's Unequal Treaties and the Search for Regional Stability in Asia* Vol. 1919-1943 (Texas: A&M University School of Law, Texas A&M Law Scholarship Press), 1919–1943, TEX. A&M L. SCH.

Lauterpacht, H. (1927). *Private Law Sources and Analogies of International Law* (Longmans, London), 155–167. Available at: https://www.aph.gov.au/Parliamentary_Business/Committees/Joint/Treaties/CMATS/Report_168_-_Certain_Maritime_Arrangements_-_Timor-Leste/section?id=committees%2Freportjnt%2F024051%2F24472.

Lowe, V. (2005). *Advocating Judicial Activism: The ITLOS Opinions of Judge Ivan Shearer*. (Australian: Australian Year Book of International Law). AUS. Y.B. INT'L L. 10, 145.

Malawer, S. S. (1977). *Imposed Treaties and International Law* (Buffalo, NY: William S. Hein & Co.), 9.

Marian, W., and Cronau, P. (2014). *Drawing the Line. Four Corners*. (UK: Four Corners Books).

Martin, L. L. (1993). "The Rational State Choice of Multilateralism," in *Multilateralism Matters: The Theory and Praxis of an Institutional Form*, vol. 91. Ed. J. G. Ruggie (Colombia: University Press), 102.

Merkouris, P. (2017). *Interpreting the Customary Rules on Interpretation*. (Cambridge, United Kingdom: Cambridge University Press, 2017) 19(1) INT'L COMM. L. R. 126-155, at 141.

MOX Plant Case. (2000). *Arbitral Tribunal Constituted Pursuant to Article 287, and Article 1 of Annex VII, of the United Nations Convention on the Law of the Sea for the Dispute Concerning the MOX Plant, International Movements of Radioactive Materials, and the Protection of the Marine Environment of the Irish Sea, Ireland v. U.K. Order No.3*.

Permanent Court of International Justice, PCIJ. (1923). *Status of Eastern Carelia. Advisory Opinion* (The Hague, Netherlands: League of Nations, 1923), P.C.I.J. Ser. B, 5, para 27.

Piggott, F. (1907). *Extraterritoriality: The Law Relating to Consular Jurisdiction and to Residence in Oriental Countries* (Hong Kong: Kelly and Walsh).

Pinto, M. C.W., Hossain, K., Oxman, B. H., Shearer, I., Watts, A., and QC, K. C. M. G. (2003). *Case concerning Land Reclamation by Singapore in and around the Straits of Johor (Malay. v. Sing.). Provisional Measures ITLOS Case No. 12* (The Hague, Netherlands: Permanent Court of Arbitration Press), para 55-57.

Prochko, V. (2018). *The International Legal View of Espionage, E-International Relations*. (Oxford, United Kingdom: Oxford University Press).

Raustiala, K. (2005). Form and substance in international agreements. *AME. J. INT'L L.* 99, 581–594. at 593. doi: 10.2307/1602292

Roben, V. (2004). The order of the UNCLOS annex VII arbitral tribunal to suspend proceedings in the case of the MOX plant at sellafield: how much jurisdiction subsidiarity? *NORDIC J. INT'L L.* 73, 223–245, at 235. doi: 10.2307/41191447

Rosenne, S. (1989). *Developments in the Law of Treaties 1945-1986* (Cambridge: Cambridge University Press), 179.

Rosenne, S. (2006). *2.* The Law and Practice of the International Court 1920–2005. 547. (Martinus Nijhoff).

Schleich, A.-M. (2018). *The Historic 2018 Maritime Boundary Treaty between Timor-Leste and Australia, ISPSW Strategy Series: Focus on Defense and International Security* (Berlin, Germany: Institut für Strategie- Politik- Sicherheits- und Wirtschaftsberatung ISPSW), Vol. 573.

Schwebel, S. M., Brownlie, I., Lowe, V., Vicuña, F. O., and Watts, A. (2006). *In the Matter of an Arbitration between Barbados and the Republic of Trinidad and Tobago, relating to the delimitation of the exclusive economic zone and the continental shelf between them, Award*, (The Hague, Netherlands: Permanent Court of Arbitration Press, 2006) para 200, 205.

Shihata, I. (1965). *The Power of the International Court to Determine its Own Jurisdiction*. (Dordrecht, Netherlands: Springer, 1965), 87.

Simpson, G. (2000). The Great Powers, Sovereign Equality and the Making of the United Nations Charter. Equality of sovereignty is a principle of the UN, but the birth of the UN merely marked the symbolic starting point of this goal. (Australian, Australian Year Book of International Law, 2000) 21(8) AUS. YB. INT'L L. 133.

Steve, C. (2016). *East Timor-Australia maritime border dispute set to be negotiated at The Hague*. (The Hague, Netherlands: ABC Radio Australia).

Tamada, D. (2019). *UNCLOS Dispute Settlement Mechanism: Contribution to the Integrity of UNCLOS*, JAP. YB. INT'L L. (Singapore: Springer Press) 61.

Tanaka, Y. (2019). *the International Law of the Sea* (Cambridge, United Kingdom: Cambridge University Press), 499.

Trinity College Library (1927). *Moore Collection for the Far East, The Unequal Treaties*. Bulletin No. 5, Issued by the American Committee for Fair Play in China (Hartford, Connecticut, USA: Trinity College Library Press).

Turner, S. (1929). *Extraterritoriality in China* (London: Longmans, Green and Co).

Van Damme, I. (2010). *Treaty Interpretation by the WTO Appellate Body* . (Oxford, United Kingdom: Oxford Journals Press, 2010) 21(3) EUR. J. INT'L L. 501-506, at 505.

Villiger, M. (2011). "The Rules on Interpretation: Misgivings, Misunderstandings, Miscarriage? The Crucible Intended by the International Law Commission," in *The Law of Treaties Beyond the Vienna Convention*. Ed. E. Cannizzaro (Oxford University Press, Oxford), 105.

Vincent, J. (1970). *The Extraterritorial System in China: Final Phase* (Cambridge, Mass: Harvard University Press).

Weisburd, A. M. (1996). The effect of treaties and other formal international acts on the customary law of human rights. *GEO. J. INT'L L COM L* 25, 99–146, at 104. doi: 10.2307/4075200

Wheaton, H. (1880). *Elements of International Law. 2 ed* (London: Boyd A. Stevens and Sons), 111.

Willoughby, W. (1922). *China at the Conference: A Report* (Johns Hopkins, Baltimore).

Wolfrum, R. (2006). *Statement to the Informal Meeting of Legal Advisors of Ministries of Foreign Affairs*. Available online at: http://www.itlos.org/fileadmin/itlos/documents/statements_of_president_/wolfrum/legal_advisors_231006_eng.pdf (accessed February 21, 2024).

Wong, D. (2003). *The Discourse of Unequal Treaties in Modern China*. (Lanham, Md.: Rowman and Littlefield Press) PAC. AFFAIR, 399–425.

Woodhead, H. (1931). Extraterritoriality in China: the Case Against Abolition *(Tientsin 1929)*. Extraterritoriality in Japan and the Diplomatic Relations Resulting in its Abolition. 1853–1899. (Tientsin, China: Yale University Press, 1931).

WTO Ministerial Conferences (2019). Key Outcomes. *World Trade Organization* (Cambridge, United Kingdom: Cambridge University Press).

Yee, S. (2013). *Conciliation and the 1982 UN Convention on the Law of the Sea*. (Taylor & Francis Group, LLC, Ocean Development & International Law Press) 44 OCEAN DEVELOPMENT & INT'L L, 315–334, at 327.

Yee, S. (2014). The south China sea arbitration (the Philippines v. China): potential jurisdictional obstacles or objections. *Chin. J. INT'L L.* 13, 682–708. doi: 10.1093/chinesejil/jmu045

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 26 November 2024
DOI 10.3389/fmars.2024.1497767

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Baiyang Xiao,
University of Szeged, Hungary
Miaomiao Yin,
Zhejiang University, China

*CORRESPONDENCE
Yu Liu
yuliu@btbu.edu.cn

RECEIVED 17 September 2024
ACCEPTED 11 November 2024
PUBLISHED 26 November 2024

CITATION
Li H and Liu Y (2024) Legal pathways for China's blue carbon conservation: a perspective of synergizing ocean and climate rule of law.
Front. Mar. Sci. 11:1497767.
doi: 10.3389/fmars.2024.1497767

COPYRIGHT
© 2024 Li and Liu. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Legal pathways for China's blue carbon conservation: a perspective of synergizing ocean and climate rule of law

Haitang Li[1] and Yu Liu[2*]

[1]Institute of Ecology and Sustainable Development, Shanghai Academy of Social Sciences, Shanghai, China, [2]School of Law, Beijing Technology and Business University, Beijing, China

Blue carbon serves as a significant natural carbon sink and presents substantial opportunities for greenhouse gas mitigation actions. This study first elucidates the importance of blue carbon conservation and its basis in international law, and then analyzes the progress and shortcomings of China's efforts in blue carbon protection in the areas of legislation, enforcement, and judicial practices related to ocean governance and climate change mitigation. Finally, from the perspective of coordinating ocean and climate governance, this paper proposes legal pathways to improve blue carbon conservation. In terms of legislation, it advocates for the explicit inclusion of the legal concept of "blue carbon" in the legal frameworks governing ocean and climate governance, and for the clarification of the legal status of "blue carbon credits". In terms of regulatory enforcement, it recommends developing a detailed implementation plan to integrate blue carbon into the China Certified Emission Reduction (CCER) system, designating a regulatory body for blue carbon trading, and establishing a multi-stakeholder governance mechanism involving government, market, and society. In the judicial realm, the paper suggests issuing judicial interpretations to clarify the scope, prerequisites, and implementation of "purchasing blue carbon credit" to prevent such purchases from becoming a "free pass" that could damage marine ecosystems

KEYWORDS

blue carbon, blue carbon ecosystems (BCEs), purchasing blue carbon credits, marine environment protection law (MEPL 2023), China, legislation, enforcement, judicial

1 Introduction

Climate change and ocean governance are common concerns that affect the fate of all humanity, and people are making various positive efforts for global greenhouse gas emission reduction and the protection of marine ecological environments (Chang et al., 2020; Wang et al., 2024). "Reducing carbon emissions" and "increasing carbon sinks" are not only the main goals of the Paris Agreement but also internationally recognized

important ways to mitigate climate change (Le Quéré et al., 2009; Wei and Wang, 2024). Blue carbon refers to the biologically driven carbon fluxes and stocks in all marine ecosystems, especially the carbon accumulation and storage in coastal ecosystems such as seagrasses, salt marshes, and mangroves (IPCC, 2019). These ecosystems exhibit high rates of carbon sequestration, act as long-term carbon sinks (IPCC, 2022a), and present significant opportunities for greenhouse gas mitigation actions (Mcleod et al., 2011; Douvere, 2021; Hilmi et al., 2023a). However, due to threats such as land use, agricultural irrigation, eutrophication, and environmental pollution, the carbon sequestration and storage capacity of blue carbon has been greatly reduced, and even releases a large amount of previously sequestered carbon, further exacerbating climate change (Waycott et al., 2009; Pendleton et al., 2012; Hejnowicz et al., 2015).

In light of the dual significance of blue carbon for ocean and climate governance, as well as the significant threats they face, the international community has begun to discuss the inclusion of blue carbon protection in marine and climate law and policy frameworks. First of all, in terms of international law, the United Nations Framework Convention on Climate Change, the Kyoto Protocol, and its REDD+ mechanism all provide an important foundation and possibility for the inclusion of blue carbon in international legal mechanisms (Orford, 2024a; Wei and Wang, 2024). Coastal blue carbon was officially included in the greenhouse gas inventory (IPCC, 2014), which is an important milestone in the international rule of law for blue carbon protection. Since then, parties to the Paris Agreement have increasingly included blue carbon projects in their NDCs (Herr and Landis, 2016; Siriwardana and Nong, 2021; Arkema et al., 2023). The United States and Australia have included blue carbon in their national greenhouse gas inventories for two consecutive times and continue to improve the content of the inventories (Vanderklift et al., 2019; Sapkota and White, 2020). In addition, some scholars have proposed including blue carbon under the Global Environment Facility, the Special Climate Change Fund, and the Adaptation Fund under the United Nations Framework Convention on Climate Change, and strengthening international cooperation (Herr et al., 2019; Feng et al., 2023).

Secondly, there are also studies on including blue carbon in domestic laws to address climate change. Australian scholars have proposed including blue carbon in Australia's Emissions Reduction Fund and integrating the ecosystem services paradigm into environmental law (Parry, 2010; Bell-James, 2023a; Howie et al., 2024); American scholars have proposed including blue carbon in market trading and incorporating it into U.S. federal laws such as the National Environmental Policy Act (NEPA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Clean Water Act (CWA), and the Coastal Zone Management Act (CZMA) (Ullman et al., 2013; Wedding et al., 2021; Orford, 2024a); Scholars from Japan, South Korea, Singapore, New Zealand, Brazil, Germany, and other countries have proposed establishing different levels of blue carbon accounting methods and trading mechanisms from their domestic laws, and including blue carbon in marine protected area legal systems to protect and restore BCEs (Nobutoki et al., 2019; Um, 2021; Duncan et al., 2022; Soares et al., 2022; Friess et al., 2023; Fink and Ratter, 2024; Stewart-Sinclair et al., 2024).

China has a long coastline and abundant blue carbon ecosystems (BCEs) (Meng et al., 2019; Zhao et al., 2022b), but they have also been impacted by human activities such as land reclamation from the sea and tidal flat reclamation, leading to severe damage to blue carbon sinks and BCEs (Xu et al., 2018; Cinar et al., 2024). Chinese scholars have mainly conducted research and proposed legal and policy recommendations in areas such as integrating blue carbon into the China Certified Emission Reduction (CCER) market (Li and Miao, 2022; Hu et al., 2024), constructing blue carbon market trading models (Cao et al., 2022; Chen et al., 2022; Li et al., 2024), enhancing the marine carbon sequestration capacity of local provinces and municipalities (Mao et al., 2023), and optimizing blue carbon management in China (Yu and Wang, 2023). However, current research predominantly focuses on the legal construction of blue carbon market mechanisms, lacking systemic and synergistic discussion on the significant role of blue carbon in global ocean governance and climate change response. Additionally, there is a scarcity of studies analyzing how the combined efforts of ocean and climate legal frameworks within a country's domestic legislative, enforcement, and judicial systems can protect blue carbon and its ecosystems.

This article proposes pathways and institutional recommendations for enhancing blue carbon protection in legislation, enforcement, and judiciary from the perspective of synergizing ocean and climate legal frameworks. First, we elucidate the importance of blue carbon protection and its international legal basis within ocean and climate governance. Second, we analyze the progress made and the institutional barriers existing in China's blue carbon protection in terms of ocean and climate law. Finally, adopting the perspective of synergistic ocean and climate legal frameworks, we offer legal pathways and suggestions for institutional improvements in China's blue carbon protection concerning legislation, enforcement, and judiciary. We hope our research can also provide a reference for blue carbon protection in other countries and contribute to the advancement of ocean and climate rule of law.

2 Background and basis in international law

Blue carbon is critically important not only for mitigating climate change but also offers numerous other benefits, including improving marine environments, enhancing water quality, protecting biodiversity, and increasing the resilience of coastal areas (Christianson et al., 2022; Bell-James et al., 2023). Consequently, multiple subfields of international environmental law, including the international law of the sea, climate law, adaptation law, pollution law, and biodiversity conservation law, are increasingly emphasizing the protection, restoration, and sustainable management of BCEs (Bustamante Beumer, 2023). However, due to the overlap among these international laws in blue carbon protection (Orford, 2024a) and in line with the focus of this research, this paper primarily concentrates on the role and

significance of blue carbon within international law of the sea and climate law. Moreover, climate change and ocean governance, as the two issues most closely related to blue carbon protection, are currently attracting significant international attention, and their protection and regulation by international law are integral to this topic (Chang et al., 2020).

Mitigating climate change through blue carbon must be based on a healthy marine ecological environment. Although BCEs account for only 0.2% of the global ocean area, they absorb and sequester half of the carbon stored in global ocean sediments (Duarte et al., 2013). Marine organisms capture more than half of the total carbon sequestered by all living organisms (Nellemann et al., 2009). If carbon is transferred from the surface layer to the deep sea (i.e., depths exceeding 1,000 meters), it can be stored and sequestered for at least 100 years (Oostdijk et al., 2022). However, human activities such as tidal flat reclamation, overfishing, and marine pollution not only lead to the loss of BCEs (Macreadie et al., 2019; Lovelock and Reef, 2020; Alongi, 2022) but also reduce the ocean's capacity to absorb and store carbon dioxide (Gruber et al., 2023; Wang et al., 2024), thereby exacerbating global climate change.

Incorporating blue carbon into climate and ocean legal frameworks can help alleviate global climate change and severe marine ecological environmental damage (Li and Miao, 2022; Bell-James, 2023a; Wei and Wang, 2024). Firstly, legislation on blue carbon protection aids in clarifying the legal basis for property rights over blue carbon and the protection of BCEs (Porter et al., 2020; Um, 2021; Stewart-Sinclair et al., 2024). Secondly, law enforcement and regulation in blue carbon protection help define the distribution of rights and responsibilities among specific administrative departments regarding the protection of BCEs (Prihatiningtyas et al., 2024) and strengthen the supervision and management of blue carbon trading market mechanisms (Cao et al., 2022; Sidik et al., 2023). Finally, judicial protection of blue carbon provides legal remedies for the loss of carbon sink functions in BCEs and compensation for marine ecological environmental damages (Basu and Mandal, 2022; Zou and Zhang, 2024).

2.1 Blue carbon and international climate law

Although the policy design and implementation specifically targeting blue carbon for climate change mitigation are still in their infancy, international laws addressing climate change have already included provisions for blue carbon protection (Hilmi et al., 2023a).

2.1.1 Blue carbon in the pre-Paris agreement era

Firstly, as the foundational convention of international climate governance, the United Nations Framework Convention on Climate Change (UNFCCC) affirms the importance of marine ecosystems in mitigating climate change. It not only defines a "sink" as any process, activity, or mechanism that removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere[1], but also includes the anthropogenic emissions by sources and removals by sinks of all greenhouse gases—including those related to the oceans—within its scope[2] (UNFCCC, 1992). These provisions have, to a certain extent, laid the international legal foundation for incorporating blue carbon into the climate governance framework.

Secondly, the Kyoto Protocol and its mechanisms of Land Use, Land-Use Change, and Forestry (LULUCF) and Reducing Emissions from Deforestation and Forest Degradation (REDD+) have established international frameworks for the sustainable management of terrestrial carbon sinks. These mechanisms allow Parties to achieve emissions reductions that can be credited through the Clean Development Mechanism (CDM), and provide measurable, reportable, and verifiable (MRV) mechanisms for forest management. They have also established voluntary carbon market mechanisms based on carbon credits aimed at forest protection (Yee, 2010; Ahmed and Glaser, 2016; Wylie et al., 2016). These legal frameworks can be directly applied to blue carbon. For instance, increasing coastal or marine biomass is akin to afforestation, which enhances carbon storage. Restoring ecosystems resembles reforestation and involves similar baseline concerns. Therefore, the Kyoto Protocol offers suitable rules for the creation and exchange of blue carbon credits (Orford, 2024a).

Thirdly, the "2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands", published in 2014, included blue carbon for the first time by providing standardized methods for measuring and reporting emissions and removals from coastal wetlands (IPCC, 2014). This inclusion enabled countries to systematically account for blue carbon in their national greenhouse gas inventories and integrate it into climate change mitigation strategies. Consequently, blue carbon was officially recognized within the global climate reporting framework, emphasizing its significance in international climate policies and agreements.

2.1.2 Blue carbon in the post-Paris agreement era

Firstly, the 2015 Paris Agreement strengthens the sustainable management and protection of significant carbon sinks and reservoirs of all greenhouse gases, including ecosystems such as oceans and forests[3] (IPCC, 2015). Moreover, blue carbon has been incorporated into the fundamental implementation tool of the Paris Agreement—the Nationally Determined Contributions (NDCs) mechanism (Herr et al., 2019; Arkema et al., 2023). Over 60 countries have included blue carbon in their NDCs emission reduction actions (Macreadie et al., 2021).

Secondly, the IPCC's "Special Report on the Ocean and Cryosphere in a Changing Climate" (SROCC) points out that ocean carbon sinks play an important role in addressing climate change (IPCC, 2019). This has led the international community to further recognize the ocean as a critical factor in climate change, gradually bringing the "Ocean-Climate" agenda into the UNFCCC.

1 Art. 1.8 of UNFCCC.

2 Art. 4.1(d) of UNFCCC.

3 Art. 5.1 of Paris Agreement.

Thirdly, the Glasgow Climate Pact explicitly links climate change mitigation with the restoration of marine carbon sink ecosystems and stipulates that the Subsidiary Body for Scientific and Technological Advice (SBSTA) under the UNFCCC will hold regular Ocean-Climate Dialogues annually starting from June 2022 (IPCC, 2021). This marks the first formal inclusion of the ocean in all areas under the UNFCCC (Lennan and Morgera, 2022). The Sharm El-Sheikh Implementation Plan continues to emphasize the role of marine ecosystems as carbon sinks and incorporates them into mitigation efforts (IPCC, 2022b). The UAE Consensus has, for the first time, included ocean issues in the "Global Stocktake" of the Paris Agreement (IPCC, 2023). Additionally, the Glasgow Pact and the Sharm El-Sheikh Implementation Plan have resolved most of the "Rule" issues related to Internationally Transferred Mitigation Outcomes (ITMOs) under the market mechanisms of Article 6 of the Paris Agreement (Jessen and Hill, 2024), providing opportunities for blue carbon credits to be included in voluntary carbon markets (Orford, 2024b).

The elevation of blue carbon's status in the United Nations climate governance is, to some extent, driven by the governance goals and models established by the Paris Agreement. Firstly, regarding governance goals, the Paris Agreement builds upon the 2°C long-term climate target set by the Convention and further proposes striving to limit the temperature increase to within 1.5°C above pre-industrial levels. This implies that, in addition to intensifying direct emission reductions, more support from carbon sink ecosystems is necessary. Consequently, blue carbon has become an internationally recognized important means of mitigating climate change (Taillardat et al., 2018; Christianson et al., 2022). Secondly, in terms of governance models, the establishment of the "bottom-up" climate governance approach in the Paris Agreement provides an institutional opportunity for Parties to explore and implement blue carbon-based climate change response actions (Herr et al., 2017; Crooks et al., 2018). Under this governance model, Parties have a high degree of autonomy in setting climate change action goals, choosing means, and selecting sectors to participate in climate actions. Therefore, blue carbon—being a solution with multiple effects such as mitigation and adaptation—naturally becomes the focus of attention for most coastal countries worldwide.

2.2 Blue carbon and international law of the sea

2.2.1 United nations convention on the law of the sea

As the "Constitution of the Oceans", the United Nations Convention on the Law of the Sea (UNCLOS) provides a legal basis for the protection of maritime rights and interests, regulating the maintenance of maritime rights and interests by countries. Although the Convention does not explicitly define blue carbon and its ecosystems, it generally calls for the protection of the marine environment and marine biological resources. For example, it states that a general obligation of parties is to protect and preserve the marine environment[4]. It requires parties to take all necessary measures, individually or jointly, in accordance with the Convention to prevent, reduce, and control pollution of the marine environment from any source[5], providing institutional guarantees for the protection and development of blue carbon.

2.2.2 International conventions on the control and prevention of marine pollution

In terms of controlling and preventing marine pollution, preliminary regulations on greenhouse gas emissions and marine environmental governance are in place. Although the UNCLOS does not explicitly address climate change issues, the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention, or LC) and its 1996 Protocol (London Protocol, or LP) regulate ocean dumping. They permit the sequestration of carbon dioxide streams from carbon capture processes in sub-seabed geological formations, marking the first regulation of carbon dioxide storage beneath the seabed (Vivian and Savio, 2024). Additionally, the 2013 amendment to the LP, which is not yet in force, includes a new Annex 4 that uses a "positive list" approach to regulate marine geoengineering techniques such as ocean fertilization. This leaves room for future legal regulation of deep-sea marine carbon sinks (Hilmi et al., 2023b).

2.2.3 International conventions on marine biodiversity conservation

In 2022, the Convention on Biological Diversity adopted the Kunming-Montreal Global Biodiversity Framework (KM-GBF)[6], which guides parties to "ensure that by 2030, at least 30% of areas of degraded terrestrial, inland water, coastal, and marine ecosystems are under effective restoration, enhancing biodiversity, ecosystem functions and services, ecological integrity, and connectivity" (Convention on Biological Diversity, 2022). This goal is an important foundation for the protection and restoration of BCEs (Bell-James et al., 2024; Fu et al., 2024). The framework also reaffirms the need to strengthen cooperation and coordinated action with existing multilateral environmental agreements, such as the UNFCCC.

Furthermore, the 2023 Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ Agreement) establishes a system of marine protected areas applicable to areas beyond national jurisdiction, including the high seas, and enhances the environmental impact assessment system for marine activities (Chang et al., 2024). These provisions will affect climate intervention activities beyond national jurisdiction and provide a legal basis for the inclusion of blue carbon projects in marine protected areas and for conducting environmental impact assessments.

4 Art. 192 of UNCLOS.

5 Art. 194(1) of UNCLOS.

6 While the KM-GBF is not an instrument of the international law of the sea per se, it plays a crucial role in the conservation of marine biodiversity and complements the objectives of the international law of the sea.

Overall, international law of the sea frameworks such as UNCLOS have paid less and later attention to climate change-related issues like blue carbon compared to the UNFCCC, which places greater emphasis on blue carbon and BCEs. This may be related to the early signing date of UNCLOS in 1982, as climate change was then an emerging issue (Elsler et al., 2022). Another important reason is the significant challenges in accounting for blue carbon, especially deep-sea blue carbon, which also restricts the development of blue carbon considerations in international law of the sea (Arkema et al., 2023; Liu et al., 2024).

3 Legal progress in blue carbon conservation

3.1 Legislation progress

3.1.1 Ocean legislation progress

The 2023 revision of the *Marine Environmental Protection Law* (MEPL2023) reflects increased emphasis and concern regarding the scope and intensity of protection for blue carbon and BCEs (Huang et al., 2024; Liu, 2024).

Firstly, the focus is on the quality and sustainability of BCEs such as mangroves, saltmarshes, and seagrasses. The MEPL 2023 newly designates "seaweed fields" and "seagrass beds" as "typical and representative marine ecosystems" and stipulates that administrative authorities have the obligation of "priority protection" for these ecosystems[7]. Additionally, MEPL 2023 provides that areas like "important marine ecosystems" are to be included in "national parks, nature reserves, or natural parks and other protected natural reserves".[8] According to the provisions of the aforementioned Article 33, BCEs such as "mangroves and seagrass beds" should be classified as "important marine ecosystems".

Secondly, by focusing on marine biodiversity, the protection of BCEs can be strengthened. The MEPL 2023 stipulates that "when marine and coastal zone resources are developed and utilized, important marine ecosystems, biological species, and biological genetic resources shall be effectively protected to maintain marine biodiversity"[9]. BCEs should be recognized as meeting the "important" criterion under this provision and receive effective protection during resource development. Furthermore, MEPL 2023 adds legal provisions for "measures such as placing artificial reefs and planting seaweed fields, seagrass beds, and corals"[10], and explicitly stipulates that "ecological repair" should focus on "improving habitats and restoring biodiversity and basic ecosystem functions", and that "ecological restoration" should be "based on natural restoration supplemented with artificial repair"[11], thereby making explicit provisions for the repair and restoration of BCEs.

Thirdly, by strengthening the prevention and control of "land-based pollutants", BCEs are protected. The MEPL 2023 stipulates that "In discharging thermal waste water into sea areas, effective measures shall be taken to ensure the conformity of the water temperature in any adjacent protected natural reserves or fishing area with the marine environment quality standards of the State and the avoidance of any damage to rare and endangered marine life and marine aquatic products by thermal pollution".[12] The inclusion of "protected natural reserves" in this provision is a new addition. As mentioned earlier, since BCEs can be incorporated into the category of "protected natural reserves", this provision can be interpreted as establishing regulations for preventing thermal pollution in BCEs.

3.1.2 Carbon market legislation progress

Since China currently lacks specific laws and regulations on climate change, the rule of law related to climate change is mainly reflected in the legal system of carbon trading (Shi and He, 2023; Wu, 2023). Therefore, this article mainly focuses on the carbon trading system, exploring the legal aspects of blue carbon in the context of climate change. China's carbon trading market comprises a mandatory Carbon Emission Allowance (CEA) trading market and a voluntary China Certified Emission Reduction (CCER) trading market. The former is limited to regulated emission enterprises, while the latter includes other societal entities beyond these enterprises and serves as an important supplement to the former (Dong et al., 2024; Li et al., 2024).

Firstly, the publication of the *Measures for the Administration of Voluntary Greenhouse Gas Emission Reduction Trading (For Trial Implementation)* in 2023 signifies the relaunch of the CCER market. These new measures revise the scope of application to include "voluntary greenhouse gas reduction projects that are conducive to carbon reduction and carbon sequestration, can avoid or reduce greenhouse gas emissions, or achieve the removal of greenhouse gases." [13] This differs from the previous enumeration of CCER projects, which was limited to "renewable energy, forestry carbon sinks, methane reduction, energy saving and efficiency improvement, etc.," thereby providing a basis for the inclusion of blue carbon sinks in CCER.

Secondly, the *Interim Regulation on the Administration of Carbon Emission Trading*, implemented in 2024 as China's first carbon trading administrative regulation—elevated from the previous legislative level of departmental rules—provides a clear legal basis for the operation and management of the national carbon market. The regulation stipulates that "key greenhouse gas emission entities included in the national carbon emission trading market

7 Art. 33 of MEPL 2023.

8 Art. 34 of MEPL 2023.

9 Art. 36(2) of MEPL 2023.

10 Art. 37 of MEPL 2023.

11 Art. 42 of MEPL 2023.

12 Art. 54 of MEPL 2023.

13 Art. 9 of Measures for the Administration of Voluntary Greenhouse Gas Emission Reduction Trading (For Trial Implementation).

14 Art. 7 of Interim Regulation on the Administration of Carbon Emission Trading.

and other entities that comply with the relevant rules of the state may participate in carbon emissions trading." [14] Although "comply with the relevant rules of the state" does not explicitly specify which regulations are included, it opens the possibility for carbon credit trading entities, such as blue carbon, to be included in the national carbon emission trading market. Additionally, the regulation allows key emission entities to "purchase certified greenhouse gas reduction volumes to offset their carbon emission allowances"[15], providing a systemic foundation for linking the voluntary carbon market for blue carbon credits with the mandatory carbon market for carbon emission allowances.

3.2 Enforcement progress

3.2.1 Ocean enforcement progress

Firstly, MEPL 2023 consolidates government responsibilities. It stipulates that "the natural resource department of the State Council" is responsible for "the restoration of national marine ecology, coastlines, and islands"[16] and "organizing the survey of marine resources."[17] Although this content does not explicitly mention blue carbon, as mentioned earlier, mangroves, saltmarshes, and seagrasses and other BCEs belong to "marine ecosystems"[18]. Therefore, the new law has mentioned to some extent the competent departments responsible for the restoration and repair of BCEs and the investigation of blue carbon. In addition, the provision that coastal county-level and higher local governments are responsible for the marine environmental protection duties within their jurisdictions[19] also strengthens the legal responsibilities of local governments for blue carbon protection.

Secondly, MEPL 2023 strengthens the regulatory system regarding pollution from construction projects affecting the marine ecological environment. The new law no longer distinguishes between coastal engineering pollution and marine engineering pollution, using a unified standard to regulate construction project pollution, thus improving the efficiency of law enforcement and supervision by local government departments (Bai et al., 2024; Huang et al., 2024). BCEs involve both coastal and marine areas (Oostdijk et al., 2022; Hilmi et al., 2023b), and the above revisions can effectively regulate the loss of BCEs caused by engineering projects such as tidal flat reclamation and land use.

Thirdly, MEPL 2023 increases administrative penalties for actions that damage "protected natural reserves." As mentioned earlier, according to the provisions of the MEPL 2023, BCEs should fall within the scope of "protected natural reserves"[20]. For those "causing damage to protected natural reserves," the new law stipulates that a fine of "between 1,000 and 10,000 yuan per square meter of the damaged area" shall be imposed[21], thereby increasing the penalty and enhancing the deterrent effect of law enforcement.

3.2.2 Carbon market enforcement progress

Firstly, the *Measures for the Administration of Voluntary Greenhouse Gas Emission Reduction Trading (Trial Implementation)* provides important executive rules for incorporating blue carbon into the voluntary emission reduction market. (1) In the general provisions section, the principle of registration is integrated throughout the entire process of voluntary emission reduction project validation, carbon credit verification, and trading in the voluntary emission reduction market. Through "registration and public disclosure," a clear basis is provided for the establishment and alteration of blue carbon credits. (2) The measures clarify the connection between the validation of voluntary emission reduction projects and the procedures for carbon credit verification, registration, and public disclosure. By publicly disclosing the compliance, completeness, and the uniqueness of the project owner to the project, they ensure the eligibility of blue carbon credit transactions after acquisition, preventing procedural defects from leading to liability for breach of contract. (3) The measures ensure effective information disclosure and coordination among project registration and trading institutions in the voluntary emission reduction market and allowance trading institutions in the national carbon market, ensuring real-time sharing of ownership changes of carbon credits in the registration systems of both types of carbon markets. For example, in the adjudication of disputes over blue carbon credit transactions, judicial authorities can apply and refer to the procedural rules such as registration and public disclosure outlined in these measures (departmental regulations), using them as the basis for resolving disputes concerning the change of ownership of blue carbon credits, the determination of the eligibility of trading entities, and the allocation of liability for breach of contract.

Secondly, the *Interim Regulation on the Administration of Carbon Emission Trading* strengthens law enforcement supervision and intensifies the prevention and severe punishment of data falsification related to carbon trading[22]. This also serves as a deterrent and preventive measure against possible fraudulent behaviors, such as data falsification, in the blue carbon trading process.

Thirdly, in 2023, the Ministry of Ecology and Environment (MEE) issued the first batch of four CCER project methodologies, including the methodology for mangrove restoration projects (CCER-14-002-V01). Since only the net increase in carbon

15 Art. 14 of Interim Regulation on the Administration of Carbon Emission Trading.

16 Art. 4 of MEPL 2023.

17 Art. 23 of MEPL 2023.

18 Art. 33 of MEPL 2023.

19 Art. 5,13,14, 18 of MEPL 2023.

20 Art. 33 and 34 of MEPL 2023.

21 Art. 96 of MEPL 2023.

22 Art. 22(2) of Interim Regulation on the Administration of Carbon Emission Trading.

emission reductions generated by projects implemented using approved methods can be traded (Li et al., 2024), the *Measures for the Administration of Voluntary Greenhouse Gas Emission Reduction Trading (Trial Implementation)* clearly stipulates that CCER projects applying for registration and their emission reductions should respectively "belong to the fields supported by the project methodologies issued by the MEE"[23] and "comply with the project methodologies issued by the MEE"[24]. The project methodology serves as the basis for the validation and implementation of CCER projects and for the accounting and verification of project emission reductions, encompassing accounting methods, monitoring methods, and requirements for project validation and emission reduction verification. The release of the mangrove restoration project methodology provides an important basis for the protection and restoration of BCEs and sufficiently demonstrates that blue carbon occupies a significant position in the relaunched CCER market.

3.3 Judicial progress

Judicial practices related to blue carbon can be divided into two types: one involves ecological damage compensation litigation for the destruction of the carbon sequestration and sink enhancement functions of BCEs; the other involves judicial practices where "purchasing blue carbon credits" is used as a means of assuming responsibility in environmental public interest litigation.

3.3.1 Judicial exploration of compensation for the loss of BCEs

MEPL 2023 stipulates the qualifications and order of priority for plaintiffs to bring claims in marine ecological environment damage compensation litigation[25], providing a legal basis for further clarifying damage compensation litigation for BCEs (Hu et al., 2024). In fact, even before MEPL 2023 came into effect, environmental public interest litigation cases concerning damage compensation for BCEs had already appeared in China's judicial practice (See Case 10 from Table 1).

For example, in June 2023, the People's Procuratorate of Ganyu District, Lianyungang City, prosecuted Chen for the crime of illegal fishing and simultaneously filed a collateral civil public interest litigation. They requested the court to order Chen to bear the cost of restoring marine fishery resources and to compensate for the partial loss of the service function of marine carbon sequestration value by purchasing blue carbon credits. The court held that "the fishing behavior not only caused the loss of marine fishery resources but also damaged the marine ecological environment, resulting in the loss of service functions such as the carbon sequestration cycle of the marine ecosystem." The final judgment was that "Chen should bear the cost of restoring marine fishery resources amounting to 310,000 yuan and compensate for the partial loss of the service function of marine carbon sequestration value of 2,808.82 yuan, which was to be used to purchase blue carbon credits" (Wei, 2023).

Another example is the administrative public interest litigation case titled "*Supervision and Protection of the Xianghai Wetland by the Tongyu County People's Procuratorate of Jilin Province*," which was released by the Supreme People's Procuratorate in 2023 as one of the "*Typical Cases of Procuratorial Organs Serving and Ensuring Carbon Peak and Carbon Neutrality*." In response to the illegal destruction of wetland ecological resources, which led to a decline in the wetlands' carbon sequestration function and carbon sink potential, the Tongyu County People's Procuratorate issued the pre-litigation procuratorial recommendation for administrative public interest litigation[26]. Upon receiving the procuratorial recommendation, the administrative agency responsible for wetland protection conducted on-site investigations. They imposed administrative fines on the violators involved in the case and, based on expert opinions, urged the violators to sow grass seeds over the 7.04 hectares of wetlands involved, thereby completing artificial restoration. Finally, the procuratorate and the administrative agency jointly inspected and approved the effectiveness of the restoration. This case demonstrates the important role of prosecutorial administrative public interest litigation in protecting and promoting the ecological service functions of wetlands, specifically carbon sequestration (The Supreme People's Procuratorate of the People's Republic of China, 2023c).

Both of the above cases are environmental public interest litigations filed in response to the destruction and loss of the carbon sequestration capacity of BCEs. These litigations aim to protect not only the marine ecological environment but also ocean carbon sequestration functions.

3.3.2 Judicial exploration of "purchasing blue carbon credits"

"Purchasing blue carbon credits" is a means of assuming responsibility in environmental civil public interest litigation and also serves as an alternative ecological restoration method that implements the concept of restorative judicial and follows natural laws. This judicial exploration, which began in coastal cities in China, is currently the primary form of blue carbon judicial practice in the country. The Supreme People's Court and the Supreme People's Procuratorate have affirmed the practice of "purchasing carbon sinks" in civil disputes and public interest litigation through judicial interpretations and official documents[27][28]. In June 2022, the

23 Art. 11(1) of Measures for the Administration of Voluntary Greenhouse Gas Emission Reduction Trading (For Trial Implementation).

24 Art. 17(1) of Measures for the Administration of Voluntary Greenhouse Gas Emission Reduction Trading (For Trial Implementation).

25 Art. 114 of MEPL 2023.

26 The pre-litigation procuratorial recommendation for administrative public interest litigation is a legal document issued by procuratorial organs to relevant administrative agencies before initiating administrative public interest litigation. Its purpose is to urge these agencies to perform their duties in accordance with the law, correct illegal acts or administrative omissions, and thus protect national interests and social public interests. If the administrative agency fails to accept the procuratorial recommendation, the procuratorial organ may file an administrative public interest lawsuit with the court.

TABLE 1 Major Judicial Cases on "Purchasing Blue Carbon Credits" in China.

No.	Case Type	Cause of Action	Decision Date	Court/Authority	Litigation/Negotiation Request	Responsibility Bearing Method	Judgment/ Execution	Source/ Case Numbers
1	Public Interest Civil Litigation Collateral to a Criminal Proceeding	Illegal Fishing Crime	2024-07	The People's Court of Xiangshan County, Zhejiang Province	Pay for ecological function and fishery resource restoration costs USD 6,830	Purchasing blue carbon credits + stock enhancement	Unknown	Criminal Case No. 289 [2024] of Zhejiang Xiangshan Court of First Instance
2			2024-07	The People's Court of Haidian District, Beijing	Pay for ecological restoration costs of USD 162,693 caused by the infringement	Voluntarily purchasing blue carbon credits as an alternative repair responsibility	Unknown	Criminal Case No. 1 [2024] of Beijing Yanqing Court of First Instance
3			2024-04	The People's Court of Xiangshan County, Zhejiang Province	Pay for ecological function and fishery resource restoration costs USD 7,868	Purchasing blue carbon credits + stock enhancement	Unknown	Criminal Case No. 125 [2024] of Zhejiang Xiangshan Court of First Instance
4			2023-01	The People's Court of Rongcheng City, Shandong Province	The defendant restores marine fishery resources through stock enhancement and seaweed farming	Planting eelgrass	The defendant has signed an eelgrass planting commission agreement with a group in Rongcheng (eelgrass planting pilot unit) and has started planting eelgrass	(The Supreme People's Procuratorate of the People's Republic of China, 2023b)
5			2023-06	The People's Court of Guannan County, Jiangsu Province	Compensate for the loss of marine fishery resources and carbon sinks	Purchasing blue carbon credits as an alternative restoration responsibility	The funds will be used for beach garbage cleaning and marine biodiversity protection	(The People's Government of Guannan County, 2023)
6		Endangering Endangered Wildlife	2023-09	The People's Court of Saihan District, Hohhot City, Inner Mongolia Autonomous Region	Pay for environmental damage compensation USD 6,311	Purchasing seawater aquaculture carbon credits through the Xiamen Marine Carbon Sink Trading Platform and obtain a marine carbon sinks verification certificate	Unknown	(The Supreme People's Procuratorate of the People's Republic of China, 2023a)
7	Criminal Proceeding	Illegal Acquisition, Transportation, and Sale of Endangered Wildlife Products	2024-04	The People's Court of Hui'an County, Fujian Province	Bear criminal responsibility	Voluntarily purchase to 1,000 tons of ocean carbon sinks and have offset, as an alternative repair for the destruction of the marine ecological environment	Proof of remorse, should be treated leniently	Criminal Case No. 831 [2023] of Fujian Anxi Court of First Instance

(Continued)

10.3389/fmars.2024.1497767

TABLE 1 Continued

No.	Case Type	Cause of Action	Decision Date	Court/Authority	Litigation/Negotiation Request	Responsibility Bearing Method	Judgment/Execution	Source/Case Numbers
8	administrative enforcement	Illegal Electric Fishing	2022-07	Fuzhou Marine and Fisheries Law Enforcement Brigade	Negotiate specific ecological environment damage compensation methods	Fisheries enforcement+ purchasing blue carbon credits	Completed	(Fuzhou Municipal Bureau of Ocean and Fisheries, 2024)
9	Environmental Civil Public Interest Litigation	Illegal Fishing with Prohibited Fishing Gear During the Closed Season	2024-03	The People's Court of Ningbo City, Zhejiang Province	Pay aquatic biological resources damage compensation USD 884	Purchasing marine fishery carbon sinks for the restoration of the damaged ecological environment	Unknown	(Ningbo Maritime Court of P.R.C, 2024)
10		Illegal Seabed Mining	2022-06	The Maritime Court in Xiamen	Pay ecological restoration costs exceeding USD 95,372	Purchasing blue carbon credits	To be fulfilled over 3 years, the defendant has purchased the first installment of 2,400t blue carbon sinks as agreed	(Fujian Court Website, 2022)

Supreme People's Court issued a judicial interpretation permitting the "purchase of forestry carbon sinks" [29]. In August 2023, the Supreme People's Procuratorate released a document stipulating that "in situations where ecological functions cannot be restored or are difficult to restore in the short term, ecological functions can be restored in public interest litigation through the form of purchasing carbon sinks." [30]

The author has searched for trial cases related to "purchasing blue carbon credits" through China Judgments Online and the official websites of local courts. As shown in Table 1, cases involving the "purchasing of blue carbon credits" are primarily civil public interest litigation collateral to criminal proceedings, environmental civil public interest litigation, and marine ecological damage compensation lawsuits. In these cases, the defendant is required to fulfill one of the alternative restoration responsibilities after damaging the marine ecological environment and the carbon sequestration function of BCEs. A few cases are criminal proceedings where the defendant voluntarily purchases blue carbon credits to express remorse and seek leniency (See Case 7 from Table 1).

4 Existing issues in blue carbon conservation

China has made numerous efforts in the protection and management of blue carbon, providing a "Chinese solution" for global ocean governance and climate change mitigation. However, as an integrated and relatively new field of research that encompasses climate change and ocean governance, influenced by various aspects such as law, politics, economy, technology, and society (Hu et al., 2024), there are still many shortcomings in the legislation, law enforcement, and judiciary aspects of China's blue carbon protection.

4.1 Legislation issues

4.1.1 Ocean legislation issues

Firstly, the legal concept of blue carbon has not been clearly defined. The absence of explicit provisions of "blue carbon" and

27 Article 21 of Interpretation by the Supreme People's Court of Several Issues Concerning the Application of Law to the Trial of Cases of Civil Disputes over Forest Resources.

28 Article 2(2) of Opinions on the Establishment and Improvement of a Collaborative Mechanism between Forestry and Grassland Administrative Law Enforcement and Procuratorial Public Interest Litigation.

29 Art. 21 of the Interpretation by the Supreme People's Court of Several Issues Concerning the Application of Law to the Trial of Cases of Civil Disputes over Forest Resources.

30 Art. 2(2) of the Opinions on the Establishment and Improvement of a Collaborative Mechanism between Forestry and Grassland Administrative Law Enforcement and Procuratorial Public Interest Litigation.

BCEs in MEPL 2023 may lead to the following issues: (1) It is not possible to clearly define the scope of protection for BCEs. For instance, it is unclear whether the protection extends to deep-sea carbon sinks and fisheries carbon sinks in addition to coastal blue carbon. The uncertainty of the scope also affects the accuracy of marine carbon sink monitoring, statistics, and accounting data. (2) It is challenging to determine the locations and boundaries of blue carbon marine protected areas, national parks, and other blue carbon protected natural reserves. Since the primary conservation objective of blue carbon marine protected areas is carbon storage, the indeterminacy of the blue carbon concept affects the concrete implementation of this system. (3) It is insufficient to reflect the emphasis and attention of marine law on climate change solutions. The absence of "blue carbon" in marine law makes it difficult to ensure that marine law takes climate change issues into account during its implementation.

Secondly, the property rights and legal attributes of blue carbon are not clearly defined. Coastal BCEs are mostly distributed along the coastlines and are governed by national laws; deep-sea carbon sinks and fisheries carbon sinks are mainly concentrated in the open ocean and deep sea, governed by international public law (Hilmi et al., 2023b). MEPL 2023 does not provide a clear definition of the coastal zone, leading to legal disputes over whether the coastal zone is state-owned or collectively owned. The unclear legal attributes of blue carbon lead to the following issues: (1) In the context of property rights conflicts or unclear definitions, the value of a significant portion of blue carbon resources will be severely underestimated, leading to the destruction of BCEs and the loss of carbon sink functions, and consequently, the tragedy of the commons (Stewart-Sinclair et al., 2024); (2) The lack of clear property rights definition hinders the implementation of blue carbon project incentive plans. For example, the unclear legal attributes of blue carbon credits may severely affect the division of responsibilities among regulatory agencies and also affect the operation of the blue carbon trading market mechanism, making it difficult to ensure the rights of all parties involved in the transaction. (3) Unclear legal attributes of blue carbon are also an important source of legal conflicts and disputes in judicial practice, and they also affect the legality of the responsibility-bearing methods for "purchasing blue carbon credits".

4.1.2 Carbon market legislation issues

Firstly, the inclusion of blue carbon in the carbon market lacks a clear legal basis. (1) China lacks specific climate change legislation, making it difficult to provide a higher-level legal basis for the carbon trading market. The *Interim Regulation on the Administration of Carbon Emission Trading*, which came into effect in 2024 (an administrative regulation), and the *Measures for the Administration of Voluntary Greenhouse Gas Emission Reduction Trading (For Trial Implementation)*, announced in 2023 (departmental rules), have provided a certain institutional space for the inclusion of blue carbon in the carbon market, but neither explicitly mentions blue carbon. This will lead to certain disputes over blue carbon in specific market transactions and judicial practices (Stewart-Sinclair et al., 2024); (2) The inclusion of blue carbon in the China Certified Emission Reduction (CCER) lacks a legal basis. According to the Law of the People's Republic of China on the Administration of Sea Areas (2002), the use of sea areas is premised on compliance with the marine functional zoning and the acquisition of sea area usage rights by the user[31]. Therefore, obtaining sea area usage rights within the project boundary is the legal basis for social forces to develop coastal blue carbon CCER projects (Li and Miao, 2022). However, since blue carbon projects have not been included in the national marine functional zoning, project owners cannot enjoy exclusive rights to blue carbon resources within the project boundary, which in turn affects the protection of rights for both parties involved in blue carbon transactions.

Secondly, there are obstacles to blue carbon data and its monitoring and accounting. The core issue of blue carbon trading is statistics and accounting (Christianson et al., 2022; Bennett et al., 2024). In 2022, the Ministry of Natural Resources issued the Marine Carbon Sink Accounting Method (HY/T 0349-2022), which systematically clarified the technical, methodological, content, and procedural aspects of China's marine carbon sink accounting, filling the gap in industry standards in this field and providing methodological support for the quantification of China's marine carbon sink resources. However, this accounting method does not include fisheries carbon sinks, leading to a lack of methodological basis for the inclusion of fisheries carbon sinks in CCER. At the same time, due to the lack of a clear administrative agency responsible for the installation and management of the near-sea data collection system (Chang et al., 2022), China has not yet fully grasped the basic data on the quantity, quality, distribution, ownership, protection, and development and utilization status of blue carbon resources, which affects the development of the blue carbon market.

4.2 Enforcement issues

4.2.1 Ocean enforcement issues

Firstly, MEPL 2023 has not clearly specified the competent authorities and their jurisdictions for monitoring blue carbon storage and carbon flux. Although the conservation and restoration of BCEs, as well as the investigation of blue carbon resources, may fall under the responsibility of the natural resources department[32], marine-based blue carbon supervision involves multiple aspects, including quantifying the current total and net carbon storage of BCEs, establishing a database of blue carbon storage and flux, valuing the carbon sequestration services of damaged BCEs and including them into the ecological damage assessment system, and regularly reporting data related to BCEs. The aforementioned blue carbon supervision also urgently needs legislative clarification. In addition, there is a lack of consistency in

31 Art. 17 of the Law of the People's Republic of China on the Administration of Sea Areas.

32 Art. 4 and 23 of MEPL 2023.

blue carbon supervision, for example, fisheries carbon sinks and coastal carbon sinks belong to different regulatory departments, and the lack of coordination between departments can lead to overlapping and contradictory rules and responsibilities, thereby affecting the overall realization of the service functions of blue carbon ecosystem services (Bell-James, 2023b).

Secondly, clear restoration measures for the carbon sequestration function of BCEs are urgently needed. Although MEPL 2023 stipulates "ecological restoration" for "damaged" marine ecosystems and "primarily natural restoration, supplemented by artificial restoration"[33], it does not clearly define the degree and standards of "damage", nor does it specify the applicable conditions and specific measures for "ecological repair" and "ecological restoration". For example, in addition to the direct restoration measures such as "planting seaweed fields, seagrass beds, and corals" stipulated by the law[34], does "ecological restoration" include alternative restoration measures such as "purchasing blue carbon credits"? In addition, when taking "ecological restoration" measures, are "carbon storage potential" and biodiversity functions considered? Because only when biodiversity and ecosystem functions and services are strengthened will ecological restoration work be effective (Bell-James et al., 2024).

Finally, the administrative penalties for damaging BCEs need to be further clarified. MEPL 2023 has increased the penalties for illegal acts that damage "protected natural reserves". Although according to the "textual interpretation" method (Chong, 2024), damaging BCEs can be subject to administrative penalties as acts of damaging protected natural reserves, according to the "the legality principle", administrative authorities need clearer legal provisions as the basis for administrative penalties (Cai, 1996). In addition, although China's local provincial and municipal fisheries law enforcement agencies have already explored the fisheries law enforcement model of "purchasing blue carbon credits" as an alternative to "administrative fines" (Fuzhou Ecological Environment Bureau, 2022), the legal basis, applicable conditions and scope of "purchasing blue carbon credits" still need to be further clarified.

4.2.2 Carbon market enforcement issues

First, the regulatory authority for blue carbon trading is unclear. According to the *Interim Regulation on the Administration of Carbon Emission Trading*[35] and the *Measures for the Administration of Voluntary Greenhouse Gas Emission Reduction Trading (For Trial Implementation)*[36], the regulatory department for carbon trading is the Ministry of Ecology and Environment. However, according to MEPL 2023, the competent department responsible for marine ecological restoration and resource survey is the Ministry of Natural Resources[37]. That is, if blue carbon can be included in the carbon market, the department responsible for monitoring, reporting and verifying data of blue carbon is the Ministry of Natural Resources, and such data is the basis for blue carbon to engage in carbon trading. However, whether the regulatory department for blue carbon trading is the Ministry of Natural Resources or the Ministry of Ecology and Environment, there is currently a certain regulatory loophole that urgently needs to be further clarified.

Second, the enforcement and supervision of blue carbon trading urgently need to be strengthened. Although the *Measures for the Administration of Voluntary Greenhouse Gas Emission Reduction Trading (Trial Implementation)* provide important rules for incorporating blue carbon into the voluntary emission reduction market, many issues remain in practice. For example, in the practice of marine carbon sink trading in areas such as Fujian, China, the "registration and public disclosure" process of some trading projects is missing (Dong et al., 2024). This may lead to unclear project boundaries, insufficient additionality demonstration, incorrect baseline scenario settings, and low feasibility of monitoring and reporting (Li and Miao, 2022), resulting in the failure to meet net carbon sink standards. This could undermine the core principles of blue carbon trading and potentially lead to "greenwashing" in blue carbon transactions. The root cause of these issues may lie in the fact that blue carbon trading is still in the exploratory stage, with underdeveloped market regulation and penalty mechanisms.

Finally, the mechanism for public participation in blue carbon trading is insufficient. Public involvement in environmental enforcement can reduce the costs for administrative departments in monitoring violations and their impacts, and alleviate some of the burden of prosecuting violators (Siedenfeld and Nugent, 2004). Additionally, social supervision, through its diversity of participants and methods, can partially compensate for the limitations of government regulation in terms of tools and effectiveness (Cao and Chang, 2023). However, due to inadequacies in data access, information disclosure, and public education, the ways in which the public can participate in the oversight of blue carbon trading remain unclear, with pathways obstructed.

4.3 Judicial issues

4.3.1 Insufficiency of compensation for the loss of BCEs

Firstly, the accounting and quantification of blue carbon function losses lack a unified standard. Although there are existing environmental public interest litigation cases related to the loss of blue carbon sequestration functions, local courts do not have clear guidelines or a unified consensus on how to calculate the value of carbon sequestration losses. The lack of standardized and normalized accounting methods results in a mismatch between the amount of "purchasing blue carbon credits" by parties and the actual degree of ecological damage they have caused. The *Marine Carbon Sink Accounting Method* provides some basis for the valuation of carbon sinks, but this method does not include fisheries carbon sinks. In judicial cases where the carbon

33 Art. 42 of MEPL 2023.

34 Art. 37 of MEPL 2023.

35 Art. 4 of Interim Regulation on the Administration of Carbon Emission Trading.

36 Art. 5 of Measures for the Administration of Voluntary Greenhouse Gas Emission Reduction Trading (For Trial Implementation).

37 Art. 4 and 23 of MEPL 2023.

sequestration function of fisheries carbon sinks has been damaged due to "illegal fishing of aquatic products," the determination of facts and remedies for compensation often rely almost entirely on scientific assessment reports, with no clear legal norms or standards. Although scientific assessment reports provide expert insights into the extent of damage, causation, and potential remedies, they cannot serve as the sole basis for legal judgments because they do not establish legal norms or standards. Due to the lack of clear legal definitions and accounting standards for "fisheries carbon sinks", different courts may interpret scientific appraisal reports differently, leading to potentially different judgments in similar cases. Meanwhile, law enforcement agencies and judicial authorities face significant challenges in holding violators legally accountable due to the absence of adequate legal framework.

Secondly, the subject responsible for litigation regarding compensation for the loss of blue carbon sequestration function remains unclear. The MEPL 2023 stipulates that the entity responsible for claiming compensation for marine ecological damage is the department exercising marine environmental supervision and management authority[38]. Under the traditional legal framework, this "government department" typically referred to the State Oceanic Administration. However, since the issuance of the *Plan for Deepening Party and State Institutional Reform* by the Central Committee of the Communist Party of China in 2018, the State Oceanic Administration was abolished, and its responsibilities for marine environmental regulation were divided between the newly established Ministry of Ecology and Environment (MEE) and the Ministry of Natural Resources (MNR). At the central level, the specific department responsible for the marine ecological damage compensation function previously held by the State Oceanic Administration has not been clearly defined, resulting in unclear government claims authority and a stalemate where various departments act independently.

Finally, the legal standing of public interest organizations in litigation is lacking. Existing legislation and judicial interpretations have yet to explicitly mention that environmental organizations can serve as qualified plaintiffs in marine environmental civil public interest litigation. Furthermore, there is no clear provision regarding the order of priority and coordination mechanisms between various potential claimants, such as government departments, procuratorial organs, and environmental organizations. This regulatory "gap" inevitably creates confusion in judicial practice, urgently requiring further refinement and clarification through future legal developments.

4.3.2 Unclear conditions for the application of "purchasing blue carbon credits"

Firstly, the types of cases where "purchasing blue carbon credits" can be applied are unclear. While there are existing judicial interpretations and official documents that stipulate the application of "purchasing blue carbon credits" in civil disputes and environmental public interest litigation[39], there are no laws, regulations, or policies that clearly define its application in criminal proceedings and administrative enforcement cases. In accordance with the principles of "legality of crime and punishment" and "rule of law in administration," the application of "purchasing blue carbon credits" in criminal and administrative cases urgently requires judicial interpretation to provide clarity. Otherwise, the misuse of "purchasing blue carbon credits" could undermine the punitive nature of criminal sanctions and potentially reduce "purchasing blue carbon credits" to a "free pass" for those who damage the marine environment (Xia, 2024).

Secondly, there is a lack of a well-established blue carbon trading mechanism. The key issue lies in whether the standards for purchasing blue carbon credits and the associated fees can achieve effective alternative restoration. Due to the current absence of a widely accepted, scientifically sound, and universally applicable basis for blue carbon accounting, the number of carbon credits "purchased" by parties often does not correspond to the extent of the damage they have caused to the marine ecological environment. For example, in judicial practice, alternative restoration is mostly carried out through "voluntary purchases," which significantly limits the standardized and objective application of "purchasing blue carbon credits" in cases of marine ecological damage.

Finally, there is a lack of follow-up supervision during the enforcement phase of judicial decisions. To ensure that funds from "purchasing blue carbon credits" are effectively utilized for marine ecological restoration and blue carbon sequestration, courts should exercise "judicial activism" (Kmiec, 2004) to monitor the implementation of blue carbon transactions, thereby ensuring that these funds genuinely contribute to marine ecological restoration. In current blue carbon judicial practice, cases are concluded once the parties have purchased blue carbon credits. Publicly available information from several courts shows that after the case is closed, it is recorded as "transaction completed and carbon credits written off." However, there is no way to determine whether the parties have subsequently achieved effective alternative restoration after purchasing the blue carbon credits. In other words, current judicial innovations in blue carbon focus more on the formality of "purchasing blue carbon credits," while the full process of how this approach achieves alternative restoration has yet to be thoroughly explored.

5 Suggestions for improving blue carbon conservation

5.1 Legislation suggestions

5.1.1 Marine legislation

Firstly, the concept of blue carbon should be clearly defined in the *Marine Environment Protection Law* (MEPL). Consider

38 Art. 114(2) of MEPL 2023.

39 Art. 21 of Interpretation by the Supreme People's Court of Several Issues Concerning the Application of Law to the Trial of Cases of Civil Disputes over Forest Resources. Article 2(2) of Opinions on the Establishment and Improvement of a Collaborative Mechanism between Forestry and Grassland Administrative Law Enforcement and Procuratorial Public Interest Litigation.

embedding the dual-carbon goals into the legislative objectives of this law. As the legislative purpose clause reflects the core values and goals of a law, it signifies the social objectives the law seeks to achieve. It is recommended to amend the first article of the legislative purpose by adding a provision to "enhance marine carbon sink capacity to address climate change." In Article 33, under "Marine Ecological Protection," a provision should be added to "enhance the carbon sequestration and storage capacity of blue carbon sinks." Additionally, this provision should clearly define the concept of blue carbon sinks.

We recommend defining blue carbon as the carbon storage and carbon flux within all marine ecosystems that can be measured, verified, and reported. On the one hand, this definition encompasses coastal blue carbon ecosystems such as mangroves, seagrass meadows, and salt marshes. This inclusion is justified because numerous methodologies for coastal blue carbon have been published (Macreadie et al., 2021; James et al., 2024; Liu et al., 2024), and the legal policies on blue carbon from major international organizations and some countries like Australia and Indonesia predominantly adopt the coastal blue carbon definition (IPCC, 2022a; Bell-James et al., 2023; Prihatiningtyas et al., 2024). On the other hand, this definition also leaves room for the future inclusion of fisheries carbon sinks and ocean carbon sinks under "blue carbon", because these types have greater carbon sequestration potential, and relevant monitoring and verification methodologies are currently being researched (Gruber et al., 2023; Jia et al., 2023).

Secondly, the legal rights of blue carbon project owners should be protected. Clearly defined and legally recognized land tenure is crucial for the successful restoration of BCEs (Fu et al., 2024; Stewart-Sinclair et al., 2024). If blue carbon projects are to obtain rights to use marine areas, it is necessary to ensure their location within marine protected areas[40]. Additionally, in light of the significant benefits of marine protected areas in enhancing carbon sequestration and mitigating climate change, many scholars have suggested incorporating blue carbon into marine protected areas and clearly defining protection objectives, boundaries, and management practices (Howard et al., 2017; Macreadie et al., 2021; Fu et al., 2024). Therefore, this paper recommends that MEPL explicitly define BCEs as "important marine ecosystems," thereby integrating them into the system of marine protected areas and other protected natural reserves[41]. Moreover, before restoration or protection projects commence, conflicts over unclear boundaries and legal rights should be resolved through transparent contractual arrangements (Bell-James et al., 2023).

5.1.2 Climate change legislation

Firstly, climate change legislation should be enacted to ensure the legality of blue carbon trading and clarify the carbon sequestration and storage functions of BCEs (Zou and Zhang, 2024). For instance, Fiji's Climate Change Act of 2021 and Chile's Framework Law on Climate Change both recognize the functions of blue carbon sinks (Keuschnigg and Higham, 2023). In addition, the legal nature of blue carbon credits needs to be clearly defined. Since blue carbon credits in market transactions must comply with the CCER requirements for project methodology, project boundaries, and additionality (Li and Miao, 2022), blue carbon credits can be defined as units that are tradable after being verified, representing a certain amount of carbon dioxide absorbed and stored from the atmosphere through the protection and restoration of BCEs by project owners. The project owners possess the rights of ownership, use, benefit, and disposal of these credits. Currently, there is debate surrounding the legal nature of blue carbon credits, including the "public right theory," "private right theory," and "dual-stage theory" (Hu et al., 2024). To ensure the smooth exercise of rights such as trading, guaranteeing, and pledging blue carbon credits, it is advisable to define them as "quasi-property rights" under private rights, as they differ from general property rights but can undergo property rights changes through "registration and public disclosure."

Secondly, the MRV system for blue carbon data should be improved. China should increase investment in fundamental research and technological innovation in blue carbon science, engage in international cooperation (Chang, 2022), and jointly conduct marine scientific research on blue carbon to enhance the global recognition of China's marine carbon sink theory and the practical operability of its monitoring and accounting methods. At the same time, leveraging modern technologies, a comprehensive marine carbon sink monitoring system should be established, utilizing remote sensing monitoring, fixed station detection, mobile monitoring, digital twins, and blockchain technologies (Dam et al., 2024; Zhao et al., 2022a). This system should be supported by digital mapping to build a BCEs database (Endris et al., 2024), as well as blue carbon stock and flux databases, enabling policymakers to conduct dynamic monitoring and assessment of BCEs across the country. Additionally, the timelines, content, and responsibility allocation for blue carbon data reporting and verification should be clearly defined. The potential of the blue carbon credit market should also be explored, and a theoretical framework and implementation plan should be developed to incorporate blue carbon into the national greenhouse gas inventory and China's Nationally Determined Contributions (NDCs) (Arkema et al., 2023).

5.2 Enforcement suggestions

5.2.1 Marine enforcement

Firstly, enhance the regulatory authority and mechanisms for BCEs. Given the importance of blue carbon monitoring and data for effective regulation (Mengis et al., 2023), it is essential to designate a competent authority responsible for monitoring blue carbon storage and flux, and to clearly define its regulatory authority. Moreover, according to existing laws, departments such as the ecological environment department, the natural resources department, and the maritime police department hold partial enforcement and regulatory authority over blue carbon within their statutory powers. Therefore, an enforcement coordination

40 Art. 17 of Law of the People's Republic of China on the Administration of Sea Areas.

41 Art. 34 of MEPL 2023.

mechanism between different departments should be established to create an efficient model for BCEs protection and pollution control. At the same time, public participation in the supervision of blue carbon protection and pollution prevention should be enhanced. Public participation is an important approach to marine environmental governance, and mechanisms for information disclosure, reporting, and public oversight of blue carbon protection enforcement should be improved.

Secondly, the principles and methods for ecological restoration measures should be clearly defined. Ecological restoration must focus on the integrity and connectivity of ecosystems (Bell-James et al., 2024). Conversely, restoring ecosystems in isolation can result in "the improvement of one ecosystem service at the expense of reducing another" (Yang et al., 2018). For instance, a decision to reintroduce tidal flows to drained wetlands may lead to the loss of freshwater bird habitats (Bell-James and Lovelock, 2019). Therefore, restoration measures must ensure that actions taken go beyond isolated attention to individual ecosystem services and instead adopt a holistic ecological approach, systematically planning restoration activities.

Finally, the conditions under which "purchasing blue carbon credits" may be applied in administrative penalties should be clarified. Since "the types of administrative penalties cannot be arbitrarily created," [42] "purchasing blue carbon credits" cannot be directly used as a form of administrative penalty. It is suggested to explore alternative pathways for its application. Specifically, based on the damage caused by the violator to the BCEs, a fine should first be imposed according to clear accounting standards. Then, through administrative negotiations, the violator can be encouraged to voluntarily purchase blue carbon credits. This "voluntary" purchase, which indirectly restores the ecosystem, aligns with the principle that "the party has actively eliminated or mitigated the harmful consequences of the illegal act[43]," allowing for the legal reduction or mitigation of administrative penalties. This method not only differs from the traditional "fine-only" enforcement approach but also indirectly protects BCEs, while providing educational and incentivizing benefits to the violator.

5.2.2 Carbon market enforcement

Firstly, the regulatory mechanism for blue carbon trading should be clearly defined. The government can establish a department specifically responsible for regulating the blue carbon market, or authorize a specialized third-party agency to carry out related oversight tasks. Climate change-related legislation should systematically establish the regulatory framework for the blue carbon trading market, with the climate change regulatory authority formulating substantive and procedural implementation rules for the market's regulatory system. Furthermore, the scope of regulation should be clarified, including the registration and disclosure of project details such as additionality, permanence, project crediting periods, and environmental impacts. Additionally, measures should be established for the verification of emissions reductions, information disclosure related to trading, on-site inspections, market access, and MRV oversight to ensure the authenticity and legality of blue carbon trading, thus preventing "greenwashing".

Secondly, a multi-stakeholder governance system should be established for supervision. The government, as the main regulatory body for blue carbon trading, should supervise and manage the operation of blue carbon projects and the trading of verified emissions reductions. Third-party verification agencies can enhance the scientific rigor of the regulatory activities for blue carbon projects, while government regulatory bodies and the private sector can collaborate through specific arrangements. Additionally, the supervisory role of market entities and social organizations should be emphasized (Fink and Ratter, 2024). For instance, during project design, public opinions should be fully considered through information disclosure and public hearing procedures, with timely feedback provided on public input. Furthermore, an expert pool system should be established, where expert opinions are issued on project validation and emissions reduction assessments for blue carbon projects. In summary, a transparent and credible system involving the participation of all stakeholders is needed to manage the blue carbon trading market (Hilmi et al., 2021).

5.3 Judicial suggestions

5.3.1 Improvements in "compensation for the loss of BCEs"

Firstly, legal recognition should be given to cases involving compensation for damages to blue carbon sequestration functions. To ensure the legality of the lawsuit, it is recommended that judicial interpretations be issued to explicitly classify "causing damage to the carbon sequestration and storage functions of blue carbon" as an illegal act of "destroying the marine ecosystem."[44] Additionally, detailed provisions should be made to specify the types of damage to BCEs, the extent of the losses incurred, and the specific methods of measurement and accounting standards.

Secondly, the entities entitled to claim compensation should be clearly defined. Given the complexity of compensation cases for blue carbon sequestration losses, it is recommended to improve the intergovernmental coordination mechanism. Specifically, the ecological environment department could serve as the primary claimant, while other departments such as the Ministry of Natural Resources, transportation, maritime affairs, fisheries, forestry, and grassland, as well as local governments at the county level and above[45], would provide coordination and support. Additionally, since such damage compensation lawsuits may overlap with administrative penalties and other administrative regulatory powers, based on the principle of "judicial restraint," it is suggested that administrative agencies exhaust all administrative control measures before filing a lawsuit for blue carbon ecological

42 Art. 16 of Law of The People's Republic of China on Administrative Penalty (2021 Revision).

43 Art. 32(1) of Law of The People's Republic of China on Administrative Penalty (2021 Revision).

44 Art. 114 (2) of MEPL 2023.

damage compensation. Moreover, the supplementary role of the procuratorial organs in filing lawsuits should be clarified—only when the administrative agencies fail to fulfill their duties and do not initiate compensation claims should the People's Procuratorate be allowed to support the lawsuit[46].

Finally, the legal standing of social organizations in litigation should be clearly defined. As an important component of the modern environmental governance system, environmental organizations should play their proper role in marine environmental protection. Granting environmental organizations, the right to sue would also help foster a mindset that encourages and supports social organizations and the public in jointly participating in blue carbon protection. Additionally, from the perspective of role division, the identity of environmental organizations as "non-regulators" means that they can only initiate environmental civil public interest litigation when both government departments and the procuratorial organs fail to bring compensation claims.

5.3.2 Regulating "Purchasing Blue Carbon Credits"

Firstly, the prerequisite for application should be the inability to directly restore the damage. According to judicial interpretations, "alternative restoration methods may be permitted when complete restoration is not possible" [47]; furthermore, judicial documents state that, when "ecological environmental damage cannot be restored," the liable party should "undertake alternative restoration under the premise of complying with relevant ecological restoration regulations, policies, and plans, to achieve equivalent restoration of the ecological environment and its services." [48] Based on these provisions, after a party causes damage to BCEs, their primary responsibility is to carry out direct restoration. Only when "complete restoration is not possible" or the party is unable to bear the responsibility for direct restoration should "purchasing blue carbon credits" be applied as an alternative restoration responsibility.

Secondly, the scope of application should primarily focus on marine-related cases. Ensuring that "purchasing blue carbon credits" occurs in marine-related cases guarantees that the object of ecological restoration is aligned with the type of ecological environment impacted by the harmful behavior, maintaining type correlation, functional substitution, and geographic proximity. On the one hand, this ensures efficiency and convenience for administrative departments and judicial authorities during enforcement and adjudication. On the other hand, it helps violators better understand the service functions of marine ecosystems, thereby maximizing the educational effect.

Finally, the implementation plan for "purchasing blue carbon credits" should be clearly defined. In terms of standards, the process should follow the technical guidelines issued by the Ministry of Natural Resources, incorporating authoritative opinions from third-party organizations and blue carbon experts. This would allow for case-by-case evaluation of the extent of damage to blue carbon sequestration functions and the calculation of carbon sinks value, ensuring that the amount of blue carbon credits purchased matches the damage caused to the marine ecological environment. During the purchasing process, transactions should be conducted with the witness and support of an authoritative local carbon emissions trading platform, ensuring smooth coordination between judicial enforcement and the blue carbon trading platform. This will ensure that the "purchasing blue carbon credits" process is legal, compliant, efficient, and transparent. In terms of tracking and supervision, it is important to enhance oversight of the funds used for alternative environmental restoration. If the funds are not fully and promptly utilized, the receiving institutions should be urged to implement corrective actions.

6 Conclusion

Blue carbon is a crucial medium that integrates ocean governance with climate change mitigation. It not only provides essential support for a healthy marine ecosystem and biodiversity but also helps mitigate global climate change through its powerful carbon sequestration capabilities. International frameworks on ocean governance and climate change mitigation have, to some extent, included provisions for blue carbon protection. This study first explains the significance of blue carbon protection and its basis in international law. It then analyzes the progress and shortcomings of China's efforts in blue carbon protection in the areas of legislation, enforcement, and judicial practices related to ocean governance and climate change mitigation.

In terms of legislation, MEPL 2023 has, to a certain extent, strengthened the protection of BCEs. However, it does not explicitly define the legal concept of "blue carbon" or the legal attributes of "blue carbon credits." In terms of enforcement, while the relaunch of the CCER market has provided a potential institutional foundation for blue carbon trading, there are still issues such as delayed regulatory enforcement of the blue carbon market and an incomplete monitoring and accounting system. On the judicial front, "purchasing blue carbon credits" as a form of assuming responsibility in environmental public interest litigation is a major innovation in China's blue carbon judicial practice. However, there are concerns about the legality and effectiveness of this method of legal responsibility.

To address these issues, this paper proposes a legal pathway for improving blue carbon protection from the perspective of coordinating ocean and climate governance. In terms of legislation, it is recommended to clarify the legal concept of "blue carbon" and the legal attributes of "blue carbon credits" in both ocean and climate governance regulations. In terms of regulatory enforcement, a detailed implementation plan for incorporating blue carbon into the CCER should be formulated, clearly defining the

45 Art. 4 and 5 of MEPL 2023.

46 Art. 114 (3) of MEPL 2023.

47 Art. 20(1) of Interpretation of the Supreme People's Court on Several Issues Concerning the Application of Law to the Trial of Environmental Civil Public Interest Litigation Cases (2020 Amendment).

48 Art. 9 of Regulations on the Management of Compensation for Ecological Damage(2022).

regulatory agencies for blue carbon trading and establishing a multi-stakeholder governance mechanism involving the government, market, and society. In terms of judicial practice, it is suggested that judicial interpretations be issued to clarify the scope, prerequisites, and implementation plan for "purchasing blue carbon credits" to prevent it from becoming a mere "free pass" for those who damage marine ecosystems.

Author contributions

HL: Conceptualization, Funding acquisition, Methodology, Writing – original draft, Writing – review & editing, Data curation, Formal analysis. YL: Data curation, Investigation, Writing – review & editing, Methodology.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was funded by the Soft Science Project from the Science and Technology Commission of Shanghai Municipality (Grant No. 23692107800).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Ahmed, N., and Glaser, M. (2016). Coastal aquaculture, mangrove deforestation and blue carbon emissions: is REDD+ a solution? *Mar. Policy* 66, 58–66. doi: 10.1016/j.marpol.2016.01.011

Alongi, D. M. (2022). Impacts of climate change on blue carbon stocks and fluxes in mangrove forests. *Forests* 13, 149. doi: 10.3390/f13020149

Arkema, K. K., Delevaux, J. M. S., Silver, J. M., Winder, S. G., SChile-Beers, L. M., Bood, N., et al. (2023). Evidence-based target setting informs blue carbon strategies for nationally determined contributions. *Nat. Ecol. Evol* 7, 1045–1059. doi: 10.1038/s41559-023-02081-1

Bai, J., Yan, Y., Cao, Y., Cui, Y., Chang, I.-S., and Wu, J. (2024). Marine ecological security shelter in China: Concept, policy framework, mechanism and implementation obstacles. *J. Environ. Manage* 351, 119662. doi: 10.1016/j.jenvman.2023.119662

Basu, A., and Mandal, S. (2022). Protecting coastal environment in India: reading laws in the context of climate change. *Asian J. Legal Education* 10, 87–100. doi: 10.1177/23220058221111299

Bell-James, J. (2023a). From the silo to the landscape: the role of law in landscape-scale restoration of coastal and marine ecosystems. *J. Environ. Law* 35, 419–436. Available at: https://academic.oup.com/jel/article-abstract/35/3/419/7252865.

Bell-James, J. (2023b). Overcoming legal barriers to coastal wetland restoration: lessons from Australia's Blue Carbon methodology. *Restor. Ecol* 31, e13780. doi: 10.1111/rec.13780

Bell-James, J., Fitzsimons, J. A., and Lovelock, C. E. (2023). Land tenure, ownership and use as barriers to coastal wetland restoration projects in Australia: recommendations and solutions. *Environ. Manage* 72, 179–189. doi: 10.1007/s00267-023-01817-w

Bell-James, J., Foster, R., Shumway, N., Lovelock, C. E., Villarreal-Rosas, J., Brown, C. J., et al. (2024). The Global Biodiversity Framework's ecosystem restoration target requires more clarity and careful legal interpretation. *Nat. Ecol. Evol* 8, 840–841. doi: 10.1038/s41559-024-02389-6

Bell-James, J., and Lovelock, C. E. (2019). Legal barriers and enablers for reintroducing tides: An Australian case study in reconverting ponded pasture for climate change mitigation. *Land Use Policy* 88, 104192. doi: 10.1016/j.landusepol.2019.104192

Bennett, M., March, A., Raguain, J., and Failler, P. (2024). Blueprint for blue carbon: lessons from Seychelles for small island states. *Oceans* 5, 81–108. doi: 10.3390/oceans5010006

Bustamante Beumer, R. (2023). *Blue Carbon in International Law: understanding challenges and opportunities for delivering multiple benefits while protecting coastal ecosystems*. Available online at: https://www.duo.uio.no/handle/10852/103488 (Accessed October 26, 2024).

Cai, D. (1996). Introduction to the administrative penalty law of China. *Columbia J. Asian Law* 10, (1996). doi: 10.7916/CJAL.V10I1.3150

Cao, X., and Chang, Y.-C. (2023). Developing the legal basis for non-state actors in China's ocean governance. *Mar. Policy* 155, 105727. doi: 10.1016/j.marpol.2023.105727

Cao, Y., Kang, Z., Bai, J., Cui, Y., Chang, I.-S., and Wu, J. (2022). How to build an efficient blue carbon trading market in China? - A study based on evolutionary game theory. *J. Cleaner Production* 367, 132867. doi: 10.1016/j.jclepro.2022.132867

Chang, Y.-C. (2022). Toward better maritime cooperation—A proposal from the chinese perspective. *Ocean Dev. Int. Law* 53, 85–104. Available at: https://www.tandfonline.com/doi/abs/10.1080/00908320.2022.2068704.

Chang, Y.-C., Javid, M., and Khan, M. I. (2024). BBNJ agreement in the purview of developing countries: A case study of Pakistan. *Mar. Policy* 165, 106201. doi: 10.1016/j.marpol.2024.106201

Chang, Y.-C., Liu, X., and Liu, S. (2022). Legal issues regarding the establishment of an offshore data collection system—A practice from China. *Mar. Policy* 140, 105077. doi: 10.1016/j.marpol.2022.105077

Chang, Y.-C., Wang, C., Khan, M. I., and Wang, N. (2020). Legal practices and challenges in addressing climate change and its impact on the oceans—A Chinese perspective. *Mar. Policy* 111, 103355. doi: 10.1016/j.marpol.2018.11.018

Chen, G., Wang, J., Xu, F., Yang, Y., Fan, M., Huang, S., et al. (2022). Progress of coastal wetland blue carbon projects in carbon market and advice on facilitating the development of blue carbon projects in China. *J. Appl. Oceanogr* 41, 177–184. doi: 10.3969/J.ISSN.2095-4972.2022.02.001

Chong, A. (2024). Restoring the environmental protection of international rivers: A case for a textual approach to interpreting global water treaties. *BU Int'l LJ* 42, 27. Available at: https://heinonline.org/hol-cgi-bin/get_pdf.cgi?handle=hein.journals/builj42&section=5.

Christianson, A. B., Cabré, A., Bernal, B., Baez, S. K., Leung, S., Pérez-Porro, A., et al. (2022). The promise of blue carbon climate solutions: where the science supports ocean-climate policy. *Front. Mar. Sci* 9. doi: 10.3389/fmars.2022.851448

Cinar, M., Hilmi, N., Arruda, G., Elsler, L., Safa, A., and van de Water, J. A. J. M. (2024). Blue carbon as a nature-based mitigation solution in temperate zones. *Sustainability* 16, 7446. doi: 10.3390/su16177446

Convention on Biological Diversity (2022). *The kunming–montreal global biodiversity framework*, CBD/COP/DEC/15/4. Montreal, Canada.

Crooks, S., Windham-Myers, L., and Troxler, T. G. (2018). Defining blue carbon: The emergence of a climate context for coastal carbon dynamics. In: *A blue carbon primer* (CRC Press). Available online at: https://www.taylorfrancis.com/chapters/edit/10.1201/9780429435362-1/defining-blue-carbon-stephen-crooks-lisamarie-windham-myers-tiffany-troxler (Accessed September 5, 2024).

Dam, B. V., Helfer, V., Kaiser, D., Sinemus, E., Staneva, J., and Zimmer, M. (2024). Towards a fair, reliable, and practical verification framework for Blue Carbon-based CDR. *Environ. Res. Lett* 19, 081004. doi: 10.1088/1748-9326/ad5fa3

Dong, J., Liu, Z., and Chen, L. (2024). Trading policy, practice and prospect on marine carbon sequestration in China. *Bull. Chin. Acad. Sci. (Chinese Version)* 39, 519–527. doi: 10.16418/j.issn.1000-3045.20230615003

Douvere, F. (2021). Blue carbon can't wait. *Science* 373, 601–601. doi: 10.1126/science.abl7128

Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I., and Marbà, N. (2013). The role of coastal plant communities for climate change mitigation and adaptation. *Nat. Clim Change* 3, 961–968. doi: 10.1038/nclimate1970

Duncan, C., Primavera, J. H., Hill, N. A. O., Wodehouse, D. C. J., and Koldewey, H. J. (2022). Potential for return on investment in rehabilitation-oriented blue carbon projects: accounting methodologies and project strategies. *Front. For. Glob. Change* 4. doi: 10.3389/ffgc.2021.775341

Elsler, L. G., Oostdijk, M., Levin, L. A., Satterthwaite, E. V., Pinsky, M. L., Crespo, G. O., et al. (2022). Protecting ocean carbon through biodiversity and climate governance. *Front. Mar. Sci* 9. doi: 10.3389/fmars.2022.880424

Endris, C., Shull, S., Woolfolk, A., Brophy, L. S., Brumbaugh, D. R., Crooks, J. A., et al. (2024). Lost and found coastal wetlands: Lessons learned from mapping estuaries across the USA. *Biol. Conserv* 299, 110779. doi: 10.1016/j.biocon.2024.110779

Feng, C., Ye, G., Zeng, J., Zeng, J., Jiang, Q., He, L., et al. (2023). Sustainably developing global blue carbon for climate change mitigation and economic benefits through international cooperation. *Nat. Commun.* 14, 6144. doi: 10.1038/s41467-023-41870-x

Fink, M., and Ratter, B. (2024). Blurring societal acceptance by lack of knowledge—insights from a German coastal population study on blue carbon. *Front. Clim* 6. doi: 10.3389/fclim.2024.1283712

Friess, D. A., Gatt, Y. M., Fung, T. K., Alemu, J. B., Bhatia, N., Case, R., et al. (2023).Blue carbon science, management and policy across a tropical urban landscape. Available online at: https://www.sciencedirect.com/science/article/pii/S0169204622002596 (Accessed September 1, 2024).

Fu, C., Steckbauer, A., Mann, H., and Duarte, C. M. (2024). Achieving the Kunming–Montreal global biodiversity targets for blue carbon ecosystems. *Nat. Rev. Earth Environ* 5, 538–552. doi: 10.1038/s43017-024-00566-6

Fujian Court Website (2022). *Xiamen maritime court hears Province's first marine civil public interest litigation filed by procuratorate*. Available online at: https://fjfy.fjcourt.gov.cn/article/detail/2022/06/id/6755869.shtml (Accessed October 28, 2024).

Fuzhou Ecological Environment Bureau (2022). *The nation's first case of blue carbon compensation for ecological damage to fisheries enforced in Yung*. Available online at: https://www.fuzhou.gov.cn/zgfzzt/shbj/xxgk/hjjg/zrst/202212/t20221216_4509311.htm (Accessed September 13, 2024).

Fuzhou Municipal Bureau of Ocean and Fisheries (2024). *Pioneering a "Carbon" path to protect fishery ecosystems*. Available online at: http://hyj.fuzhou.gov.cn/zwgk/hydt/202404/t20240426_4815604.htm (Accessed October 28, 2024).

Gruber, N., Bakker, D. C. E., DeVries, T., Gregor, L., Hauck, J., Landschützer, P., et al. (2023). Trends and variability in the ocean carbon sink. *Nat. Rev. Earth Environ* 4, 119–134. doi: 10.1038/s43017-022-00381-x

Hejnowicz, A. P., Kennedy, H., Rudd, M. A., and Huxham, M. R. (2015). Harnessing the climate mitigation, conservation and poverty alleviation potential of seagrasses: prospects for developing blue carbon initiatives and payment for ecosystem service programmes. *Front. Mar. Sci* 2. doi: 10.3389/fmars.2015.00032

Herr, D., Blum, J., Himes-Cornell, A., and Sutton-Grier, A. (2019). An analysis of the potential positive and negative livelihood impacts of coastal carbon offset projects. *J. Environ. Manage* 235, 463–479. doi: 10.1016/j.jenvman.2019.01.067

Herr, D., and Landis, E. (2016). *Coastal blue carbon ecosystems. Opportunities for nationally determined contributions. Policy brief* (Gland, Switzerland: IUCN. Washington, DC: TNC). Available online at: https://www.mangrovealliance.org/wp-content/uploads/2017/08/BC-NDCs_FINAL.pdf (Accessed September 2, 2024).

Herr, D., Unger, M., Laffoley, D., and McGivern, A. (2017). Pathways for implementation of blue carbon initiatives. *Aquat. Conserv.: Mar. Freshw. Ecosyst.*, 27, 116–129. doi: 10.1002/aqc.2793

Hilmi, N., Benitez Carranco, M. B., Broussard, D., Mathew, M., Djoundourian, S., Cassotta, S., et al. (2023a). Tropical blue carbon: solutions and perspectives for valuations of carbon sequestration. *Front. Clim* 5. doi: 10.3389/fclim.2023.1169663

Hilmi, N., Chami, R., Sutherland, M. D., Hall-Spencer, J. M., Lebleu, L., Benitez, M. B., et al. (2021). The role of blue carbon in climate change mitigation and carbon stock conservation. *Front. Clim* 3. doi: 10.3389/fclim.2021.710546

Hilmi, N., Sutherland, M., Farahmand, S., Haraldsson, G., van Doorn, E., Ernst, E., et al. (2023b). Deep sea nature-based solutions to climate change. *Front. Clim* 5. doi: 10.3389/fclim.2023.1169665

Howard, J., McLeod, E., Thomas, S., Eastwood, E., Fox, M., Wenzel, L., et al. (2017). The potential to integrate blue carbon into MPA design and management. *Aquat. Conserv* 27, 100–115. doi: 10.1002/aqc.2809

Howie, A. H., Rullens, V., Thomas, A., Kondylas, S., Russell, S. K., Reeves, S. E., et al. (2024). Seas the opportunity: multi-criteria decision analysis to identify and prioritise blue carbon wetland restoration sites. *Front. Environ. Sci* 12. doi: 10.3389/fenvs.2024.1431027

Hu, X., Shan, H., and Zhang, Q. (2024). Institutional obstacles and countermeasures to improve the chinese ocean carbon sink trading market. *Sustainability* 16, 5673. doi: 10.3390/su16135673

Huang, L., Zhou, R., and Wang, Q. (2024). Toward better governance of the marine environment: an examination of the revision of China's marine environmental protection law in 2023. *Front. Mar. Sci* 11. doi: 10.3389/fmars.2024.1398720

IPCC (2014). *2013 supplement to the 2006 IPCC guidelines for national greenhouse gas inventories* (Wetlands: IPCC). Available online at: https://www.ipcc.ch/publication/2013-supplement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories-wetlands/ (Accessed September 2, 2024).

IPCC (2015). *Paris agreement to the united nations framework convention on climate change* (Bonn: UNFCCC). Available online at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf?gad_source=1&gclid=Cj0KCQjwiuC2BhDSARIsALOVfBJ2Q1R5v-XSvcarvlaoJ5wA1H9DgnLpEq8YcBxMOc0QVgQTHrDmOpgaAlqWEALw_wcB (Accessed September 5, 2024).

IPCC (2019). *The ocean and cryosphere in a changing climate: special report of the intergovernmental panel on climate change. 1st* (Cambridge, UK and New York, NY, USA: Cambridge University Press). doi: 10.1017/9781009157964

IPCC (2021). *Glasgow Climate Pact, Decision -/CP.26, advance unedited version*. Available online at: https://unfccc.int/sites/default/files/resource/cop26_auv_2f_cover_decision.pdf?gad_source=1&gclid=Cj0KCQjwiuC2BhDSARIsALOVfBKZTFaQ2OrRH8AmhwzSpMCG59DUCvnNZZxBZPOxeBUJkM9I7ET8YhMaAoefEALw_wcB (Accessed September 5, 2024).

IPCC (2022a). *Climate change 2022: mitigation of climate change. Working group III contribution to the IPCC sixth assessment report*. Eds. P. R. Shukla, J. Skea and A. Reisinger (Geneva: IPCC).

IPCC (2022b). *Sharm el-Sheikh Implementation Plan–cop27_auv_2_cover decision*. Available online at: https://unfccc.int/sites/default/files/resource/cop27_auv_2_cover%20decision.pdf (Accessed September 8, 2024).

IPCC (2023). *Outcome of the first global stocktake-cma2023_L17_adv.pdf*. Available online at: https://unfccc.int/sites/default/files/resource/cma2023_L17_adv.pdf (Accessed September 8, 2024).

James, K., Macreadie, P. I., Burdett, H. L., Davies, I., and Kamenos, N. A. (2024). It's time to broaden what we consider a 'blue carbon ecosystem.'. *Global Change Biol* 30, e17261. doi: 10.1111/gcb.17261

Jessen, B. J., and Hill, K. (2024). Sea Grant at the Blue Carbon Frontier: Integrating Law, Science, Community Values, and Economics. *Oceanography* 37, 84. Available at: https://ersp.lib.whu.edu.cn/s/org/tos/G.https/oceanography/article/sea-grant-at-the-blue-carbon-frontier-integrating-law-science-community-values-and-economics?;x-chain-id=9qji9f5divb4.

Jia, R., Li, P., Chen, C., Liu, L., and Li, Z.-H. (2023). Shellfish-algal systems as important components of fisheries carbon sinks: Their contribution and response to climate change. *Environ. Res* 224, 115511. doi: 10.1016/j.envres.2023.115511

Keuschnigg, I., and Higham, C. (2023).How the law might be supporting a watershed moment for the oceans within the climate movement. In: *Grantham Research Institute on climate change and the environment*. Available online at: https://www.lse.ac.uk/granthaminstitute/news/how-the-law-might-be-supporting-a-watershed-moment-for-the-oceans-within-the-climate-movement/ (Accessed September 13, 2024).

Kmiec, K. D. (2004). The origin and current meanings of judicial activism. *Calif. L. Rev* 92, 1441. Available at: https://heinonline.org/HOL/Page?handle=hein.journals/calr92&id=1453&div=&collection.

Lennan, M., and Morgera, E. (2022). The glasgow climate conference (COP26). *Int. J. Mar. Coast. Law*, 37, 137–151. doi: 10.1163/15718085-bja10083

Le Quéré, C., Raupach, M. R., Canadell, J. G., Marland, G., Bopp, L., Ciais, P., et al. (2009). Trends in the sources and sinks of carbon dioxide. *Nat. Geosci* 2, 831–836. doi: 10.1038/ngeo689

Li, P., Liu, D., Liu, C., Li, X., Liu, Z., Zhu, Y., et al. (2024). Blue carbon development in China: realistic foundation, internal demands, and the construction of blue carbon market trading mode. *Front. Mar. Sci* 10. doi: 10.3389/fmars.2023.1310261

Li, X.-W., and Miao, H.-Z. (2022). How to incorporate blue carbon into the China certified emission reductions scheme: legal and policy perspectives. *Sustainability* 14, 10567. doi: 10.3390/su141710567

Liu, R. (2024). Revision of China's marine environmental protection law: history, background and improvement. *Front. Mar. Sci* 11. doi: 10.3389/fmars.2024.1409772

Liu, J., Failler, P., and Ramrattan, D. (2024). Blue carbon accounting to monitor coastal blue carbon ecosystems. *J. Environ. Manage* 352, 120008. doi: 10.1016/j.jenvman.2023.120008

Lovelock, C. E., and Reef, R. (2020). Variable impacts of climate change on blue carbon. *One Earth* 3, 195–211. doi: 10.1016/j.oneear.2020.07.010

Macreadie, P. I., Anton, A., Raven, J. A., Beaumont, N., Connolly, R. M., Friess, D. A., et al. (2019). The future of Blue Carbon science. *Nat. Commun* 10, 3998. doi: 10.1038/s41467-019-11693-w

Macreadie, P. I., Costa, M. D. P., Atwood, T. B., Friess, D. A., Kelleway, J. J., Kennedy, H., et al. (2021). Blue carbon as a natural climate solution. *Nat. Rev. Earth Environ* 2, 826–839. doi: 10.1038/s43017-021-00224-1

Mao, Z., Liu, H., and Zhang, Z. (2023). Enhancing the ocean carbon sink capacity of Shandong province, China, under the "dual carbon" goal. *Front. Mar. Sci* 10. doi: 10.3389/fmars.2023.1305035

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., et al. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Front. Ecol. Environ* 9, 552–560. doi: 10.1890/110004

Meng, W., Feagin, R. A., Hu, B., He, M., and Li, H. (2019). The spatial distribution of blue carbon in the coastal wetlands of China. *Estuarine Coast. Shelf Sci* 222, 13–20. doi: 10.1016/j.ecss.2019.03.010

Mengis, N., Paul, A., and Fernández-Méndez, M. (2023). Counting (on) blue carbon—Challenges and ways forward for carbon accounting of ecosystem-based carbon removal in marine environments. *PloS Climate* 2, e0000148. doi: 10.1371/journal.pclm.0000148

Nellemann, C., Corcoran, E., Duarte, C. M., Valdés, L., De Young, C., Fonseca, L., et al. (2009).Blue carbon: The role of healthy oceans in binding carbon. In: *UNEP arendal*. Available online at: https://core.ac.uk/download/pdf/72053306.pdf (Accessed September 2, 2024).

Ningbo Maritime Court of P.R.C (2024). *Purchasing "Blue Carbon" for marine ecological restoration: Zhejiang takes new steps in marine environmental resources adjudication*. Available online at: https://mp.weixin.qq.com/s/EQrFANB831eiGa0SmolDmg (Accessed October 28, 2024).

Nobutoki, M., Yoshihara, S., and Kuwae, T. (2019). "Carbon offset utilizing coastal waters: yokohama blue carbon project," in *Blue carbon in shallow coastal ecosystems*. Eds. T. Kuwae and M. Hori (Springer Singapore, Singapore), 321–346. doi: 10.1007/978-981-13-1295-3_12

Oostdijk, M., Elsler, L. G., Ramírez-Monsalve, P., Orach, K., and Wisz, M. S. (2022). Governing open ocean and fish carbon: perspectives and opportunities. *Front. Mar. Sci* 9. doi: 10.3389/fmars.2022.764609

Orford, A. D. (2024a). *Blue carbon law*. Available online at: https://digitalcommons.law.uga.edu/fac_artchop/1610/ (Accessed September 2, 2024).

Orford, A. D. (2024b). Blue carbon, red states, and Paris Agreement Article 6. *Front. Clim* 6. doi: 10.3389/fclim.2024.1355224

Parry, M. (2010).A property law perspective on the current Australian carbon sequestration laws, and the green paper model. Available online at: https://search.informit.org/doi/pdf/10.3316/ielapa.201204568 (Accessed March 22, 2024).

Pendleton, L., Donato, D. C., Murray, B. C., Crooks, S., Jenkins, W. A., Sifleet, S., et al. (2012). *Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems*. Available online at: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0043542 (Accessed ptember 1, 2024).

Porter, R., Katter, C., and Lee, C. (2020). *Legal issues affecting blue carbon projects on publicly-owned coastal Wetlands*. Available online at: https://docs.rwu.edu/law_ma_seagrant/96/ (Accessed September 4, 2024).

Prihatiningtyas, W., Wahyuni, I., Wijoyo, S., Rahman, A., and Noventri, A. C. (2024). Strengthening blue carbon ecosystem governance in Indonesia: opportunities for national determined contributions. *RGSA* 18, e06358–e06358. doi: 10.24857/rgsa.v18n9-085

Sapkota, Y., and White, J. R. (2020). Carbon offset market methodologies applicable for coastal wetland restoration and conservation in the United States: A review. *Sci. Total Environ* 701, 134497. doi: 10.1016/j.scitotenv.2019.134497

Shi, H., and He, X. (2023). The legal guarantee for achieving carbon peak and neutrality goals in China. *Int. J. Environ. Res. Public Health* 20, 2555. doi: 10.3390/ijerph20032555

Sidik, F., Lawrence, A., Wagey, T., Zamzani, F., and Lovelock, C. E. (2023). Blue carbon: A new paradigm of mangrove conservation and management in Indonesia. *Mar. Policy* 147, 105388. doi: 10.1016/j.marpol.2022.105388

Siedenfeld, M., and Nugent, J. S. (2004). The friendship of the people: citizen participation in environmental enforcement. *Geo. Wash. L. Rev* 73, 269. doi: 10.2139/ssrn.509105

Siriwardana, M., and Nong, D. (2021). Nationally Determined Contributions (NDCs) to decarbonise the world: A transitional impact evaluation. *Energy Economics* 97, 105184. doi: 10.1016/j.eneco.2021.105184

Soares, M. O., Bezerra, L. E. A., Copertino, M., Lopes, B. D., Barros, K. V., de, S., et al. (2022). Blue carbon ecosystems in Brazil: overview and an urgent call for conservation and restoration. *Front. Mar. Sci* 9. doi: 10.3389/fmars.2022.797411

Stewart-Sinclair, P. J., Bulmer, R. H., Macpherson, E., and Lundquist, C. J. (2024). Enabling coastal blue carbon in Aotearoa New Zealand: opportunities and challenges. *Front. Mar. Sci* 11. doi: 10.3389/fmars.2024.1290107

Taillardat, P., Friess, D. A., and Lupascu, M. (2018). Mangrove blue carbon strategies for climate change mitigation are most effective at the national scale. *Biol. Lett* 14, 20180251. doi: 10.1098/rsbl.2018.0251

The People's Government of Guannan County (2023). *Province's first case of ecological restoration through purchasing marine carbon sinks was concluded with immediate court verdict*. Available online at: http://www.guannan.gov.cn/gnzx/gnyw/content/908e32d3-f9c7-46b0-9f4e-eb5df202ab42.html (Accessed October 28, 2024).

The Supreme People's Procuratorate of the People's Republic of China (2023a). *Inner Mongolia: "Procuratorial + Carbon Sink" adds greenery to the Northern Frontier*. Available online at: https://www.spp.gov.cn/zdgz/202309/t20230907_627549.shtml (Accessed October 28, 2024).

The Supreme People's Procuratorate of the People's Republic of China (2023b). *New era procuratorial publicity week | planting "seaweed" on the seabed: major achievements in micro-innovation of Procuratorial Public Interest Litigation*. Available online at: https://www.spp.gov.cn/spp/zdgz/202306/t20230606_616570.shtml (Accessed October 28, 2024).

The Supreme People's Procuratorate of the People's Republic of China (2023c). *Typical cases of procuratorial organs serving to guarantee carbon peak and carbon neutrality_Supreme people's procuratorate of the people's republic of China*. Available online at: https://www.spp.gov.cn/spp/xwfbh/wsfbh/202306/t20230605_616289.shtml (Accessed September 11, 2024).

Ullman, R., Bilbao-Bastida, V., and Grimsditch, G. (2013). Including blue carbon in climate market mechanisms. *Ocean Coast. Manage* 83, 15–18. doi: 10.1016/j.ocecoaman.2012.02.009

Um, D.-B. (2021). Configuring legitimate blue carbon rights for coastal fishing villages based on forestry carbon MRV. *J. Coast. Res* 114, 380–384. Available at: https://meridian.allenpress.com/jcr/article-abstract/114/SI/380/471678.

UNFCCC (1992). *United nations framework convention on climate change*. Available online at: https://unfccc.int/resource/docs/convkp/conveng.pdf?gad_source=1&gclid=Cj0KCQjwiuC2BhDSARIsALOVfBIMr6qhKxhMIZpm00PVvwogJro4v1R9zxcAOmII4L5jADQmHHNw/pj8aAmS0EALw_wcB (Accessed September 5, 2024).

Vanderklift, M. A., Marcos-Martinez, R., Butler, J. R., Coleman, M., Lawrence, A., Prislan, H., et al. (2019). Constraints and opportunities for market-based finance for the restoration and protection of blue carbon ecosystems. *Mar. Policy* 107, 103429. Available at: https://www.sciencedirect.com/science/article/pii/S0308597X18304846.

Vivian, C., and Savio, L. D. (2024). *The london convention and protocol: adapting to address the ocean-climate crisis*. *Int. J. Mar. Coast. Law*, 39, 519–527. doi: 10.1163/15718085-bja10178

Wang, S., Yan, D., Wang, C., Wu, L., and Huang, Y. (2024). A bibliometric analysis of blue carbon, (1993–2023): evolution of research hot topics and trends. *Front. Mar. Sci* 11. doi: 10.3389/fmars.2024.1430545

Waycott, M., Duarte, C. M., Carruthers, T. J. B., Orth, R. J., Dennison, W. C., Olyarnik, S., et al. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proc. Natl. Acad. Sci* 106, 12377–12381. doi: 10.1073/pnas.0905620106

Wedding, L. M., Moritsch, M., Verutes, G., Arkema, K., Hartge, E., Reiblich, J., et al. (2021).Incorporating blue carbon sequestration benefits into sub-national climate policies. In: *Global environmental change*. Available online at: https://www.sciencedirect.com/science/article/pii/S0959378020307895 (Accessed September 1, 2024).

Wei, L. (2023). *An illegal fishing case in Lianyungang was sentenced in court*. Available online at: http://news.cenews.com.cn/html/2023-06/28/content_87721.htm (Accessed September 11, 2024).

Wei, X., and Wang, Q. (2024). Policy suggestions for tapping the potential of ocean carbon sinks in the context of "double carbon" goals in China. *Front. Mar. Sci* 11. doi: 10.3389/fmars.2024.1298372

Wu, S. (2023). A systematic review of climate policies in China: Evolution, effectiveness, and challenges. *Environ. Impact Assess. Rev* 99, 107030. doi: 10.1016/j.eiar.2022.107030

Wylie, L., Sutton-Grier, A. E., and Moore, A. (2016). Keys to successful blue carbon projects: Lessons learned from global case studies. *Mar. Policy* 65, 76–84. doi: 10.1016/j.marpol.2015.12.020

Xia, Z. (2024). Are China's blue carbon credits a free pass to harm its oceans? *Dialogue Earth*. Available at: https://dialogue.earth/en/ocean/are-chinas-blue-carbon-credits-a-free-pass-for-ocean-polluters/.

Xu, W., Dong, Y., Teng, X., and Zhang, P. (2018). Evaluation of the development intensity of China's coastal area. *Ocean Coast. Manage* 157, 124–129. doi: 10.1016/j.ocecoaman.2018.02.022

Yang, W., Jin, Y., Sun, T., Yang, Z., Cai, Y., and Yi, Y. (2018). Trade-offs among ecosystem services in coastal wetlands under the effects of reclamation activities. *Ecol. Indic* 92, 354–366. doi: 10.1016/j.ecolind.2017.05.005

Yee, S. (2010). *REDD and BLUE carbon: carbon payments for mangrove conservation*. Available online at: https://escholarship.org/uc/item/2bc6j8pz (Accessed September 4, 2024).

Yu, J., and Wang, Y. (2023). Evolution of blue carbon management policies in China: review, performance and prospects. *Climate Policy*. 23, 254–267. Available at: https://www.tandfonline.com/doi/abs/10.1080/14693062.2022.2142493.

Zhao, P., Ge, S., He, D., Zhong, C., Wang, B., Wang, X., et al. (2022b). Incorporating coastal blue carbon into subnational greenhouse gas inventories. *Front. Mar. Sci* 9. doi: 10.3389/fmars.2022.932984

Zhao, C., Sun, J., Gong, Y., Li, Z., and Zhou, P. (2022a). Research on the blue carbon trading market system under blockchain technology. *Energies* 15, 3134. doi: 10.3390/en15093134

Zou, K., and Zhang, L. (2024). Reconceptualising seaweed cultivation in China: climate law and policy implications. *Carbon Manage.* 15, 2349941. Available at: https://www.tandfonline.com/doi/abs/10.1080/17583004.2024.2349941.

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 09 December 2024
DOI 10.3389/fmars.2024.1483677

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Alina Miron,
Université d'Angers
Qi Xu,
Jinan University, China

*CORRESPONDENCE
Shiqi Liang
shiqi.liang@student.unsw.edu.au

RECEIVED 20 August 2024
ACCEPTED 11 November 2024
PUBLISHED 09 December 2024

CITATION
Liang S (2024) Reflections on the interpretation and application of the due diligence obligation in international climate litigation: a comparative study of *Daniel Billy* et al. *v. Australia* and the COSIS advisory opinion. *Front. Mar. Sci.* 11:1483677. doi: 10.3389/fmars.2024.1483677

COPYRIGHT
© 2024 Liang. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Reflections on the interpretation and application of the due diligence obligation in international climate litigation: a comparative study of *Daniel Billy* et al. *v. Australia* and the COSIS advisory opinion

Shiqi Liang*

Law & Justice, University of New South Wales, Sydney, NSW, Australia

This article examines the interpretation and implementation of due diligence obligation in international climate litigation and advisory opinions, specifically by comparing *Daniel Billy* et al. *v. Australia* and the COSIS Advisory Opinion. It offers insights into the definition of due diligence obligation, the criteria for breach, and the remedies available under various legal frameworks. The due diligence obligation is not solely a direct duty under a specific treaty; it also imposes a positive obligation of conduct that must be evaluated within a broader legal framework. This method facilitates systemic integration. It facilitates the citation of pertinent regulations and precedents from different domains of international law during treaty interpretation. This approach promotes the harmonization and integration of various legal systems. The essay performs a comparative analysis of two cases. It analyses the implementation of the due diligence obligation in the realms of environmental and human rights protection. The emphasis is on the legal responsibility of States about climate change. The paper ultimately outlines the significance of the two instances for the future of international environmental law and the protection of human rights, highlighting the crucial role of due diligence responsibilities in combating climate change.

KEYWORDS

climate change, COSIS advisory opinion, ITLOS, international law, *Daniel Billy* et al. *v. Australia*, UNHRC

1 Introduction

The latest developments in climate change litigation have unfolded new grounds for reflection. *Daniel Billy* et al. *v Australia* (*Daniel Billy* et al.) (United Nations Human Rights Committee, 2022) in 2021 before the United Nations Human Rights Committee (UNHRC) exemplified the first successful climate complaint before international human rights organizations. In addition, on 21 May 2024, the International Tribunal for the Law of the Sea (ITLOS) issued an advisory opinion at the request of the Commission on Small Island States, pronouncing various issues relevant to the marine environment (COSIS Advisory Opinion).

Concerning the COSIS Advisory Opinion (2024) (International Tribunal for the Law of the Sea (ITLOS), 2024), the current literature has primarily explored the evolving role of the ITLOS in addressing marine environmental issues and the legal interpretation of clauses of relevant treaties, such as the United Nations Convention on the Law of the Sea (UNCLOS) (Mingozzi, 2023). Regarding *Daniel Billy* et al., scholars focus mainly on the lack of a judgment on the right to life (Lentner and Weronika, 2024; Luporini, 2023; Mcgaughey et al., 2024). The UNHRC made the first connection between climate change and indigenous cultural rights to habitation, demonstrating that a human rights approach is viable for resolving climate litigation (United Nations Human Rights Committee, 2014). The views of the UNHRC are not binding for international or domestic courts or tribunals. However, they are regarded as having precedentially legal value by informing future climate litigation within the human rights field (Tiger, 2022).

Notably, the UNHRC and the ITLOS have adopted the concept of due diligence in their opinions. While the general context of the two cases remains identical as related to climate change, the two institutions adopted the due diligence obligation in different ways. Such a difference deserves thorough research because the due diligence obligation is not limited to the direct obligation in the text of the treaty (Boyle, 2016). However, it also creates a positive obligation of conduct, which needs to be assessed in the context of a broader regulatory framework that goes beyond the direct obligation of the treaty. In addition, the due diligence obligation open possibilities for systemic integration (Roland Holst, 2022). It means that other relevant rules and tools of international law can be referred to when interpreting a treaty. Such an approach to interpretation takes into account not only the provisions of a single treaty but also rules in areas such as international environmental law and climate law that are relevant to it, thus achieving harmonization and integration between different bodies of law. Therefore, this paper aims to fill the gap by comparing the two cases in terms of definitions, standards of breaches, and reparations.

The *Daniel Billy* et al. was selected to assess the application of the due diligence obligation. The reason was that it highlights the intersection of environmental torts and human rights in climate change in the territory of a particular State (Peel and Osofsky, 2018; Savaresi and Auz, 2019; Pietro, 2021; Savaresi and Setzer, 2022). Also, by citing international treaties like the Paris Agreement and UNFCCC, the case emphasizes the close relationship between climate change and human rights, highlighting the international obligations of States (Maguire and McGee, 2017).

Additionally, the COSIS Advisory Opinion indicates that the obligation of due diligence is often celebrated as a potent tool for advancing the development of the law of the sea (Weston, 2024). It plays a crucial role in addressing deficiencies and gaps which emerge due to advancements in scientific understanding related to oceanic threats and innovative strategies for marine conservation (Weston, 2024). Similarly, this advisory opinion directly expresses points about human rights. The focus on small island States also shares a similar perspective as the focus on indigenous groups in *Daniel Billy* et al (Hagiarian, 2023). It cannot be ignored that *Daniel Billy* et al. occurred due to climate change caused by ocean acidification and that the main focus of the advisory opinion was also on how to address ocean acidification.

The remainder of this paper will proceed as follows: Section 2 and Section 3 will analyze the two cases adopting due diligence. Section 4 compares the application of the due diligence obligation in two cases: definition, violation and remedies. This section will also focus on how they apply different areas of law to the interpretation of due diligence obligation. Section 5 will summarize the full text.

2 Reflections on the due diligence obligation in the *Daniel Billy* et al. *v. Australia*

The following sections analyze the due diligence obligation in the case of *Daniel Billy* et al. Section 2.1 examines the decision, highlighting key arguments and outcomes. Section 2.2 addresses how the UNHRC approaches due diligence in this context, analyzing its interpretation and application of international treaties and climate litigation. Section 2.3 reflects on the judgment, assessing its broader impacts on human rights and environmental law.

2.1 Decision of *Daniel Billy* et al. *v. Australia*

Daniel Billy and eight other islanders (the claimants), representing six children, submitted an appeal to the UNHRC. They asserted that Australia did not implement adequate protective measures against the effects of climate change. They contended that this inaction has rendered their homeland progressively unfit for sustainable existence. The claimants are indigenous residents from the low-lying Torres Strait Islands. A report from the Torres Strait Regional Authority (2014) says that their islands are highly vulnerable to sea level rise and extreme climate events. Climate change makes Torres Strait Island one of Australia's most at-risk.

The claimants mentioned that Australia's failure to act violated their lives and those of their children. This failure breaches several rights under the International Covenant on Civil and Political Rights (ICCPR), including the right to life, privacy, culture, family, and home. It violates children's and future generations' rights (United Nations Human Rights Committee, 2022). The claimants

also stated that Australia has offended against Article 2 of the ICCPR, which obliges countries to take positive measures to stop infringements of the above rights (United Nations Human Rights Committee, 2022).

The UNHRC found that Australia did not satisfy its due diligence obligation under the ICCPR, especially regarding the islanders' rights under Articles 17 and 27 (United Nations Human Rights Committee, 2022). Australia neither implemented effective action to shield Torres Strait Islanders' private lives, families, homes and culture from climate change nor provided adequate and timely remedies because of flooding, erosion and loss of resources, contravening their rights under Article 17 (United Nations Human Rights Committee, 2022). Moreover, the islanders' culture, which was closely linked with their traditional land and surrounding marine environment, suffered a loss. This violated their rights under Article 27 of the ICCPR (United Nations Human Rights Committee, 2022). The UNHRC also quoted similar cases from the past, such as *Ominayak v. Canada* (1984), where those same indigenous rights and environmental degradation issues were addressed. As a result, the United Nations Human Rights Committee (2022) decided that Australia failed to undertake the due diligence obligation and must take steps to forestall such invasion of human rights and provide appropriate remedies for those affected in *Daniel Billy* et al. The UNHRC has asked Australia to detail how it implements these recommendations within 180 days (United Nations Human Rights Committee, 2022).

2.2 How the UNHRC deals with the due diligence obligation in the *Daniel Billy* et al. *v. Australia*

The UNHRC's decision notably focused on Australia's adherence to the due diligence obligation towards the Torres Strait Islander community. It is vital to assess Australia's fulfilment of the obligation under the 2015 Paris Agreement and the ICCPR, especially regarding adaptation measures (Lavell et al., 2012). As a party to both agreements, Australia must fulfil due diligence by assessing risks and implementing all feasible measures that can reasonably prevent foreseeable human rights abuses and minimize the impact of such climate catastrophe (United Nations Human Rights Committee, 2022).

Articles 6, 17, 24(1), and 27 of the ICCPR include concrete obligation of States to safeguard individuals under their jurisdiction against infringement of these rights, the UNHRC underlines (United Nations Human Rights Committee, 2022). These covers are acting to stop predictable hazards and life-threatening circumstances resulting from the effects of unfavorable climate change. The United Nations Human Rights Committee (2022) emphasizes in General Comment No. 36 that human rights should not be understood as safeguarding life itself. It also includes ensuring human dignity and living conditions that enable people to live in dignity in a healthy and safe environment. Some of the most urgent and significant hazards should also be seen as threats against human rights. Such include the deterioration of the environment, the impacts of climate change, and the trend of development lacking sustainability (United Nations Human Rights Committee, 2022).

The United Nations Human Rights Committee (2022) emphasizes the need to safeguard indigenous peoples' rights so they may enjoy their unique civilization and maintain their traditional way of life, which is directly related to their region and its resources. The United Nations Human Rights Committee (2022) concluded, directly affecting these rights is Australia's failure to act effectively in the face of climate change, mainly about environmental devastation on indigenous territory and people most dependent on natural resources. The United Nations Human Rights Committee (2022) observed that Australia's adaptation measures, including building seawalls, must be revised and completed promptly. Fast and substantial implementation of these activities is essential to safeguard the homes and livelihoods of the islands from the consequences of climate change, thereby ensuring efficient fulfilment of the due diligence obligation.

Australia's inadequate adaptation measures are mainly in the following areas. First, many critical initiatives outlined in the Torres Strait Regional Adaptation and Recovery Plan 2016-21 still have not received the necessary funding (United Nations Human Rights Committee, 2022). However, several coastal protection measures have been implemented in Boigu and Poruma Island (United Nations Human Rights Committee, 2022). This exemplifies Australia's inadequacy in allocating essential resources and implementing strategic long-term measures to effectively tackle the hazards presented by climate change (Miguel Wilson et al., 2010).

The UNHRC did not express a view on Australia's climate change mitigation policies, but this organization observed that Australia's attempts to decrease greenhouse gas (GHG) emissions are inadequate. United Nations Human Rights Committee (2022) condemned Australia for persistently advocating for exploiting and utilizing fossil fuels. The government must transition to sustainable and renewable energy sources, which is necessary to exercise due diligence. The government must still adopt and execute effective policies to substantially decrease emissions following global obligations (United Nations Human Rights Committee, 2022).

2.3 Reflections on the judgment concerning the due diligence obligation

The UNHRC members Duncan Laki Muhumuza and Gentian Zyberi offered critical insights into a state's obligation of due diligence under the human rights framework. Muhumuza views failure to significantly reduce GHG emissions and halt fossil fuel reliance as direct threats to the islanders' right to life, which enriches the definition in Article 6 of the ICCPR highlighted by the Urgenda Foundation v. the State of Netherlands (The State of Netherlands v. Urgenda Foundation, 2019). The State party must protect the claimants' right to a dignified existence and prevent the blatantly predicted loss of life brought on by climate change.

Furthermore, Zyberi focused on climate action, demonstrating a need for international cooperation and ambitious state-level mitigation policies (United Nations Human Rights Committee, 2022). He argued that the global endeavor was insufficient, but more notably, those States with high output had a greater responsibility to stop exacerbating climate change hazards (Peel and Osofsky, 2018). On the other hand, Zyberi argued for the operationalization of a positive integration between mitigation and adaptation measures to effectively continue to safeguard human rights standards supported by scientific evidence (United Nations Human Rights Committee, 2022).

This ruling has important implications for international environmental law and human rights protection. It emphasizes that States have a duty to adopt due diligence obligation to protect individuals from the adverse effects of climate change, which violates fundamental human rights (Luporini, 2023). Luporini (2023) argues that this decision reinforces the need for positive measures to adapt to and mitigate climate change in order to fulfil human rights obligations.

Daniel Billy et al. (2022) (United Nations Human Rights Committee 2022) determined that due diligence was essential in preventing climatic disasters. At the same time, the legal responsibility of states to protect vulnerable populations from environmental destruction was illustrated. Furthermore, the COSIS Advisory Opinion (2024) (International Tribunal for the Law of the Sea (ITLOS), 2024) has further deepened the definition of due diligence, combining scientific knowledge and international treaties or cases to provide an adynamic and updated framework of guidance for States to address global environmental challenges more effectively.

3 The due diligence obligation in the COSIS advisory opinion on the climate change

The section below continues to an in-depth and comprehensive recasting of due diligence in international law of the sea and international climate treaties based on the COSIS Advisory Opinion. The critical points of the advisory opinion are broken out in this part. It looks at its legal ramifications, especially with relation to States including adaptive and mitigating policies in their national agendas. It underlines that ITLOS has broadened the concept of "due diligence" to include a proactive and dynamic approach; COSIS Advisory Opinion suggests that States use scientific data and international standards in their environmental policy. This study intends to open the path of knowledge on the interpretation of ITLOS due diligence and the response of the academic research community, which will be developed in section 3.3.

3.1 Main elements of the advisory opinion and Legal interpretation of due diligence obligation

The COSIS Advisory Opinion makes clear that the due diligence obligation requires States to integrate prevention and mitigation strategies into their national policies actively, not just to control direct pollution but also to address the more comprehensive environmental damage associated with climate change (Luporini, 2023). The International Tribunal for the Law of the Sea (ITLOS) (2024) highlights the importance of adopting high standards of behavior obligation due to the risk of severe and potentially irreversible damage to marine ecosystems from inadequate and lagging measures.

In the law of the sea and the international climate change regulation, the COSIS Advisory Opinion enriched the definition of due diligence. Particularly in the climate's legal framework, such as UNFCC, due diligence is the obligation of States to meet specific emission reduction targets to prevent ocean acidification. For the oceans, Articles 192 and 194 of UNCLOS obligate States to protect and preserve the marine environment from all pollution sources and ensure that their activities do not harm other States or areas beyond national jurisdiction. (International Tribunal for the Law of the Sea ITLOS, 2024). In both legal frameworks, the definition of due diligence plays a role in formulating standards for unified national conduct.

The due diligence standard in the international legal framework is dynamic and open to development. This advance is driven by changes in circumstances, advancements in scientific understanding, and improvements in technological capabilities. Therefore, the ITLOS has highlighted the critical relationship between science and the law. The ITLOS demands that States incorporate the most current scientific data and international norms into their policies. For instance, the Paris Agreement seeks to limit the global temperature increase to below 1.5 degrees Celsius above pre-industrial levels, necessitating substantial reductions in GHG emissions over the next few decades. More and more governments are taking measures, USA and China have announced their joint targets for efforts to limit GHG emissions during the next ten to fifteen years (The White House Office of the Press Secretary, 2014). From this, the ITLOS introduces a proactive and dynamic requirement that adapts to the complexities of environmental management in the age of climate change.

Furthermore, ITLOS stresses that the high risks of severe and irremediable harm to the marine environment are making it critical that there be a strict due diligence standard in place. Integrating scientific insights into environmental policies goes beyond the content of legal judgments, running through to practical implementation (International Tribunal for the Law of the Sea ITLOS, 2024). The International Tribunal for the Law of the Sea (ITLOS), 2024 underscores that it is essential to monitor and assess environmental impacts using established scientific methods under Article 204 of UNCLOS. This scientific approach ensures that environmental policies are based on accurate and up-to-date information, enhancing their effectiveness and reliability (International Tribunal for the Law of the Sea ITLOS, 2024). It further emphasizes that due diligence obligation must be flexible and adaptive to the capabilities and specific conditions of each State (International Tribunal for the Law of the Sea ITLOS, 2024). This nuanced approach allows for strategies tailored to each country's technological, economic, and resource capacities (International Tribunal for the Law of the Sea ITLOS, 2024). In particular,

developed countries may be encouraged to adopt advanced technical solutions, whereas developing countries could focus more on cost-effective measures. This interpretation raises the standard of differential responsibility in global environmental governance (Peel and Schechinger, 2017).

3.2 Impacts on the COSIS advisory opinion on the interpretation of the due diligence

Many scholars stress the importance of this advisory opinion in harmonizing international obligations and new scientific standards for the environment (Weston, 2024; Deng et al., 2024), This fusion also ensures that due diligence is not just a static duty but an active and continuing one. This viewpoint has the capacity to influence national policies and lay the groundwork for international collaboration. The advisory opinion is the foundation for forthcoming legislative and policy frameworks, especially with environmental conservation. In addition, ITLOS serves as a prime example of implementing due diligence by considering each State's technological, financial, and personnel circumstances while maintaining fairness (Paavola and Neil Adger, 2006). ITLOS offers nations comprehensive and meticulous elucidation, assisting them in fulfilling their international obligations in line with UNCLOS.

However, doubts and criticisms exist about the advisory opinion's feasibility and legal basis. Certain scholars must exhibit greater concern for the practicality of converting these extensive duties into implementable policy (Rothwell, 2023; Roland Holst, 2022). Even though these obligations have a legal basis, applying them internally might cause some problems due to their general and sometimes vague nature (Rothwell, 2023; Roland Holst, 2022). Another thing to consider in relation to procedure and substance is whether the ITLOS finds itself in trouble when it gives advisory opinions. Some scholars wonder whether the ITLOS has a sufficient legal basis to exercise its advisory functions. It has been argued that despite ITLOS justifying and reinforcing its advisory capacity through interpretations of both Article 21 of its Statute and Article 138 of its Rules in response to a request by the Sub-Regional Fisheries Commission (SRFC Advisory Opinion) (International Tribunal for the Law of the Sea (ITLOS), 2015), the present advisory opinion continues to encounter legal challenges regarding its jurisdiction (Mingozzi, 2023).

4 A comparative study on the interpretation and application of the due diligence obligation in two cases

This section explores the definition and evolution of the due diligence obligation in international law by analyzing the case of *Daniel Billy* et al. and the COSIS Advisory Opinion, highlighting the shift in the law towards a precautionary and scientific approach, particularly within climate change challenges. The boundaries of due diligence obligation violations are also explored, how States can fulfil their legal duties in the context of environmental challenges, and the importance of adaptation and mitigation remedies is discussed.

4.1 Stand of defining the due diligence obligation

This section examines *Daniel Billy* et al. and the COSIS Advisory Opinion to define international due diligence. International legal system is shifting toward a proactive preventive strategy, especially in the face of climate change. It emphasizes states taking preventive steps and safeguarding culture and human rights, especially vulnerable area. For a complete understanding of the due diligence responsibility to address climate change within law of sea and human right framework, it contrasts two cases' definitions and illustrates the relationship between domestic law and global environmental governance.

4.1.1 A high standard for setting the due diligence obligation in the *Daniel Billy* et al. *v. Australia*

The United Nations Human Rights Committee (2022) emphasizes that the due diligence obligation requires States to take positive measures to prevent foreseeable threats to human rights. This includes adopting adaptation and mitigation measures to address the negative impacts of climate change (Luporini and Savaresi, 2023). States must deploy appropriate means, use their best efforts, and do everything possible to achieve these outcomes. Mayer (2022) recalls Article 4(9) of the Paris Agreement, which requires parties to be informed of the outcomes of the global situation when communicating new Nationally Determined Contributions (NDCs). He contends that other agreement sections only offer recommendations or expectations without binding legal authority. Mayer (2022, p55) argues that Article 4 (4) of the Paris Agreement imposes varying obligations based on a country's level of development. He suggests that developed nations are expected to lead by setting broad, absolute emission reduction targets. In contrast, developing countries are encouraged to gradually adopt similar economy-wide emission reductions or limitations over time. He further observes that Article 4(3) imposes no binding commitment. The text states that each party's successive NDCs "will … reflect its highest possible ambition." This use of "will" signals an expectation rather than a legally enforceable obligation. In this way, *Daniel Billy* et al. is an entry point for establishing the expectations in the agreement as a matter of state responsibility through a human-right approach.

In this case, the due diligence obligation here reflects distinct environmental, cultural, and human rights considerations. First, the case references *Käkkäläjärvi* et al. *v. Finland* (2018) emphasizes the importance of protecting the rights of indigenous and minority communities, whose cultural and traditional practices are closely linked to the natural environment. This content enriches the definition of due diligence obligation, as it requires measures beyond the general protection of the environment, including the protection of cultural heritage and traditional ways of life (United Nations Human Rights Committee, 2022).

Moreover, due diligence requires proactive and preventive measures rather than reactive responses. Climate change is persistent and cumulative, changing and intensifying hazards daily and predictably threatening the right to life and health. This perspective aligns with the The State of Netherlands v. Urgenda

Foundation (2019), where proactive measures were considered necessary to address climate threats. However, there remains a significant concern from the claimants that has not been addressed, resulting in the continued violation of their right to life, which is potential climate hazards. Australia needs to anticipate and mitigate potential environmental risks before they cause harm. This includes responding to existing threats and anticipating future challenges posed by climate change. This approach emphasizes the forward-looking nature of due diligence and aims at prevention rather than remediation after the event (Farkas et al., 2013).

Given the severe and potentially irreversible impacts of climate change on Torres Strait Islanders and that Australia is a high total emitter and can assume a high level of responsibility, the due diligence obligation, in this case, sets a high standard (Peel and Osofsky, 2018). Australia must demonstrate that it has taken all practicable and reasonable measures to protect the Islanders' rights. This high standard reflects the urgency and significance of the risk and requires strong and effective State action (United Nations Human Rights Committee, 2022).

4.1.2 The dynamic standard for establishing due diligence obligation in the COSIS advisory opinion

The ITLOS mentions the concept of due diligence in several paragraphs in the COSIS Advisory Opinion. The first description is in paragraph 234, where the ITLOS links such a concept with the definition adopted by the Seabed Disputes Chamber. According to this approach, the definition of due diligence is "connected" to the "obligations of conduct", which is consistent with the Responsibilities and obligations of States with respect to activities in the Area (Seabed Advisory Opinion) in 2011. This view is identical to the nature of the State's due diligence obligation under Article 194, paragraph 1 (International Tribunal for the Law of the Sea ITLOS, 2024). In deconstructing the concept of due diligence, the COSIS Advisory Opinion (2024) (International Tribunal for the Law of the Sea (ITLOS), 2024) highlights the precautionary approach as essential. This statement also continues the Seabed Advisory Opinion published in 2011 (International Tribunal for the Law of the Sea ITLOS, 2024). This approach aligns with the duty of due diligence outlined in Article 194, paragraph 1. Even when scientific evidence on the likelihood and severity of potential harm to the marine environment is lacking, this obligation still applies and must be met (International Tribunal for the Law of the Sea ITLOS, 2024).

Following paragraph 234, the International Tribunal for the Law of the Sea (ITLOS) (2024) subsequently dives deeper into the concept of due diligence in paragraph 235, revealing the detailed requirements of such obligations, mainly a certain level of vigilance. In this passage, the ITLOS refers to *Argentina v. Uruguay*, adjudicated by ICJ. For instance, creating laws, setting up administrative procedures, and establishing an enforcement system are essential. These measures must be in place to regulate the relevant activities and ensure the system operates effectively. Such operators could monitor activities undertaken by public and private operators.

Immediately after that, in paragraph 239, the COSIS Advisory Opinion (International Tribunal for the Law of the Sea (ITLOS), 2024) discusses another feature of the due diligence obligation-"variable concept". This view is consistent with the Seabed Advisory Opinion. The definition of due diligence is not fixed. Consequently, articulating due diligence in broad terms is challenging (International Tribunal for the Law of the Sea ITLOS, 2024). Due diligence varies because each situation demands a unique response. Factors like scientific and technological data, international rules and standards, the level of risk, and the urgency of the issue must all be taken into account (International Tribunal for the Law of the Sea (ITLOS), 2011).

Based on the severe and continuing worsening of marine pollution caused by human emissions of greenhouse gases, the definition of the duty of due diligence arrived at by the COSIS Advisory Opinion through a reading of Article 194(1). Previous cases and advisory opinions emphasize the obligation to take all necessary steps to prevent, reduce, and control marine pollution caused by human induced GHG emissions (International Tribunal for the Law of the Sea ITLOS, 2024).

In paragraph 254 of the COSIS Advisory Opinion, The International Tribunal for the Law of the Sea (ITLOS) (2024) made it clear that the duty of due diligence in article 194, paragraph 2, is the exact nature of due diligence obligation in paragraph 1. Although the scope of application of the two paragraphs differed, both required States to take essential actions to prevent, reduce, and control marine pollution (International Tribunal for the Law of the Sea ITLOS, 2024). Paragraph 255 further stressed that this obligation of due diligence applies not only to the conduct of States but also to conduct relating to private entities. Citing the interpretation of paragraph 1, the International Tribunal for the Law of the Sea (ITLOS) (2024) held that States were not only required to take actions but also to ensure that those actions effectively responded to potential pollution risks. In paragraph 257, the ITLOS clarified the nature of the obligation of due diligence, noting that it was a mandatory requirement based on objective criteria rather than an obligation that relied on State discretion. In paragraph 258, the ITLOS confirmed that the obligation in article 194, paragraph 2, was essentially an obligation of due diligence, particularly when responding to transboundary pollution, which required States to take measures of a higher standard to avoid environmental damage to other States. The COSIS Advisory Opinion notes that Article 194(2) provides a richer interpretation of the definition of the duty of due diligence, particularly when dealing with transboundary pollution; the obligation of due diligence is not only a behavioral requirement but also an objective and strict obligation that must be fulfilled in a given situation.

In paragraph 395, the ITLOS explains that the obligation under Article 192 of the UNLOCS is an obligation of due diligence. This due diligence emphasizes the need for States to take appropriate measures to protect and preserve the marine environment, including the duty to prevent and minimize environmental damage. This is further developed in paragraph 396, where it is noted that this obligation requires not only that the State itself take action but also that it ensures that non-state actors under the jurisdiction or control of the State comply with these protective measures. In paragraph 397, the ITLOS discussed that the content

of the due diligence obligation relies on specific treaty obligations and that the nature of the obligation may evolve as environmental policy and scientific understanding evolve. Here, the ITLOS emphasized that the due diligence obligation is dynamic and requires States to continuously adapt their environmental protection strategies in the light of current scientific knowledge and technological capabilities. Overall, in international environmental law, due diligence functions as a conduct-based obligation. It demands that States consistently evaluate and address activities that could affect the marine environment. States must also take precautionary measures to prevent or reduce environmental harm (Matz-Lück and van Doorn, 2017).

In paragraph 422 of COSIS advisory opinion, the ITLOS clarified that the duty to "seek to achieve consensus" under article 63, paragraph 1, and the duty to cooperate under article 64, paragraph 1 are due diligence. This is explained, in part, by reference to the Request for Advisory Opinion submitted by the Sub-Regional Fisheries Commission, Advisory Opinion in 2015, which requires the States concerned to conduct consultations in good faith by Article 300 of the UNCLOS and to ensure that these consultations are substantive and meaningful (International Tribunal for the Law of the Sea (ITLOS), 2015). Through this interpretation, the ITLOS has clarified that the due diligence obligation goes beyond mere formal cooperation and requires the States concerned to demonstrate active and substantial efforts in practice to achieve shared conservation and resource management objectives.

From the above observation, the definition of due diligence adopted by the International Tribunal for the Law of the Sea (ITLOS) (2024) is a conduct obligation rather than result. States must take all reasonable and practical measures to prevent, minimize or control possible environmental impacts in light of the latest scientific knowledge and technological advances (Baars, 2023). This includes the continuous updating of environmental protection measures, the conduct of comprehensive environmental impact assessments prior to activities that may significantly impact the marine environment (Poisel, 2012), and the use of precautionary measures to prevent significant harm to the marine environment where scientific evidence is incomplete (International Tribunal for the Law of the Sea ITLOS, 2024, para242). In addition, the due diligence obligation requires States to cooperate with other States and regional organizations to manage shared resources and address environmental challenges (International Tribunal for the Law of the Sea ITLOS, 2024).

4.1.3 Comparing the variability of the definition in the two cases

Daniel Billy et al. and COSIS Advisory Opinion all recognize that States must implement proactive, preventive measures instead of reactive responses (Alan, 2019; James, 2024). In *Daniel Billy* et al., the UNHRC mandates Australia to establish stringent climate mitigation targets, necessitating actions that precede environmental degradation (United Nations Human Rights Committee, 2022). Similarly, the COSIS Advisory Opinion (International Tribunal for the Law of the Sea (ITLOS), 2024) mandates States to undertake all necessary measures to curb marine pollution preemptively, especially pollution exacerbated by climate change effects such as ocean warming and acidification.

The specific underpinning of due diligence is a critical element in both contexts. The Australian case stipulates that national efforts must align with the best available scientific data to ensure that mitigation and adaptation strategies are effective and appropriate for the scale of environmental risks (United Nations Human Rights Committee, 2022; International Tribunal for the Law of the Sea (ITLOS), 2011; International Tribunal for the Law of the Sea (ITLOS), 2024). However, the frameworks diverge significantly in their legal and contextual application. The *Daniel Billy* et al. operates within a national legal context where due diligence is linked directly to domestic law obligations and encompasses broader human and cultural rights, explicitly addressing the impacts on Indigenous communities (United Nations Human Rights Committee, 2022). This inclusion of cultural dimensions highlights a unique layer of legal obligation that requires measures not only for environmental protection but also for safeguarding cultural heritage (United Nations Human Rights Committee, 2022). Conversely, the COSIS Advisory Opinion is framed within the international legal context of UNCLOS, focusing on the collective responsibilities of States to manage the global marine environment (Natalie, 2020; International Tribunal for the Law of the Sea (ITLOS), 2001). This international scope broadens the due diligence requirement to include global cooperative measures and emphasizes the need for collective action in addressing transboundary environmental issues.

Furthermore, the COSIS Advisory Opinion introduces a dynamic aspect of due diligence that adjusts to technological and scientific advancements over time, reflecting an evolving standard that must accommodate ongoing changes in environmental conditions and capabilities of States (International Tribunal for the Law of the Sea ITLOS, 2024). This contrasts with the more static application in *Daniel Billy* et al., where the obligations are set within a specific national policy framework without the explicit requirement for adaptation to evolving global standards (United Nations Human Rights Committee, 2022). In *Daniel Billy* et al. and *Ioane Teitiota v New Zealand* (2020), the United Nations Human Rights Committee (2022) determined that the threat to life was potential rather than immediate. The gradual rise in sea levels and climate change were not viewed as an "imminent" or "foreseeable" threat to the right to life. However, one scientific and factual situation will not remain unchanged. Climate change is a continuing and increasing hazard to people's lives (Pachauri et al., 2014). Moreover, the threat of climate change to food security and residential security is imminent.

4.2 The degree of infringement of the due diligence obligation

This Part provides an in-depth analysis of the boundaries of due diligence obligation breaches. It explores specific applications in international law through the *Daniel Billy* et al. and the COSIS Advisory Opinion. These discussions have highlighted the importance of States' fulfilment of their legal obligations when responding to foreseeable environmental challenges. Next, a

comparison of the due diligence standards in the two cases is made to explore their application in different legal frameworks and how they complement each other while also integrating into other environmental law and human rights frameworks in order to better understand and implement this legal principle, especially in the context of global climate governance.

4.2.1 Breach of due diligence in *Daniel Billy* et al. *v. Australia* for delayed adaptation measures

In the case of *Daniel Billy* et al., the United Nations Human Rights Committee (2022), it examined whether the Australian government had fulfilled its due diligence obligation under Articles 17 and 27 of the ICCPR.

Article 17 mandates protection against arbitrary or unlawful interference with one's privacy, family, and home (United Nations Human Rights Committee, 2022). The judgment found that the Australian government failed to implement timely and effective adaptation measures to protect the Torres Strait Islands from predictable environmental impacts such as flooding and extreme weather, thereby increasing their vulnerability to such events (United Nations Human Rights Committee, 2022). The United Nations Human Rights Committee (2022) notes that the State party has not explained the delay in constructing the seawall on the island where the claimants live. The State party has not refuted the claimants' allegations regarding the specific impact of climate change on their family and private lives. The claimants describe in detail the impact of flooding on villages, ancestral burial grounds, traditional gardens, and private lives, pointing to the reduction of marine resources and the salinization of the land (United Nations Human Rights Committee, 2022). The United Nations Human Rights Committee (2022) notes that these allegations include the withering of traditional gardens as a result of seawater infiltration, the decline of nutritionally and culturally important marine species, coral bleaching and ocean acidification, and the threat to houses and ancestral burial grounds from flooding and erosion. The claimants emphasize the importance of these changes to cultural rituals and community life. Accordingly, the UNHRC found that the State party had violated the claimant's rights under Article 17 of the ICCPR.

Furthermore, Article 27 safeguards the rights of minorities to enjoy their own culture, which, for indigenous communities, is often closely linked to the environment and the sustainable use of natural resources (United Nations Human Rights Committee, 2022). The enjoyment and exercise of individuals' rights under Article 27 must be dependent on the ability of the minority group to which they belong as a whole to maintain and transmit its culture, language or religion, which is aligned with the opinion in *Käkkäläjärvi* et al. *v. Finland* (2018). The United Nations Human Rights Committee (2022) notes the claimants' claim that climate change has weakened their ability to maintain their culture, resulting in a decline in the viability of their islands and the surrounding seas and the erosion of the land and natural resources used for their traditional fishing, farming and cultural ceremonies (United Nations Human Rights Committee, 2022). The United Nations Human Rights Committee (2022) also notes that the State party has not refuted the claimants' argument that they cannot practice their culture on the Australian mainland because there is no land suitable for their traditional way of life. The United Nations Human Rights Committee (2022) considers that the impact of climate change on the claimants' community was foreseeable, as community members began to raise this issue as early as the 1990s. Although the State party has constructed seawalls on the islands where the claimants live, the delay in launching these projects demonstrates the need for more response. In conclusion, the United Nations Human Rights Committee (2022) considers The State's failure to implement timely and adequate adaptation measures violates its positive obligation to protect the cultural rights of minorities. This neglect endangers the claimants' ability to preserve their traditional way of life, pass down their culture and traditions, and use land and sea resources for future generations. Accordingly, the UNHRC found that the State party had violated the claimant's rights under Article 27 of the ICCPR (Tigre, 2022).

The above analyses of Articles 17 and 27 show that the violation of the criterion of the adequacy and timeliness of adaptive measures and the results of the hazards caused by delayed and insufficient measures are also part of the criteria for breach of due diligence. The above analyses of Articles 17 and 27, where the criterion is violated, are that the adequacy and timeliness of the adaptive measures and the results of the hazards caused by the delays and inadequacy of the measures are also part of the evaluation system.

The UNHRC decision makes clear that Specific criteria for violating the due diligence obligation go beyond mere violations of the right to life. They also cover the failure to address pre-existing and indirect impacts of climate hazards that affect other fundamental rights, such as cultural rights and the right to housing. The specific criteria for breach of the duty of due diligence in *Daniel Billy* et al. involve the failure of the State to protect not only the physical environment but also the social and cultural well-being of its population in the face of environmental challenges.

4.2.2 Breach of due diligence in COSIS advisory opinion for lack of preventive and cooperative measures

This section must address the criteria for breaching due diligence responsibilities under the COSIS Advisory Opinion as follows. According to Article 235 of UNCLOS and the general rules of State responsibility, the occurrence of damage is not a prerequisite for State responsibility (International Tribunal for the Law of the Sea ITLOS, 2024). However, if there is damage but no internationally wrongful act, responsibility cannot be established. This suggests that the question of attribution lies in a breach of the duty of due diligence and not merely in the occurrence of damage (International Tribunal for the Law of the Sea (ITLOS), 2011).

Criteria for breach of due diligence obligation are mentioned in paragraph 47 firstly, which is the obligation of States to take 'timely and adequate' measures to prevent future harm and to preserve the present State of affairs, which encompasses both positive measures of protection and negative obligations not to aggravate the status quo(International Tribunal for the Law of the Sea ITLOS, 2024). In other words, measures taken by States that do not meet the level of

timeliness and sufficiency may be found to be in breach of the due diligence obligation. The United Nations General Assembly has issued multiple statements emphasizing the detrimental effects of climate change on marine ecosystems and creatures, as well as the imperative to mitigate its impacts. Climate change-related due diligence obligation should therefore correspond to the characteristics of climate change.

Second, failure to demonstrate sufficient vigilance and enforcement may be found to be a failure to fulfil the due diligence obligation (International Tribunal for the Law of the Sea ITLOS, 2024; Pulp Mills on the River Uruguay (Argentina v. Uruguay), 2010). In paragraph 356 of the COSIS Advisory Opinion, ITLOS reaffirms the importance of vigilance and prevention, as seen in the *South China Sea arbitration* (2016). The ruling stressed that due diligence in marine environmental protection demands the implementation of proper measures and consistent vigilance in their enforcement and administrative control.

Additionally, International Tribunal for the Law of the Sea (ITLOS) (2024) highlighted specific climate mitigation goals in paragraph 77. These include "limiting global warming to 1.5°C" and achieving a 43 percent reduction in global greenhouse gas emissions by 2030 in Sharm el-Sheikh Implementation Plan (United Nations Framework Convention on Climate Change (UNFCCC), 2022), which is aligned with the Paris Agreement. If current NDCs collectively fall short of this target, States would fail to respond to their due diligence obligation. However, in the COSIS Advisory Opinions, the ITLOS is unlikely to specify what measures States need to take or how much more they need to do. This is especially true since the Paris Agreement allows States to freely determine the content of their NDCs as long as they are progressively ambitious. At the same time, it also emphasized the specific content of the duty of due diligence needs to be assessed on a case-by-case basis, and failure to take the 'necessary measures' in a given situation constitutes a breach of the duty of due diligence. This flexibility allows for the progressive development of treaty obligations in a broader normative context. However, due diligence is unlikely to exceed the existing climate change targets.

In the International Tribunal for the Law of the Sea (ITLOS) (2024)'s view of paragraph 297, Part XII of the UNCLOS embodies the duty to cooperate. This principle underpins most multilateral climate treaties, including the UNFCCC and the Paris Agreement, which interpret and apply it in different ways. The ITLOS noted that, given that the global impact of anthropogenic greenhouse gas emissions necessarily requires the collective action of States, the duty to cooperate is an integral part of the general obligation under articles 194 and 192 of the UNCLOS. Specific co-operation measures are explained in the COSIS Advisory Article 194, paragraph 1, so the following are the criteria that would lead to a breach of the duty of due diligence, including failure to take preventive measures, neglect of the duty to cooperate, disproportionate unilateral action, neglect of global efforts to reduce emissions and failure to carefully consider appropriate measures in specific cases (International Tribunal for the Law of the Sea ITLOS, 2024).

Also, pollution of the marine environment from any source under Article 194, paragraph 1 of the UNCLOS necessarily includes pollution that has yet to occur, such as future or potential pollution. Therefore, Failure to successfully prevent future or potential pollution and to reduce and control existing pollution is a violation of the due diligence standard. Moreover, the formulation of Article 192 highlights that States are required not only to actively take measures to protect and improve the State environment but also to refrain from acts that may lead to its deterioration. Thus, the obligation of due diligence is not only one of repair and prevention but also one of cessation of damage. For example, Australia's reliance on and use of coal energy is a continuing detriment and breach of due diligence obligation.

Furthermore, the introduction of alien species into specific parts of the marine environment as a result of climate change and ocean acidification can also lead to breaches of the due diligence obligation, which can be found in paragraph 231 of the COSIS Advisory Opinion. The (International Tribunal for the Law of the Sea ITLOS, 2024) is aware that marine geoengineering has been discussed and regulated in a number of forums, including the 1972 Convention on the Prevention of Marine Pollution and its 1996 Protocol and the Convention on Biological Diversity. This change may bring about significant and harmful changes to the marine environment. Article 196 (1) provides that other effects of climate change that do not fall within the definition of pollution may give rise to specific obligations to protect the marine environment from future threats.

4.2.3 Reflections on the variability of the criteria in the two cases

In short, the due diligence violation standard in both the case and COSIS Advisory Opinion emphasizes the timeliness and adequacy of the measures. At the same time, both examples cite other treaties and international decisions in explaining the breach standard for more detailed elaboration, answering how treaties should be used in specific climate change cases (International Tribunal for the Law of the Sea ITLOS, 2024). Having summarized the commonalities between *Daniel Billy* et al. and the COSIS Advisory Opinion regarding breaches of standards, the following analysis focuses on how their differences can complement and build upon each other.

In *Daniel Billy* et al., the United Nations Human Rights Committee (2022) found Australia violated the 'rights to privacy, life and family' and 'cultural rights' but did not rule on the violation of Article 24 of the UNCLOS, which directly relates to the rights of children and future generations. This decision reveals an inconsistency in the UNHRC's application of the 'future harm' rule: while accepting the 'future harm' rule in assessing violations of the 'right to culture', the 'right to life' was not ruled upon in the case of the 'right to life', leading to differences in the standard of protection of the different rights (Kahl, 2023). This position fails to adequately address future intergenerational rights and their protection, particularly the rights of children and future generations in the context of environmental and climate change.

However, COSIS Advisory Opinion restated the opinion mentioned by ICJ the environment 'represents the living space, the quality of life and the health of mankind, including future generations' (International Court of Justice, 1996). The due diligence obligation to safeguard the marine environment against climate change holds significant potential for progressive interpretation (Permanent Court

of Arbitration, 2016). Notably, the obligations outlined in Articles 192 and 194 have been progressively interpreted to encompass both 'protection' against future harm and 'preservation' aimed at maintaining and enhancing the current State of the marine environment. This dual interpretation imposes a positive obligation to actively implement measures for protection and preservation alongside a negative obligation to prevent any degradation of the existing marine conditions, highlighting a forward-looking approach to environmental stewardship (Permanent Court of Arbitration, 2016).

Actual, in similar contexts of human rights and the marine environment, as well as climate change, the international judiciary could incorporate a 'future' and 'cooperation' reading of the environmental change and general protection obligations of the ITLOS into the Decision of *Daniel Billy* et al., where issues such as the rights of the child and life would require forward-looking solutions, and where the impacts of the solutions should be intergenerational.

In the *Pulp Mills* Case, Judge Trindade emphasized the link between culture and the rights of future generations (Trindade, 2006). Trindade (2010) argued that it was crucial to bring the concept of 'potential or intended victims' into the practice of human rights treaties, citing the Goa principle that each generation inherits the natural and cultural heritage of previous generations, both as beneficiaries and guardians, which reinforces the responsibility to pass on this heritage to future generations (International Court of Justice, 2006). However, this comment refers to another issue: how future judicial decision-making will define 'future generations' in the context of intergenerational equity. Such questions may be more appropriately addressed through case-by-case analyses (Bhardwaj, 2023).

The cross-regional character of the due diligence obligation in relation to climate change and the fact that the obligation to cooperate is also included in the standard for its breach make it possible for *Daniel Billy* et al. to refer to the treatment of *Pulp Mills* as well. The ITLOS (2015) expressed a view of co-operation in the SRFC Advisory Opinion based on *Pulp Mills* cases. The obligations to "seek to agree" under Article 63, paragraph 1, and to cooperate under Article 64, paragraph 1, are considered "due diligence" duties. These require the involved States to engage in good faith consultations, as outlined in Article 300 of the UNCLOS, which was carried over into the COSIS Advisory Opinion.

4.3 The remedies and compensation after the violation of the due diligence obligation

This paper examines remedies for breaches of due diligence obligation in the *Daniel Billy* et al. and the COSIS Advisory Opinion. *Daniel Billy* et al. focused on immediate adaptation measures that States should take to protect populations affected by climate change. However, ITLOS was only covering primary obligations, which focused on preventative and long-term strategies, highlighting UNCLOS's role in tackling ocean acidification and global climate liability. The following sections analyze the reasons why ITLOS, as an advisory opinion for a number of small island States, lacks targeted compensatory measures like the Decision of *Daniel Billy* et al, and make additional recommendations for future advisory opinions.

4.3.1 Emphasis on adaptation remedies in *Daniel Billy* et al. *v. Australia*

Paragraphs 11 and 12 of the United Nations Human Rights Committee (2022) decision indicate the remedies from the Australian Government. According to Article 2(3)(a) of the ICCPR, when a state party is found to have violated rights under the Covenant, it is obligated to provide effective remedies to the victims. This includes offering comprehensive compensation to individuals whose rights have been infringed, engaging in meaningful consultations with affected communities to assess their needs, continuously implementing necessary measures to ensure community members can continue to live safely on their respective islands, and monitoring and reviewing the effectiveness of these measures, addressing any deficiencies promptly (United Nations Human Rights Committee, 2022). The State party must also take steps to prevent similar violations in the future.

In addition, through its ratification of the Optional Protocol, a State has recognized the competence of the United Nations Human Rights Committee (2022) to determine whether there has been a violation. The State party further ratified Article 2 of its commitment to guarantee that all individuals within its territory and subject to its jurisdiction the rights recognized in the Covenant shall continue to enjoy them without discrimination or provide an adequate remedy when violations occur. The United Nations Human Rights Committee (2022) requests the State party to give effect within 180 days to its views and information on the action taken for forwarding such actions. Furthermore, the UNHRC requests that it be widely publicized and given publicity as well.

Apart from the above general obligations that need to be implemented under the treaty, specific measures are also of concern, particularly those that the Australian Government needs to advance promptly and adequately. This component includes both mitigation and adaptation measures. For adaptation measures, Australia needs to continue to implement an adaptation plan that ensures the long-term habitability of islands affected by climate change, and many of the actions in the Torres Strait Regional Adaptation and Resilience Plan identified for the period 2016-21 will need to be funded. Although the UNHRC does not specifically require Australia to implement a specific mitigation plan, it notes that Australia's promotion of the extraction and use of fossil fuels, particularly thermal coal for power generation, has resulted in high GHG emissions.

From the above analysis, UNHRC's main emphasis in its decision is on adaptive measures. In other words, the human rights framework is more adept at addressing adaptation issues than mitigation measures (Luporini, 2023). This is because the impacts of climate change on human rights are more direct and immediate in the context of adaptation (Hall and Weiss, 2012; Mayer, 2022; Heri, 2022). For example, rising sea levels and extreme weather directly threaten people's habitat, food and water resources, and adaptation measures can quickly mitigate these threats. In a

separate opinion, however, Zyberi points out another missing remedies in the decision. The mitigation measures are necessary within a general standard for due diligence under the ICCPR in climate change to reduce GHG emissions and adaptation measures to protect against the impacts of climate change (United Nations Human Rights Committee, 2022). The reasons why the mitigation measures must be addressed will be shown in section 4.3.2.

4.3.2 Emphasis on primary obligations over remedies in COSIS advisory opinion

In paragraph 284 of the COSIS Advisory Opinion, ITLOS deals with primary obligations under UNCLOS, in particular the responsibility of States to protect and preserve the marine environment (International Tribunal for the Law of the Sea ITLOS, 2024). The Advisory Opinion does not explicitly address the issue of remedies or compensation, but rather emphasizes the responsibility of States to fulfil the due diligence obligation. Article 235 of UNCLOS clarifies that States are responsible for fulfilling their international obligations to protect and preserve the marine environment and are liable under international law (International Tribunal for the Law of the Sea ITLOS, 2024). 'Responsibility' in this context refers to the primary obligation, while "assumption of responsibility" refers to the secondary obligation arising from the breach of the primary obligation (International Tribunal for the Law of the Sea (ITLOS), 2011). This emphasizes the attribution of responsibility to the State when it fails to fulfil its due diligence obligation. Consequently, the State is required to remedy for breach of the due diligence standard but does not go further to discuss specific remedial or compensatory mechanisms. Article 235 (2) of the UNCLOS provides that States shall ensure that adequate means of compensation or other relief are available under their legal systems for damage arising from marine pollution caused by natural or legal persons. This suggests that States are not only obliged to prevent pollution, but also to provide compensation or remedies for victims of pollution under their domestic legal framework.

The Advisory Opinion emphasizes the importance of States fulfilling their due diligence obligation. For example, ITLOS mentions that countries need to set national targets and action programs with maximum ambition to meet their international commitments to reduce emissions, based on the emission reduction targets of established treaties and their own national realities. The IPCC report states that to limit global warming to 1.5°C, the world must achieve net-zero emissions of carbon dioxide by 2050, and significantly reduce other greenhouse gases such as methane emissions (IPCC, 2023). International Tribunal for the Law of the Sea (ITLOS) (2024) also highlights that international agreements under the International Maritime Organization, the International Civil Aviation Organization, and the Montreal Protocol reflect global efforts to combat climate change, primarily through new GHG reduction targets.

Secondly, countries should adopt appropriate mitigation measures to achieve the established emission reduction targets. The COSIS Advisory Opinion, based on the provisions of the UNCLOS and other treaties, states that countries should achieve their emission reduction targets through mitigation measures (International Tribunal for the Law of the Sea ITLOS, 2024). According to Article 4.2 of the Paris Agreement, each Party shall meet the temperature and emissions targets in the agreement by developing, communicating, and consistently maintaining Nationally Determined Contributions, while implementing domestic mitigation measures. The IPCC states that ways to achieve these targets include reducing energy demand, advancing the decarbonization of electricity and other fuels, advancing the electrification of end-use energy, significantly reducing emissions from agriculture, and implementing some form of CO2 removal technology (Masson-Delmotte et al., 2018).

In addition, the provision of technical support and international cooperation by developed countries to developing countries is an important way to help countries achieve their emission reduction targets. Although developed countries are more responsible for ocean acidification and pollution, their help is more in the form of international cooperation and technical support than remedial measures (International Tribunal for the Law of the Sea ITLOS, 2024). Articles 202 and 203 of the UNCLOS emphasize that, through international cooperation and technical assistance, developed countries should help developing countries to prevent, reduce and control pollution of the marine environment associated with anthropogenic emissions of greenhouse gases (International Tribunal for the Law of the Sea ITLOS, 2024). ITLOS also notes that this obligation reflects the principles of 'common but differentiated responsibilities' and 'respective capabilities', emphasizing that wealthy countries should help countries with lesser capabilities (International Tribunal for the Law of the Sea ITLOS, 2024). It also notes that this obligation reflects the principles of "common but differentiated responsibilities" and "respective capabilities", emphasizing that rich countries should help countries with lesser capabilities to meet their environmental protection obligations.

In summary, ITLOS has concentrated on the State's responsibility to meet its due diligence requirements, rather than extensively addressing the remedies or liabilities associated with violations of such responsibilities. The remedies and compensation matters are examined thoroughly in certain case rulings.

4.3.3 Reflections on variability of remedies in the two cases

The reasons for not discussing mitigation measures as part of remedies in the main Decision of *Daniel Billy* et al. are as follows. Firstly, the human rights framework emphasizes that States have positive obligations towards the inhabitants of their territories and that adaptation measures are often local, with States taking direct action to protect the rights of their inhabitants (Luporini, 2023). Moreover, In the case of adaptation measures, causation and responsibility are relatively simple to determine. States need to be held directly responsible for the impacts of climate change within their territories (Ottavio, 2018). Finally, adaptation measures can provide immediate benefits and rapidly improve the living conditions of communities affected by climate change (Luporini, 2023).

However, mitigation measures are more appropriate as remedies for lagged damages and allocation of responsibility arising from climate issues, which was mentioned in the COSIS Advisory Opinion. While ITLOS does not discuss remedies in depth, the role of mitigation measures that extend from State obligations is that they can help States fulfill their due diligence

obligation. Firstly, mitigation measures address damages that arise in future contexts that are not necessarily in the short-term interests of the government in power (Sands, 2016), such as the Dutch government's position prior to the *Urgenda* was on the official position of the 'gold-plated' policy of the E.U. environmental directives: no effort would be made to go beyond the E.U. minimum standards unless it was in the 'vital Dutch interest' (Squintani et al., 2009). The latest judgement in *Urgenda* may force the Dutch government to reassume its environmental leadership role, at least on climate change mitigation issues. (The European parliament and the council of the European union, 2009). The Court ordered the Dutch government to adopt a policy of reducing emissions by at least 25 per cent from 1990 levels by 2020 instead of the currently projected 17 to 20 per cent reduction in Urgenda Foundation v. State of the Netherlands (2015).

Additionally, using mitigation measures is not only a way for countries to raise standards but also to promote further national responsibility for mitigating climate change hazards. Mitigation measures emphasize international cooperation and a high standard of due diligence obligation. In the Urgenda Foundation v. State of the Netherlands (2015) case, the Court rejected the government's argument that Dutch emissions have a negligible impact on global climate change, it did not accept methods of prorating liability for pollution. In addition, the Court referred to the Netherlands' emission reduction targets under the Kyoto Protocol, which indicated that the Dutch government had committed itself to implementing emission reduction measures that might be too high concerning its emissions (Urgenda Foundation v. State of the Netherlands, 2015). These elements suggest that even though the Netherlands' emissions may be small in global proportion, the Court found that the Dutch government is responsible for reducing greenhouse gas emissions and contributing to global climate action. This judgement emphasizes that even countries with small emissions must recognize their responsibility for global climate change (Van Zeben, 2015). Based on the above analysis, although Australia argues that not all climate harm suffered in the Torres Strait came from domestic contributions in *Daniel Billy* et al., the lack of long-term mitigation measures could also lead to a remedy. Totally, environmental degradation was scientifically based and predictable, requiring the State to take on more ambitious goals for remediation.

In the face of poor consideration of mitigation measures in climate litigation, national and international organizations should also make the following efforts. First, international organizations should advocate for incorporating the precautionary principle into customary international law and minimizing the adverse effects of climate change through the adoption of effective mitigation measures (International Tribunal for the Law of the Sea (ITLOS), 2011). There is also a need for countries to develop a consensus that simply following the temperature targets of the Paris Agreement will not fully address environmental problems such as ocean acidification (Roland Holst, 2022). The magnitude of the problem of ocean acidification reveals that the failure to address it directly through targeted measures, as well as the possibility of exacerbating the problem through mitigation strategies that increase the carbon sink in the oceans, underscores the need for concerted action under different frameworks. This emphasizes effectively integrating efforts between different regulatory regimes to address such environmental challenges (Roland Holst, 2022). The UNCLOS has re-emphasized its relevance as a framework for the governance of mitigation actions targeting ocean acidification by explicitly defining ocean CO2 uptake and ocean acidification as forms of marine pollution (Scott, 2020; Harrould-Kolieb, 2020). This approach not only contributes to broader climate change mitigation efforts but is also in line with the promoted goal of making the precautionary principal part of customary international law (Roland Holst, 2022).

Therefore, remedies for breaches of due diligence require both timely adaptation measures for short-term repair and preservation and a focus on mitigation measures at the international level. At the same time, countries need the most ambitious mitigation targets to create an emission gap.

5 Conclusion

The discourse surrounding the due diligence obligation in climate change litigation has evolved to encapsulate a comprehensive understanding of its theoretical and practical implications. Drawing on the insights from the COSIS Advisory Opinion and *Daniel Billy* et al., several consequential observations emerge that forecast the potential future of due diligence obligation within climate change mitigation and policy adaptation.

Firstly, the utilization of due diligence in *Daniel Billy* et al. and COSIS Advisory Opinion draws attention to the interrelationship between human rights and environmental law. This recognition serves as a turning point in due diligence obligation of a higher standard. The States and international organizations should consider how governments should act to diminish climate change damage or protect vulnerable areas. However, the varied application of due diligence across different legal frameworks highlights the necessity for more cohesively integrating the principles of international environmental law and human rights framework.

Secondly, by adopting a proactive and flexible approach to due diligence, the ITLOS has demonstrated a new way of dealing with environmental issues to the international community. By explaining the legal responsibilities through the latest technology and scientific data into a precedent for future legal interpretation, the ITLOS can be said to be both ahead of its time in terms of flexibility and in line with the characteristics of climate change – persistent and cumulative. In the process, the law changes and develops in response to changes in environment and technology.

In addition, the COSIS advisory opinion and *Daniel Billy* et al. demonstrate the critical importance of the advisory role to the UNHRC and the ITLOS in the development of a global framework of environmental and human rights law. This is because it helps to bridge the gap between jurisdictions and thus contributes to more effective and equitable governance of particular climate change issues on a global scale.

In sum, the exploration of due diligence in climate change litigation and advisory opinions suggests a shift towards a more integrated and proactive legal approach to environmental issues on a broader scale. As the climate legal framework continues to evolve,

the principle of due diligence promises to be central to guiding State action and ensuring that environmental and human rights protections are comprehensively addressed.

Author contributions

SL: Writing – review & editing, Writing – original draft.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

During the writing process, OpenAI's ChatGPT (version 4.0) was used to assist with language polishing, including sentence structure optimization and terminology standardization. The final content was further reviewed and edited by the author to ensure academic rigor and originality.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Alan, B. (2019). Litigating climate change under part XII of the LOSC. *Brill* 34, 1–24. doi: 10.1163/15718085-13431097

Baars, L. P. (2023). The salience of salt water: an ITLOS advisory opinion at the ocean-climate nexus. *Int. J. Mar. Coast. Law* 38, 581–602. doi: 10.1163/15718085-bja10137

Bhardwaj, C. (2023). Adaptation and human rights: a decision by the Human Rights Committee Daniel Billy et al. v. Australia CCPR/C/135/D/3624/2019. *SAGE J.* 25, 154–161. doi: 10.1177/14614529231169544

Boyle, A. (2016). Climate change, ocean governance and UNCLOS. *Univ. Edinburgh Res. Explorer*, 211–230. Available at: https://www.research.ed.ac.uk/en/publications/climate-change-ocean-governance-and-unclos.

Deng, Y., Zhang, H., Pratap, A., Failou, B., Hussain, A., and Maharani Putri, H. (2024). Integrating climate change into global ocean governance: the ITLOS advisory opinion on the specific obligations of state parties to the united nations convention on the law of the sea. *J. Island Mar. Stud.* 1, 1–17. doi: 10.59711/jims.11.110011

Farkas, B., Kembabazi, A., and Safdi, S. (2013). *Human Rights and Climate Change Obligations* (New Haven: Yale Law School).

Hagiarian, B. (2023). The *Daniel Billy v Australia* case: its semantics and the characterization of a climate threat as a cause for migration. *Amsterdam Law Forum* 15, 10.

Hall, M., and Weiss, D. (2012). *Article Avoiding Adaptation Apartheid: Climate Change Adaptation and Human Rights Law*. Available online at: https://center-hre.org/wp-content/uploads/2012/08/37-2-hall-weiss-avoiding-adaptation-apartheid.pdf (Accessed 14 Aug. 2024).

Harrould-Kolieb, E. R. (2020). The UN Convention on the Law of the Sea: A governing framework for ocean acidification? *Rev. European Comp. Int. Environ. Law* 29, 257–270. doi: 10.1111/reel.12321

Heri, C. (2022). Climate change before the european court of human rights: capturing risk, ill-treatment and vulnerability. *Eur. J. Int. Law* 33, 925–951. doi: 10.1093/ejil/chac047

International Court of Justice (1996). *Legality of the Threat or Use of nuclear weapons*. Available online at: https://www.icj-cij.org/case/95 (Accessed July 8, 1996).

International Court of Justice (2006). Pulp Mills on the River Uruguay (Argentina v. Uruguay). Available online at: https://www.icj-cij.org/case/135 (Accessed May 4, 2006).

International Tribunal for the Law of the Sea (ITLOS) (2001). *The MOX Plant Case (Ireland v. United Kingdom), Provisional Measures*. Available online at: https://www.itlos.org/fileadmin/itlos/documents/cases/case_no_10/published/C10-O-3_dec_01.pdf (Accessed November 20, 2001).

International Tribunal for the Law of the Sea (ITLOS) (2011). Responsibilities and obligations of states sponsoring persons and entities with respect to activities in the area (Advisory opinion). *ITLOS Rep.* 10, 10–78. Seabed Advisory Opinion.

International Tribunal for the Law of the Sea (ITLOS) (2015). Request for an advisory opinion submitted by the sub-regional fisheries commission (SRFC) (Advisory opinion). *ITLOS Rep.* 4, 4–70. SFRC Advisory Opinion.

International Tribunal for the Law of the Sea (ITLOS) (2024). Request for an advisory opinion submitted by the commission of small island states on climate change and international law advisory opinion (COSIS) (Advisory opinion). *ITLOS Rep.* 31, 2–153. COSIS Advisory Opinion.

IPCC (2023). *CLIMATE CHANGE 2023 Synthesis Report A Report of the Intergovernmental Panel on Climate Change*. Available online at: https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_FullVolume.pdf (Accessed March 20, 2023).

James, H. (2024). *Saving the Oceans Through Law: The International Legal Framework for the Protection of the Marine Environment* (Oxford, United Kingdom: Oxford Academic).

Kahl, V. (2023). Human Rights Protection in the Climate Crisis 2.0: The UN Human Rights Committee's Landmark Decision in *Daniel Billy* et al. *v. Australia*. *Verfassung Recht Und Übersee* 55, 287–378. doi: 10.5771/0506-7286-2022-3

Lavell, A., Oppenheimer, M., Diop, C., Hess, J., Lempert, R., Li, J., et al. (2012). "'Managing the risks of extreme events and disasters to advance climate change adaptation," in *A special report of working groups i and II of the intergovernmental panel on climate change (IPCC)*, vol. 3. Eds. C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, et al. (Cambridge: Cambridge University Press), 25–64.

Lentner, G. M., and Weronika, C. (2024). Daniel Billy et al. v Australia (Torres Strait Islanders Petition): Climate change inaction as a human rights violation. *Rev. European Comp. Int. Environ. Law* 1, 136–143. doi: 10.1111/reel.12527

Luporini, R. (2023). Climate Change Litigation before International Human Rights Bodies: Insights from *Daniel Billy* et al. *v. Australia* (*Torres Strait Islanders* Case). *Ital. Rev. Int. Comp. Law* 3, 238–259. doi: 10.1163/27725650-03020005

Luporini, R., and Savaresi, A. (2023). International human rights bodies and climate litigation: don't look up? *SSRN Electronic J.* 32, 267–278. doi: 10.2139/ssrn.4230278

Maguire, A., and McGee, J. (2017). A universal human right to shape responses to a global problem? The role of self-determination in guiding the international legal response to climate change. *Rev. European Comp. Int. Environ. Law* 26, 54–68. doi: 10.1111/reel.12193

Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P., et al. (2018). *Global warming of 1.5°C An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty Edited by Science Officer Science Assistant Graphics Officer*. Available online at: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf.

Matz-Lück, N., and van Doorn, E. (2017). Due diligence obligations and the protection of the marine environment. *L'Observateur Des. Nations* 42, 177–195.

Mayer, B. (2022). Climate change mitigation as an obligation under human rights treaties? *Am. J. Int. Law* 115, 409–451. doi: 10.1017/ajil.2021.9

Mcgaughey, F., Maguire, A., and Purcell, S. (2024). *Torres strait islanders leading the charge on the human rights implications of climate change:* Daniel billy

et al. v Australia. Available online at: https://www.able.uwa.edu.au/:data/assets/pdf_file/0007/3699430/McGaughey.Maguire.Purcell.Daniel-Billy.pdf (Accessed January 20, 2024).

Miguel Wilson, S., Richard, R., Joseph, L., and Marie Williams, E. (2010). Climate change, environmental justice, and vulnerability: an exploratory spatial analysis. *Environ. Justice* 3, 13–19. doi: 10.1089/env.2009.0035

Mingozzi, P. C. (2023). The contribution of ITLOS to fight climate change: prospects and challenges of the COSIS request for an advisory opinion. *Ital. Rev. Int. Comp. Law* 3, 306–324. doi: 10.1163/27725650-03020008

Natalie, K. (2020). *Adapting UNCLOS Dispute Settlement to Address Climate Change IFRC* (Ifrc.org). Available online at: https://disasterlaw.ifrc.org/media/3956 (Accessed 14 Aug. 2024).

Ottavio, Q. (2018). Climate change and state responsibility for human rights violations: causation and imputation. *Netherlands Int. Law Rev.* 65, 185–215. doi: 10.1007/s40802-018-0110-0

Paavola, J., and Neil Adger, W. (2006). Fair adaptation to climate change. *Ecol. Economics* 56, 594–609. doi: 10.1016/j.ecolecon.2005.03.015

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., et al. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Eds. Core Writing Team,, R. K. Pachauri and L. A. Meyer (Geneva, Switzerland: IPCC).

Peel, J., and Osofsky, H. M. (2018). A rights turn in climate change litigation? *Transnational Environ. Law* 7 (1), 37–67. doi: 10.1017/s2047102517000292

Peel, J., and Schechinger, J. (2017). "Climate change," in *The Practice of Shared Responsibility in International Law*. Eds. A. Nollkaemper and I. Plakokefalos (Cambridge University Press, Cambridge), 1009–1050.

Permanent Court of Arbitration (2016). *The South China Sea Arbitration (The Republic of Philippines v. The People's Republic of China)* (The Hague, Netherlands: Pca-cpa.org). Available at: https://pca-cpa.org/en/cases/7/.

Pietro, P. (2021). Cambiamento climatico e diritti umani: sviluppi nella giurisprudenza nazionale. *Ordine Internazionale E Diritti Umani* 3, 596–605.

Poisel, T. (2012). "Deep seabed mining: Implications of seabed disputes chamber's advisory opinion," in *Australian International Law Journal*, vol. 19. (International Law Association - Australian Branch, Sydney, NSW, Australia), 213–233. doi: 10.3316/ielapa.331557646583287

Pulp Mills on the River Uruguay (Argentina v. Uruguay) (2010). Judgment. *International Court of Justice (ICJ) Reports*, 14.

Roland Holst, R. J. (2022). Taking the current when it serves: Prospects and challenges for an ITLOS advisory opinion on oceans and climate change. *Rev. European Comp. Int. Environ. Law* 32, 217–225. doi: 10.1111/reel.12481

Rothwell, D. R. (2023). Climate change, small island states, and the law of the sea: the ITLOS advisory opinion reques. *ASIL Insights* 27, 2–6.

Sands, P. (2016). Climate change and the rule of law: adjudicating the future in international law. *J. Environ. Law* 28, 19–35. doi: 10.1093/jel/eqw005

Savaresi, A., and Auz, J. (2019). Climate change litigation and human rights: pushing the boundaries. *Climate Law* 9, 244–262. doi: 10.1163/18786561-00903006

Savaresi, A., and Setzer, J. (2022). Rights-based litigation in the climate emergency: mapping the landscape and new knowledge frontiers. *J. Hum. Rights Environment*. doi: 10.1163/18786561-00903006

Scott, K. N. (2020). Ocean acidification: A due diligence obligation under the LOSC. *Int. J. Mar. Coast. Law* 35, 382–408. doi: 10.1163/15718085-bja10005

South China Sea arbitration. (2016). *Permanent court of arbitration (2016) the South China Sea arbitration (the Republic of the Philippines v. The People's Republic of China), PCA Case No. 2013-19, Award, 12 July 2016*. Available online at: https://www.pcacases.com/web/view/7 (accessed November 26, 2024).

Squintani, L., Aragão, A., Macrory, R., Jans, J., and Wegener, B. (2009). Gold plating' of european environmental measures? *J. Eur. Environ. Plann. Law* 6, 1–18. doi: 10.2139/ssrn.1485386

The European parliament and the council of the European union (2009). Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020. *Off. J. Eur. Union* 17, 136–148. Available online at: http://data.europa.eu/eli/dec/2009/406/oj

The State of Netherlands v. Urgenda Foundation (2019). *Supreme court of the netherlands, case no. 19/00135*.

The White House Office of the Press Secretary (2014). *FACT SHEET: U.S.-China Joint Announcement on Climate Change and Clean Energy Cooperation* (Washington, D.C., United States: whitehouse.gov). Available at: https://obamawhitehouse.archives.gov/the-press-office/2014/11/11/fact-sheet-us-China-joint-announcement-climate-change-and-clean-energy-c.

Tiger, M. A. (2022). U.N. Human Rights Committee finds that Australia is violating human rights obligations towards Torres Strait Islanders for climate inaction. *Sabin Center Climate Change Law*. Available at: https://blogs.law.columbia.edu/climatechange/2022/09/27/u-n-human-rights-committee-finds-that-Australia-is-violating-human-rights-obligations-towards-torres-strait-islanders-for-climate-inaction/.

Tigre, M. A. (2022). U.N. Human Rights Committee finds that Australia is violating human rights obligations towards Torres Strait Islanders for climate inaction - Climate Law Blog. *Climate Law Blog*. Available at: https://blogs.law.columbia.edu/climatechange/2022/09/27/u-.

Torres Strait Regional Authority (2014). *'Torres Strait Climate Change Strategy 2014-18: Building Community Adaptive Capacity and Resilience', Annex 1*, Vol. iii. Thursday Island, Queensland, Australia: Torres Strait Regional Authority.

Trindade, C. (2006). *Separate Opinion of judge Cançado Trindade 'General Principles of Law'*. Available online at: https://jusmundi.com/en/document/pdf/opinion/en-pulp-mills-on-the-river-Uruguay-Argentina-v-Uruguay-separate-opinion-of-judge-cancado-trindade-tuesday-20th-april-2010 (Accessed 17 Aug. 2024).

Trindade, A. A. C. (2010). Separate opinion in pulp mills on the river uruguay (Argentina v. uruguay). *International Court of Justice Reports*, 122.

United Nations Human Rights Committee (2014). *Caselaw Database* (ESCR-Net). Available online at: https://www.escr-net.org/caselaw/2022/daniel-billy-et-al-vs-Australia-torres-strai (Accessed 13 Aug. 2024).

United Nations Human Rights Committee (2022). *Views adopted by the Committee under article 5(4) of the Optional Protocol, concerning Communication No. 3624/2019, 135th session, UN Doc CCPR/C/135/D/3624/2019 (22 September 2022) [2.1-2.2] ('Daniel Billy et al. v Australia')*. Geneva, Switzerland: United Nations Office of the High Commissioner for Human Rights (OHCHR).

United Nations Framework Convention on Climate Change (UNFCCC). (2022). *Sharm el-Sheikh Implementation Plan*. Available at: https://unfccc.int/documents/624441.

Urgenda Foundation v. State of the Netherlands (2015). *C/09/456689/HA ZA 13-1396 (ECLI: NL: RBDHA: 2015:7145)*. The Hague, Netherlands: Supreme Court of the Netherlands.

Van Zeben, J. (2015). Establishing a governmental duty of care for climate change mitigation: will urgenda turn the tide? *Transnational Environ. Law* 4, 339–357. doi: 10.1017/S2047102515000199

Weston, J. C. L. (2024). The international tribunal for the law of the sea and the request for an advisory opinion on climate change and its effects: potential challenges and opportunities. *Católica Law Rev.* 8, 13–34. doi: 10.34632/catolicalawreview.2024.16059

frontiers | Frontiers in Marine Science

TYPE Systematic Review
PUBLISHED 20 December 2024
DOI 10.3389/fmars.2024.1465289

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
M. Rafiuddin Ahmed,
University of the South Pacific, Fiji
Periyadan K. Krishnakumar,
King Fahd University of Petroleum and Minerals, Saudi Arabia

*CORRESPONDENCE
Ferdaus Mohamat-Yusuff
ferdius@upm.edu.my

RECEIVED 16 July 2024
ACCEPTED 19 November 2024
PUBLISHED 20 December 2024

CITATION
Leng Q, Mohamat-Yusuff F, Mohamed KN, Zainordin NS and Hassan MZ (2024) Impacts of thermal and cold discharge from power plants on marine benthos and its mitigation measures: a systematic review.
Front. Mar. Sci. 11:1465289.
doi: 10.3389/fmars.2024.1465289

COPYRIGHT
© 2024 Leng, Mohamat-Yusuff, Mohamed, Zainordin and Hassan. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Impacts of thermal and cold discharge from power plants on marine benthos and its mitigation measures: a systematic review

Qingxue Leng[1], Ferdaus Mohamat-Yusuff[1]*, Khairul Nizam Mohamed[1], Nazatul Syadia Zainordin[1] and Mohd Zafri Hassan[2]

[1]Faculty of Forestry and Environment, Universiti Putra Malaysia, Selangor, Seri Kembangan, Malaysia, [2]Faculty of Agriculture, Universiti Putra Malaysia, Selangor, Seri Kembangan, Malaysia

Introduction: Power plants discharge thermal and cold effluents that significantly alter marine environments, impacting various organisms, including benthic communities. While thermal discharge has received considerable research attention, the impacts of cold discharge remain underexplored. This systematic review synthesizes existing research on the effects of power plant discharges on marine benthic ecosystems.

Methods: A systematic literature search was conducted using Scopus, PubMed, and Web of Science, following PRISMA guidelines, covering studies from 1974 to 2024. A total of 58 articles were included in this review. CiteSpace was used to visualize trends, and statistical analysis was conducted to assess relationships between environmental parameters and changes in benthic abundance.

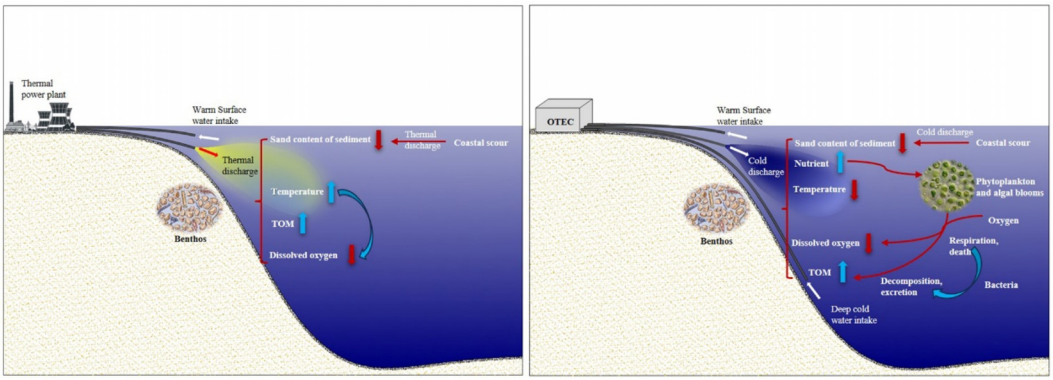
Results: A significant negative correlation was observed between temperature differentials, ambient temperature, and benthic abundance. Thermal discharge generally led to reduced benthic diversity and abundance, with occasional increases under low ambient temperatures. Cold discharge effects remain less documented, with evidence primarily focused on phytoplankton and fish. Additionally, dissolved oxygen, pH, and bottom sediment composition were significantly altered by power plant discharge. Detection and mitigation measures are crucial to managing these impacts. Mitigation measures include distributed discharge for cold effluents, advanced heat recovery systems, and careful site selection to minimize impacts on sensitive ecosystems. Long-term management and adaptive strategies are essential to reduce adverse effects and maintain ecological balance.

Discussion: Thermal discharges adversely impact marine benthic organisms by decreasing biodiversity and changing community structure, largely due to elevated temperatures and reduced oxygen levels. Cold discharges present

unique challenges that require further research to fully understand their ecological impacts. Mitigation measures, such as distributed discharge for cold effluents and advanced heat recovery systems for thermal discharges, are essential to minimize the environmental impact of power plant operations.

KEYWORDS

thermal emission, cold emission, ocean thermal energy conversion, benthos, mitigation actions



GRAPHICAL ABSTRACT

Highlights

- Research on cold discharge's impact on benthos is notably deficient.
- Temperature difference is negatively correlated with changes in benthic abundance.
- The discharge alters the levels of dissolved oxygen, pH, and bottom material.
- Mitigation measures are available for both thermal and cold emissions' impacts.

1 Introduction

Electricity is one of the driving forces of economic development in all nations. In 2021, the world's total electrical energy generated was 617791617 TJ (IEA, 2024). The world's existing electricity generation is mainly divided into six types of sources: fossil fuels (57.2%), nuclear (11.7%), hydroelectricity (13.5%), wind (10.8%), solar (3.1%), and other renewables (3.7%). The performance of thermoelectric power generation depends heavily on cooling systems, which are the most water-consuming component of the thermoelectric power generation process (Pan et al., 2018).

In a thermal power plant system, the cooling mechanism involves drawing water from nearby estuaries or oceans. Following heat exchange in the condenser, this water is discharged back into the corresponding aquatic ecosystem via an outflow channel, despite being at a higher temperature. In the case of the Ocean Thermal Energy Conversion (OTEC) power plant, cold water is utilized for condenser heat exchange before being released into the aquatic ecosystem via the discharge channel, typically at a temperature lower than that of the surrounding environment (Masutani and Takahashi, 2001). Those power plants required substantial water intake to facilitate the cooling process for the condensers. According to the current production process, directly cooled power plants are typically situated on open coastlines or estuaries and requires 35–50 m^3/s of cooling water per 1000 MWe of power produced (Venugopalan et al., 2011; Wither et al., 2012), and a large amount of discharge leads to disturbances in the substrate (Deabes, 2020). The large volumes of water used for cooling and discharged by power plants can modify the physical and chemical properties of the surrounding environment, including the stratification and circulation of seawater, as well as the levels of salinity, dissolved oxygen, and pH (Muthukumar et al., 2022; Xu et al., 2021). Additionally, chlorine is commonly employed to

mitigate biofouling within cooling ducts (Padhi et al., 2019; Taylor, 2006). However, the impact of elevated temperatures will be exacerbated by the concurrent discharge of biocides like chlorine (Chavan et al., 2017; Jenner et al., 1997). Marine organisms are highly sensitive to changes in temperature, dissolved oxygen, and salinity gradients (Mariu et al., 2023; Gao et al., 2023), and the thermal and cold discharge from power plants have significant impacts on their behavior and ecology.

The discharge of thermal and cold effluents carry significant implications for marine ecosystems, exerting considerable impacts on the growth and reproductive patterns of numerous species (Michie et al., 2020; Kim et al., 2017), as well as on the structure and composition of various communities, such as phytoplankton (Chuang et al., 2009; Kim et al., 2017), zooplankton (Jebakumar et al., 2018), fish (Teixeira et al., 2012), and benthic organisms (Bensoussan et al., 2010; Riera et al., 2011; Mazik et al., 2013; Bozorgchenani et al., 2018).

Benthos plays a crucial role as both consumers and decomposers in the food chain of aquatic ecosystems. Therefore, the study of benthic organisms is essential for understanding the structure and function of these ecosystems (Baldanzi et al., 2013; Nicastro and Bishop, 2013; Lamadrid-Rose and Boehlert, 1988). Benthic organisms inhabited the seabed or its immediate vicinity. Benthos can be classified into three categories according to their size: macrobenthos, meiobenthos, and microbenthos. Macrobenthos are primarily composed of Cnidaria, Polychaeta, Mollusca, Crustacea, and echinoderms, as well as other species such as sponges, bryozoans, sipunculans, spoonworms, worms, and benthic fishes (Li and Xu, 2021). Macrobenthos play a crucial role in the energy and material cycling within the benthic ecosystem, including nutrient cycling, decomposition, pollutant diffusion and burial, and secondary productivity (Ellingsen and Gray, 2002; Snelgrove, 1998). Meiobenthos is a diverse group of small benthic organisms that play a critical role in the structure and function of benthic ecosystems (Schratzberger and Ingels, 2018). They are typically between 42 and 500 μm in size and include over 20 categories of Metazoa and Protozoa, such as Nematodes, Cnidarians, Platyhelminthes, Nemerteans, Rotifers, Priapulids, Annelids (primarily Polychaetes), Arthropods (including Copepods, Halacaroids, Ostracods, etc.), and Mollusks (McIntyre, 1969; Urban-Malinga, 2014). Meiobenthos act as an intermediate link between microbenthos and macrobenthos and play an essential role in the marine benthic ecosystem. They are involved in nutrient cycling, decomposition, and the diffusion and burial of pollutants (Schratzberger and Ingels, 2018). Moreover, they have a short life cycle, high fecundity, and are sensitive to environmental changes, making them valuable indicators of environmental pollution (Islam et al., 2024; Ridall and Ingels, 2021).

Various factors play pivotal roles in shaping the abundance, diversity, distribution, and functional attributes of aquatic organisms. These factors include but are not limited to water temperature, salinity levels, hydrodynamic dynamics, sedimentary processes, oxygen concentrations, sediment grain size, prevailing currents, and the availability of nutrients (Ingels et al., 2011; Zeppilli et al., 2013; Górska et al., 2014; Pusceddu et al., 2014). Benthos is a highly vulnerable group when it comes to the impact of thermal discharge, as their capacity to evade is limited. With many benthic species being either sessile or sedentary, some even have remained in the same spot throughout their entire lives (Zeppilli et al., 2015; Schratzberger et al., 2023). For this reason, benthos is regarded as an ideal group to monitor and determine the effects of various types of pollutants (Warwick and Clarke, 1993). Compared with cold discharge, research on the impact of power plants on benthic ecosystems predominantly focuses on thermal discharge. This phenomenon is acknowledged to pose a substantial threat to benthic organisms, resulting in habitat degradation and heightened mortality rates (Vaquer-Sunyer and Duarte, 2011). This thermal discharge is observed to hinder growth and development (Kim et al., 2017), as well as affect metabolic activity (Kim et al., 2017). Furthermore, there is substantial empirical evidence highlighting the detrimental effects of thermal discharge on benthic abundance, biodiversity, and community structure (Farshchi et al., 2020; Cai et al., 2023; West et al., 2021; Bozorgchenani et al., 2018). Conversely, exploring cold discharge effects on marine organisms remains relatively scant, with existing studies predominantly focusing on phytoplankton and fish (Myers et al., 1986; Billman et al., 2006; Golmen et al., 2005; Liu, 2018; Giraud et al., 2019). This phenomenon underscores the insufficient understanding of the effects of cold discharge on marine benthic communities.

In recent years, the impact of power plant discharge on Marine ecosystems, especially benthic organisms, has received increasing attention. This review uses sources such as Scopus, PubMed, and Web of Science to develop a detailed database compiling existing literature on the effects of power plant discharge on benthic organisms. This review seeks to 1) employ CiteSpace software to analyze and visualize the literature, elucidating the spatial and temporal distribution of research in this area and identifying emerging hotspots of interest; 2) examine the effects of coastal power plant discharge on benthos community structure, with a particular focus on the relationship between temperature differentials and variations in benthic abundance; 3) assess how various environmental factors—including dissolved oxygen, pH, and bottom material—affect benthic organisms, emphasizing the complex interplay among these factors; 4) provide insights that can inform the formulation of environmental policies designed to mitigate the impacts of thermal and cold effluents on marine biodiversity, advocating for a holistic approach to address these challenges.

2 Data and methods

2.1 Data collection

The initial phase of this study involved the systematic identification of relevant scholarly literature through a comprehensive review of peer-reviewed scientific articles available on the Scopus, PubMed, and Web of Science platforms spanning the period from 1974 to 2024 by adopting PRISMA methodology (Moher et al., 2015). The search fields encompassed titles, abstracts, and keywords, utilizing the following search criteria (Guimarães et al., 2023): ("sea*" OR

"marine" OR "shore" OR "ocean*" OR "coastal zone" OR "coastline" OR "estuary") AND ("thermal discharge" OR "thermal pollution" OR "thermal stress" OR "cold discharge" OR "cold shock" OR "cooling water" OR "warming" OR "temperature" OR "heat") AND ("power plant*" OR "thermal plant*" OR "power station*" OR "Ocean Thermal Energy Conversion power station" OR "Ocean Thermal Energy Conversion power plant") AND ("benthos" OR "benthic*" OR "invertebrate" OR "mussel" OR "mollusca" OR "crustacea" OR "polychaeta" OR "community" OR "biodiversity" OR "diversity") NOT ("river*" OR "lake*"). Macrobenthic and microbenthic organisms are selected as biological indicators in this study due to their ease of observation, identification, and greater stability, which render them suitable for assessing environmental changes (Islam et al., 2024; Nayak et al., 2022). These organisms' characteristics facilitate the monitoring of ecological shifts with precision.

To evaluate the organisms impacted by thermal emissions, we encompassed all benthic organisms exhibiting alterations in biological and ecological indices (e.g., morphology, reproduction, diversity). Given the scarcity of research about the effects on benthic organisms caused by cold discharge, investigations into organisms affected by cold emissions were expanded to include phytoplankton and fish. Owing to the heterogeneity observed in the taxonomic classification systems utilized across diverse scholarly articles, ranging from species-level to genus-level classifications, the resultant data have been systematically organized and analyzed at the class level to facilitate coherent comparisons.

Factors documented in preliminary studies regarding the impact of thermal and cold emissions from power plants on local biodiversity were extracted and consolidated. The influencing factors of the main study were categorized into three groups: (1) solely temperature; (2) temperature and other factors; and (3) solely other factors, such as salinity, nutrients, chlorine, radioactivity, and so on. The systematic analysis was limited to effects falling within the first and second categories, as they explicitly delineated the impact of temperature variations on benthic organisms.

A total of 615 articles were identified, comprising 296 from the Web of Science, 254 from Scopus, and 65 from PubMed. Following the removal of duplicate studies, the remaining articles underwent screening based on title and abstract. Subsequently, the content of the articles underwent screening to exclusively include studies focusing on the impact of water temperature on benthic organisms. Finally, 58 articles were deemed suitable for inclusion in the systematic review, while 9 articles were included in the quantitative analysis (Figure 1). Readers are directed to consult the supplementary material, "List of Articles Included in the Systematic Review," for specific documents referenced in this study. Forty-nine studies were excluded from the quantitative analysis due to the absence of data on benthic abundance or temperature.

2.2 Analysis methods

The effects of five factors on changes in benthic abundance between influence and reference sites were assessed. Two of these factors were intrinsic to the operation of the power plant under investigation, namely 1) generation capacity and 2) cooling water discharge.

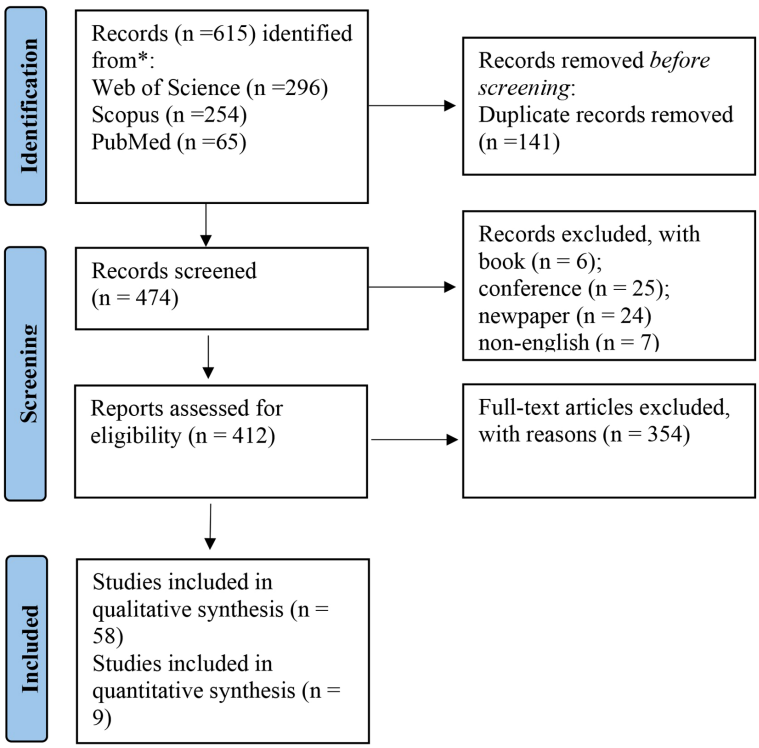


FIGURE 1
PRISMA flow diagram for the systematic review.

10.3389/fmars.2024.1465289

TABLE 1 Electrical generating capacity (MWe) of the power plants studied by the articles included in the systematic review.

ID	Authors	Year	Power plants	Country	Generation capacity (MWe)
1	Kolehmainen et al	1974	Costa Sur power station	USA	1110
2	Burton et al	1976	Calvert Cliffs Nuclear power plant	USA	1750
3	Alden Iii	1979	Floride power plant	Mexico	897
4	Loi et al	1979	Calvert Cliffs Nuclear power plant	USA	1750
5	Crema et al	1980	Piombino power plant	Italy	320
6	Kastendiek et al	1981	San Onofre Nuclear power plant	USA	450
7	Møller et al	1983	29 power plants	Denmark	770-6000
8	Snoeijs	1989	Forsmark Nuclear power plant	Sweden	3320
9	Bamber	1990	Angra Nuclear power plant	Brazil	1884
10	Hoglund & Thomas	A1992	Oskarshamn Nuclear power plant	Sweden	1450
11	Ahamed et al	1992	Madras Atomic power station	India	230
12	Sasikumar et al	1993	Madras Atomic power station	India	230
13	Schroeter et al	1993	Onofre Nuclear power plant	USA	2254
14	Suresh et al	1993	Madras Atomic power station	India	230
15	Zimina et al	1994	Leningrad Nuclear power plant	Russia	1850
16	Suresh et al	1996	Madras Atomic power station	India	230
17	Attrill & Thomas	1996	West Thurrock power station	UK	1300
18	Wong et al	1998	Nuclear power plant (1, 2)	China (Taiwan)	2945
19	Lardicci et al	1999	Torre del Sale power station	Italy	640
20	Masilamoni et al	2002	Madras Atomic power station	India	230
21	Rajagopal et al	2003	Madras Atomic power station	India	230
22	Chou et al	2004	Nuclear power plant	China (Taiwan)	1960
23	Hwang et al	2004	Nuclear power plant (1, 2)	China (Taiwan)	1960
24	Schiel et al	2004	Diablo Cove power plant	USA	2256
25	Zvyagintsev et al	2004	Vladivostok Heat power plant	Russia	–
26	Steinbeck et al	2005	Diablo Cove power plant	USA	2256
27	Martin & Planque	2006	Flamanville Nuclear power plant	France	2660
28	Wang et al	2008	Daya Bay Nuclear power plant	China	1888
29	Teixeira et al	2009	Brazilian Nuclear power plant	Brazil	1900
30	Hussain et al	2010	Madras Atomic power station	India	230
31	Arieli et al	2011	Hadera power plant	Israel	2650
32	Murugesan et al	2011	Tuticorin Thermal power plant	India	1050
33	Wang et al	2011	Daya Bay nuclear power plant	China	1888
34	Falfushynska et al	2012	Khmelnytskyi nuclear power plant	Ukraine, Belarus	2000
35	Simard et al	2012	Gentilly-2 nuclear power station	Canada	925
36	Teixeira et al	2012	Brazilian nuclear power plant	Brazil	1900
37	Mazik et al	2013	Heysham 2 nuclear power station	UK	1320
38	Florin et al	2013	Forsmark nuclear power plant	Sweden	3320
39	Bryan et al	2014	Bayshore power plant	USA	3239

(Continued)

TABLE 1 Continued

ID	Authors	Year	Power plants	Country	Generation capacity (MWe)
40	Krepski et al	2014	Dolna Odra power plant	Poland	1772
41	Cardoso-Mohedano et al	2015	Kuosheng nuclear power plant	UK, Mexico	4131
42	Yanygina	2015	Belovo power plant	Russia	–
43	Dallas et al	2016	Hadera and Nachsolim power plant	Israel, Germany	1888
44	Kim et al	2017	Dae-San power plant	Korea, China (Taiwan)	3914
45	Bozorgchenani et al	2018	Neka power plant	Iran	2214
46	Dong et al	2018	Tianwan nuclear power plant	China	2120
47	Lin et al	2018	Ningde nuclear power plant	China	2000
48	Deabes et al	2020	El-Burullus power plant	Egypt	–
49	Farshchi et al	2020	Pareh-Sar power plant	Iran	648
50	Lan et al	2020	Houshi power plant	China	–
51	Rao et al	2021	Daya Bay nuclear power plant	China	1888
52	West et al	2021	Shannonbridge power plant	Ireland	264
53	Kalimuthu et al	2022	Tanjung Kidurong power plant	Malaysia	515
54	Cai et al	2023	Daya Bay nuclear power plant	China	1888
55	QIAO et al	2023	Wenzhou power station	China	2000
56	Macias et al	2024	Kospo Namjeju power station	Korea	–
57	Oshimi et al	2021	OTEC power plant	Japan	1
58	Giraud et al	2019	OTEC power plant	France	10

These articles are identified by study identity (ID), first author, country, and year of publication.
"–" indicated that related information was not found.

Additionally, 3) the distance (0–100 m) between the discharge point and sampling sites (the influence point), 4) ambient water temperature, and 5) the temperature difference between the influence point and the reference point were considered regulatory factors.

Changes in benthic abundance determined based on Equation 1:

$$\text{Benthic abundance changes} = (Ai - Ar)/Ar \quad (1)$$

Where Ai is the abundance of benthos at the influence site, and Ar is the abundance of benthos at the reference site.

If an impacted site was contrasted with multiple reference sites, the average temperature was computed by aggregating data from all reference sites. In cases where multiple study areas were delineated, the data closest to the outfall was prioritized. When textual information regarding temperature, standard deviation, and the sample size was absent but figures were available, data were extracted using the WebPlotDigitizer tool (https://automeris.io/WebPlotDigitizer/).

The temporal evolution of scientific findings regarding the impacts of thermal and cold emissions from power stations on benthos over the past decade was analyzed using CiteSpace. Additionally, the categories with the highest number of publications on this topic were identified. After compiling the data for each power plant investigated in the preliminary study (Table 1), distribution plots were generated utilizing R 4.3.1 software (R Core Team, 2023). All statistical analyses were conducted in R 4.3.1 software.

3 Result and discussion

3.1 Temporal and spatial variations in the influence of coastal power plant cooling water on benthic organisms

Supplementary Figure S1 depicts the number of research articles and reviews concerning the impacts of thermal and cold effluents from coastal power plants on benthic biodiversity spanning from 1974 to 2024. Notably, there was a steady increase in the number of publications over ten years, with the most substantial surge observed between the periods 1995–2004 and 2005–2014, rising from 10 to 15 articles (Supplementary Figure S1). In terms of publication frequency by category, the highest proportion of articles was published in the category ENVIRONMENTAL SCIENCES (26.7%), followed by the categories MARINE & FRESHWATER BIOLOGY (16.1%) and ECOLOGY (10.7%) (Supplementary Figure S2).

3.1.1 Spatial variation of related studies

Figure 2 demonstrated a wide geographical representation in the study, with contributions from 22 countries and regions. Nevertheless, research on this topic exhibits uneven distribution worldwide. Among coastal regions, China, the USA, India, and Russia exhibited the highest number of publications in this review,

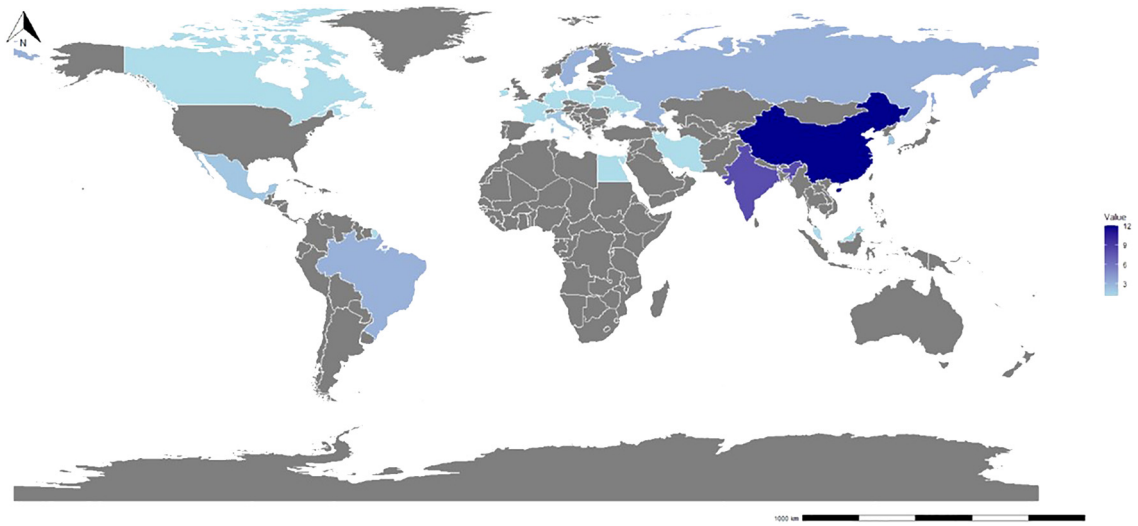


FIGURE 2
The relative distribution and volume of studies reviewed by countries around the world.

accounting for 12, 8, 8, and 3 articles, respectively. These countries contributed approximately 52.5% of the total studies. The underlying reason for this phenomenon could be attributed to the dominant role of power generation in these countries on a global scale, thereby amplifying the environmental challenges associated with power plant emissions. According to data released by the International Energy Agency (IEA) as of 2024, these four countries were ranked 1, 2, 3, and 4 in terms of power generation (IEA, 2024). Among the countries examined, the United States stood out as the first to focus on the impact of thermal discharge from power plants on marine benthic organisms (Kolehmainen et al., 1974; Burton et al., 1976). In relative terms, China's research in this field commenced more than two decades later. However, it is noteworthy that China has increasingly devoted attention to this research direction in recent years (Cai et al., 2023; Qiao et al., 2023). Concurrently, research in India predominantly concentrated on assessing the effects of the Madras Atomic Power Station on marine life, including benthic organisms (Murugesan et al., 2011).

This study identified a scarcity of research addressing the impact of power plant discharge on marine benthic organisms within tropical regions, with current literature primarily limited to India (8), Brazil (3), Mexico (2), and Malaysia (1). Interestingly, all 14 articles identified within these regions exclusively examined the effects of thermal discharge. Conversely, there were limited studies

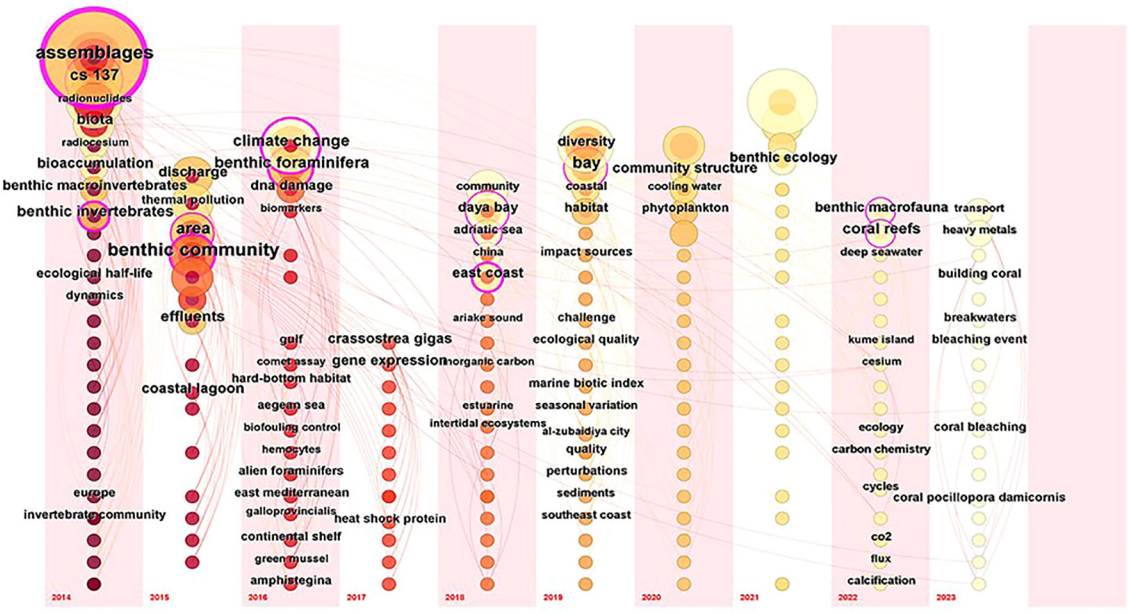


FIGURE 3
Visualize the last ten years of keywords through a time series.

investigating the impacts of cold discharge from power plants on marine benthic organisms in tropical areas. Furthermore, on a global scale, only two studies were located concerning the effects of cold discharge from power plants on marine life, with a primary emphasis on fish populations (Oshimi et al., 2021) and phytoplankton dynamics (Giraud et al., 2019). This notable absence of research on the effects of cold discharge from power plants, particularly Ocean Thermal Energy Conversion (OTEC) plants, underscored a significant gap in understanding the potential ecological impacts within tropical marine ecosystems.

3.1.2 Temporal variation of relevant studies

Figure 3 presented a time series keyword map delineating the study of power plant impacts on coastal benthic organisms spanning the years 2014 to 2023. This visualization encompassed 197 high-frequency words interconnected by 622 lines. The density of the network map is 0.0322, indicating that 3.22% of the potential relationships in the network have been realized. This result underscores the limited interaction among those keywords. Notably, the modularity degree Q attained a value of 0.8055, surpassing the threshold of 0.3, thereby indicating a reasonable level of structural organization within the dataset. Furthermore, the silhouette score, registering at 0.957, exceeded the threshold of 0.4, thereby supporting the credibility and coherence of Figure 3.

Figure 3 highlights high-frequency keywords (frequency > 7) over the past decade, with the size of each circle representing the co-occurrence frequency of the corresponding keyword. Notably, during this period, nine keywords — “assemblages”, “benthic community”, “benthic macrofauna”, “benthic foraminifera”, “benthic invertebrates”, “coral reefs”, “east coast”, “bay”, and “climate change”—were observed with high frequency. These keywords respectively highlight the most researched organism groups, biological indices, study sites, and environmental issues contributing to the increase in water temperatures.

The high frequency with which the term “assemblages”, “benthic community”, and “benthic invertebrates” appeared in the 2014 and 2015 keyword clouds indicates a substantial volume of research focused on the impact of power plant thermal emissions on the benthic community and assemblages of benthic invertebrates (Bryan et al., 2014; Cardoso-Mohedano et al., 2015).

The frequent use of the term “climate change” reflects its role in exacerbating the impact of thermal emissions from power plants on benthic organisms. This is due to the fact that the burning of fossil fuels in power plants is a significant contributor to climate change (Osman et al., 2023). Furthermore, climate change has accelerated ocean surface warming (Garcia-Soto et al., 2021; Oh et al., 2024; Dalpadado et al., 2024), thereby intensifying the effects of thermal emissions on benthic organisms (Farshchi et al., 2020; Wasti et al., 2022).

Between 2022 and 2023, the most prevalent keywords are “ benthic macrofauna “ and “coral reefs”. This trend underscored the growing importance of studying the influence exerted by coastal power plant wastewater on the composition and dynamics of macrobenthic and coral reef communities in the specified region (West et al., 2021; Qiao et al., 2023).

3.2 Impact of water temperature changes on benthos

The literature reviewed in this study does not indicate any instances where thermal emissions from power plants have no impact on benthic communities and their abundance. Specifically, 62.5% of the studies reported that thermal emissions have detrimental effects on benthic organisms, leading to reduced biodiversity and abundance (Arieli et al., 2011; Hussain et al., 2010; Teixeira et al., 2009; West et al., 2021). Conversely, 25% of the studies noted an increase in benthic abundance attributed to thermal emissions, primarily due to low ambient temperatures (Farshchi et al., 2020; Simard et al., 2012) or minimal temperature differentials (Bozorgchenani et al., 2018; Bryan et al., 2014). Additionally, 12.5% of the studies indicated that the impact of thermal emissions on benthic organisms varied seasonally; specifically, during winter, lower ambient temperatures resulted in increased benthic abundance, while in other seasons, the effects were generally negative (Titelboim et al., 2016).

3.2.1 Benthic biodiversity parameters for population, community, and ecosystem

Of the 58 articles, 56 specifically highlighted temperature as a crucial factor in the observed alterations of ecological indicators among benthic organisms. These articles further conducted qualitative investigations into these phenomena. The most cited biodiversity parameters among those that suffered alterations were related to changes in the structure and composition of populations, communities, and ecosystems, namely: abundance (20.5%), community structure (13.94%), distribution (13.12%), species richness (9.84%), density (8.2%), and species evenness (6.56%), which together accounted for >70% of the total parameters affected (Figure 4).

There is clear evidence that the abundance, community structure, and distribution of benthic organisms are influenced by thermal discharges. A meta-analysis of 75 studies conducted by Guimarães et al. (2023) demonstrated a significant increase in water temperature near nuclear power plants due to thermal emissions compared to reference areas, with a mean increase of 4.38°C (95% CI = 3.72-5.03). This increase in temperature can harm benthic communities, potentially leading to habitat loss, decreased biodiversity indices, or even species extinction. These findings are consistent with those of Farshchi et al. (2020), who studied macrobenthos near the outlet of the Neka power plant in the southern Caspian Sea. Farshchi et al. (2020) determined that thermal emissions from the power plant significantly affected macroinvertebrate abundance, species richness, species composition, and assemblage structure when comparing impacted and control stations. Although there is limited research on the impact of cold emissions on benthic community structure,

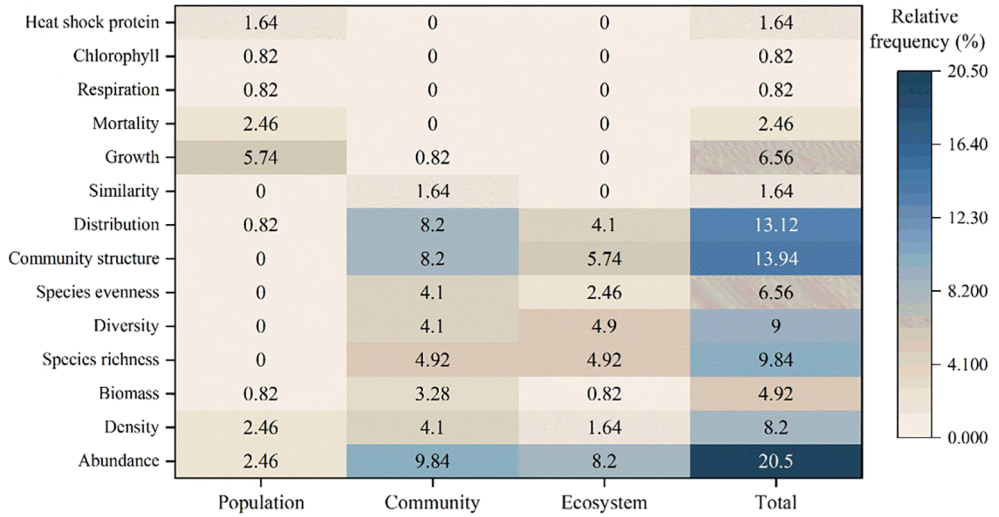


FIGURE 4
The relative citation frequency (%) of benthic biodiversity parameters affected by coastal power plant discharge is analyzed across population, community, and ecosystem levels.

studies examining seasonal variations have shown that lower ambient temperatures can lead to significant shifts in community structure (Li et al., 2020) and diversity (Bacouillard et al., 2020), and a marked decrease in biomass (Ying et al., 2020).

Temperature affects not only the ecological indices of benthic communities but also significantly influences the physiological activities of individual organisms (Deldicq et al., 2021). Vaquer-Sunyer and Duarte (2011) demonstrated that higher temperatures reduce the mean survival time of marine benthic organisms by more than 50% under anoxic conditions. Similarly, Kim et al. (2017) reported that proximity to thermal wastewater outlets results in decreased abundance and smaller sizes of Crassostrea gigas, alongside significantly elevated levels of heat shock proteins hsp70 and hsp90 mRNA (Kim et al., 2017). Conversely, excessively low temperatures have been shown to hinder the growth and development of benthic invertebrates' eggs and larvae (Zeng et al., 2020; Everall et al., 2015), and even cause high mortality rates of benthic invertebrates (Colella et al., 2012; Thieltges et al., 2004).

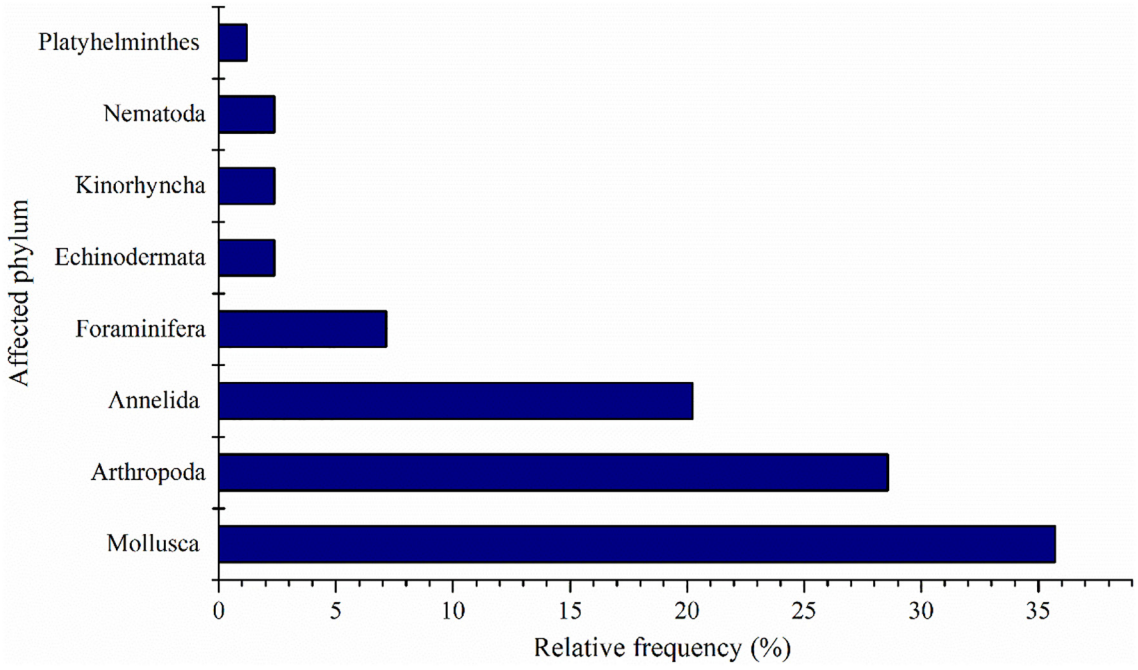


FIGURE 5
Relative frequency (%) of benthic classes impacted by temperature variations in the discharge area of power plants.

Furthermore, the metamorphosis of marine benthos is temperature-dependent, with colder water significantly prolonging the time to metamorphosis (Gangur and Marshall, 2020; Gall et al., 2021).

3.2.2 Benthic assemblage structure and species composition

The effects of elevated temperatures linked to power plant discharge were frequently discerned through alterations in the composition of biological communities, facilitating the assessment and observation of ecological parameters about community composition and structure. These parameters included abundance, spatial distribution, dominance, density, and species richness (Farshchi et al., 2020).

Utilizing data extracted from 56 published articles investigating alterations in benthic organisms near power plant outfalls, it was noted that Mollusca garnered the highest citation frequency (35.71%), followed by Arthropoda (28.57%), and Annelida (20.24%). Collectively, these taxa accounted for over 84.52% of the total benthic community impacted by power plant effluents (Figure 5).

The significant alteration of benthic community structure by power plant discharge could be attributed to the limited ability of sessile and slow-moving benthic organisms to migrate to less stressful environments, rendering them particularly vulnerable to acute temperature stress (Smith et al., 2023). Elevated temperatures were associated with mass mortality events in Gastropoda and Foraminifera (Arieli et al., 2011; Schiel et al., 2004; Titelboim et al., 2016). Additionally, these temperature increases could result in reduced egg production in scallops and crabs, posing challenges to recovering losses incurred through fishing activities (Caputi et al., 2019). Nevertheless, thermal discharge could create a conducive environment for thermal-tolerant species of *Mytilopsis leucophaeata* (Florin et al., 2013), *Periwinkles*, and *Cthamalid barnacles* (Suresh et al., 1993). Conversely, lower water temperatures influence benthic community dynamics. Heip and Craeymeersch (1995) investigated benthic organisms in the same marine region and observed that macrofaunal body weight, density, and diversity increased linearly as water temperatures decreased. In contrast, the distribution patterns and trends within the meiofauna differed significantly, which had a notable impact on the overall structure of the benthic community.

3.2.3 Benthic abundance

Considerable evidence attests to the significant elevation of temperature within thermal discharge zones in contrast to reference regions (Farshchi et al., 2020; Cai et al., 2023; Bozorgchenani et al., 2018). Guimarães et al. (2023), through a meticulous meta-analysis, demonstrated a substantial increase of 4.38°C in water temperature adjacent to nuclear power plant outlet. Furthermore, their findings revealed a correlation between temperature fluctuations and the geographical latitude of power plant installations (Guimarães et al., 2023). Nevertheless, consensus remained elusive regarding the precise impact of variables such as temperature differentials, ambient environmental conditions, and the volume of power plant effluent on benthic organisms. Our research utilized the Spearman correlation coefficient to examine the impact of several variables, including generation capacity, cooling water discharge, distance between discharge points and sampling locations, ambient water temperature, and temperature differential between influence and reference points, on variations in benthic abundance. Findings indicated that plant age, temperature difference ($P < 0.05$) and ambient temperature ($P < 0.01$) exhibited statistically significant effects, displaying a negative correlation (Figure 6). Notably, the analysis revealed no statistically

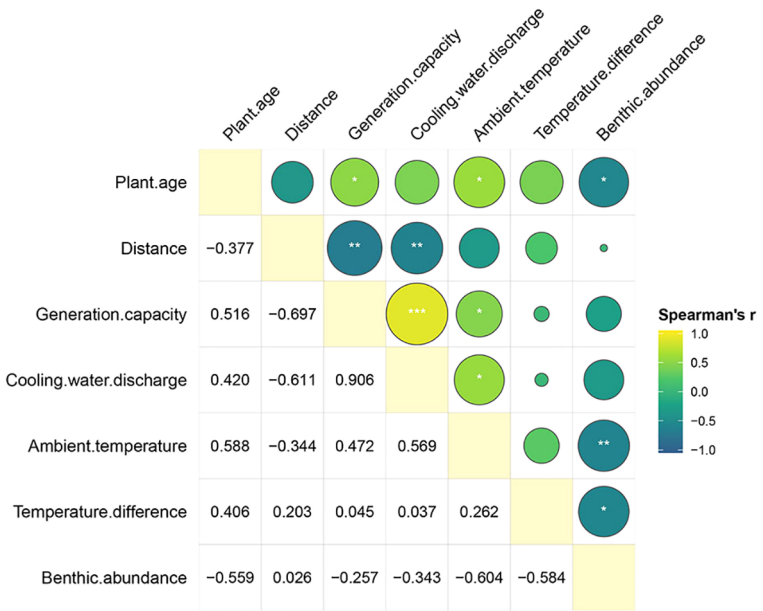


FIGURE 6
Spearman correlation coefficients (r) assessed relationships between 5 factors and benthic abundance changes. Significance levels were denoted by asterisks (***, **, and *) for p-values < 0.001, 0.01, and 0.05, respectively.

10.3389/fmars.2024.1465289

significant associations between changes in benthic abundance and factors such as generation capacity, cooling water discharge, or the distance between discharge points and sampling points.

This study revealed a direct correlation between the magnitude of the temperature variance between the impacted and control sites and the extent of benthic abundance decline. Indeed, as far back as 1984, GESAMP emphasized that to uphold the ecological integrity of marine environments, temperature differentials near power plants should not have surpassed 7°C in subtropical waters and 5°C in tropical waters (GESAMP, 1984). Arai et al. (2015) demonstrated that the composition of benthic communities was substantially influenced by temperature disparities.

Benthos had a limited tolerance for high temperatures, with a maximum water temperature range of approximately 35-45.8°C (Saraswat et al., 2011; Hamilton and Gosselin, 2020). Different species had different temperature preferences and tolerances, and changes in water temperature affected their growth, reproduction, and survival (Jones et al., 2010; Cardoso-Mohedano et al., 2015). In tropical regions where surface sea temperatures frequently exceed 30°C, even a temperature increase of less than 5°C also adversely affect certain organisms, pushing them beyond their thermal tolerance limits (Kimmerer and Weaver, 2013; Farshchi et al., 2020). Yang et al. (2020) investigated the effects of various environmental factors on benthic organisms and found that temperature variation is the most critical factor influencing changes in benthic abundance and tolerance characteristics. Specifically, benthic abundance was lower in summer compared to spring, when decreased temperatures led to an increase in abundance.

From Figure 6, there is a significant negative correlation between benthic abundance and power plant operational time ($P < 0.05$). This indicates that as the operational time of the power plants increases, benthic abundance decreases. In the initial years of operation, thermal discharges from power plants can significantly alter the community structure and abundance of benthic organisms; however, these changes typically stabilize over time. The Daya Bay Nuclear Power Station has been operational since 1994, and Wang et al. (2008) conducted an extensive assessment of ecological indicators in Daya Bay over a 22-year period (1982-2004). Their findings revealed a marked decline in both the average biomass and species richness of benthic animals near the nuclear power plant, with biomass decreasing from 317.9 g/m² in 1991 to 45.24 g/m² in 2004, and species richness declining from 250 species in 1991 to 177 species in 2004. However, field investigations conducted in 2021 and 2023 indicated that thermal discharges from the power plant had minimal impact on larger benthic organisms in the surrounding marine environment (Rao et al., 2021; Cai et al., 2023). This phenomenon may be attributed to the substantial influence of domestic and industrial sewage discharge, as well as mariculture activities, on the ecological integrity of Daya Bay, alongside the gradual stabilization of community structure and abundance trends over time. Consequently, no significant differences were observed in the composition and functional diversity of the macrobenthic community between the thermal discharge area and the control area (Rao et al., 2021).

Similarly, the Madras Atomic Power Station, which began full operations in 1984, has been the subject of seven studies examining the effects of thermal emissions on benthic communities from 1992 to

TABLE 2 List of various coastal environmental factors affected by cooling water discharge from power plants.

Title	Country	Plant age (year)	Generation capacity (MW)	Cooling water discharge (m^3/s)	Discharge area (km)	Discharge depth (m)	Ambient temperature (°C)	Temperature difference (°C)	Influence sites		Reference
									Increase	Decrease	
Daya Bay nuclear power plant	China	30	1,968	95	1–28	< 10	14.8–29.1	0.2–4.2	Oils, Arsenic, Total phosphorus, and Silicate	Salinity, DO, suspended solids, chromium	Cai et al., 2023
Pare–Sar power plant	Iran	7	648	42	0–0.7	5	30.81	0.7–3.8		Chlorophyll-a, Phaeopigment	Farshchi et al., 2020
							9.4	0.3–0.5	Chlorophyll-a, Phaeopigment		
Orot Rabin power plant	Israel	35	2590	–	1.5	0.5	12–31.5	0.59–4.7		Total dissolved solid	Titelboim et al., 2016
Neka power plant	Iran	39	2214	57.8	1.0	3.6	12.2–12.43	2.16–3.01	Clay, Organic content,	Sand, Chl-a, Pha-a	Bozorgchenani et al., 2018
							28.39–28.48	5.01–5.20			

(Continued)

TABLE 2 Continued

Title	Country	Plant age (year)	Generation capacity (MW)	Cooling water discharge (m^3/s)	Discharge area (km)	Discharge depth (m)	Ambient temperature (°C)	Temperature difference (°C)	Influence sites		Reference
									Increase	Decrease	
Daya Bay nuclear power plant	China	15	1,968	95	1–25	< 10	19.3–22.6	2.1–3.5		COD, pH, Nitrate	Wang et al., 2008
							27.5–29.1	0.5–1.3			
							27.0–27.8	0.2–1.2	DO, Ammonium, Phosphate, Chl-a		
							14.8–18.3	2.7–4.2			
Wasit power plant	Iraq	21	–	–	0.1–20	0.5	15–33	1.2–5.8	pH, BOD, Total Dissolved Soiled, Conductivity, Turbidity	DO	Jebure and Meshjel, 2019
Dolna Odra power plant	Poland	40	700	–	10	–	17.7	6.5	Conductivity, Phosphate, total nitrogen	pH, DO	Krepski et al., 2014
Forsmark nuclear power plant	Sweden	30	–	–	4	< 5	2.2–11.8	4.9–6.4		Nitrate, Phosphate	Hillebrand et al., 2010
Jaitapur nuclear power plant	India	–		–	20	–	24–28.4	–	Total Alkalinity	DO, Ammonia, pH	Sivaperumal et al., 2022
Madras Atomic power plant	India	9	500	35	0.5	2	29.2–34.2	2.3–3	Salinity and DO not have too much fluctuation		Suresh et al., 1993
OTEC power plant	Japan	–	1	3.6	0.2	–	28.8	−10.3	Nitrate, TCO_2	pH	Oshimi et al., 2021
OTEC power plant	France	–	10	28	0.4–0.6	45–500	28	-20	Heavy metals, Nitrate, Silicic acid, Phosphate, Phaeopigment		Giraud et al., 2019

10.3389/fmars.2024.1465289

2010. Research conducted in 1992 and 1993 documented a 25% reduction in species richness at the outlet, with significant seasonal variations. During this period, ambient temperatures ranged from 37.0 to 37.6°C, resulting in near-total mortality of macrobenthos, with the exceptions of periwinkles and Chthamalid barnacles (Ahamed et al., 1992; Sasikumar et al., 1993; Suresh et al., 1993). Subsequently, the community structure evolved steadily, leading to a focus on the thermal tolerance and physiological characteristics of individual species. From 1996 to 2003, studies primarily investigated the thermal tolerance and physiological responses of copepods (Suresh et al., 1996), bivalves (Masilamoni et al., 2002), and oysters (Rajagopal et al., 2003) in proximity to the emission outlet. Additionally, Hussain et al. (2010) reported that the population of Donax cuneatus was notably rare within 100 meters of the mixing zone, while the control group exhibited a density of 64.0 ± 3.6 to 88.3 ± 9.6 ind/m^2.

3.3 Effects of power plant discharge on changes in other environmental parameters

As depicted in Table 2, thermal emissions from power plants generally coincided with a decline in dissolved oxygen, pH, chlorophyll-a, and phaeopigment levels in the vicinity of the discharge outlet, with the exception being during periods of exceptionally low ambient water temperature. Concurrently, there was an observable increase in conductivity, clay, and organic content near the outfall under these circumstances. Conversely, cold emissions from power plants exhibited an elevation in nitrate, silicic acid, phosphate, chlorophyll-a, and phaeopigment concentrations. Notably, fluctuations in other environmental factors, such as salinity, are comparatively restrained.

3.3.1 Dissolved oxygen

In the realm of Ocean Thermal Energy Conversion (OTEC), where the process involved the uptake of deep, nutrient-rich seawater, a pertinent phenomenon emerges wherein the disparity in density between the discharged plume and its ambient surroundings triggered a tendency for the plume to either ascend or descend to an equilibrium depth. This intricate interplay gave rise to an artificially induced zone enriched with nutrients, as observed in the study by Comfort and Vega (2011). When this plume equilibrium occurs within the zone of light penetration, there is the potential to stimulate phytoplankton and algal blooms (Giraud et al., 2019).

Simultaneously, the discharge of thermal effluent from power plants introduced a marked temperature elevation in proximity to the outfall. This not only reduces water viscosity and increases water vapor pressure, directly influencing the dissolved oxygen-carrying capacity of seawater, as suggested by Ali et al. (2020), but also indirectly influenced the dissolved oxygen levels by affecting microbial activity due to the temperature elevation. Breitburg et al. (2018) observed that rising oceanic temperature, coupled with heightened nutrient discharge into coastal waters, synergistically accelerated microbial respiration-driven oxygen consumption. This process reduced oxygen solubility in water, and prolonged the replenishment duration of atmospheric oxygen to the aquatic environment.

Nevertheless, oxygen was vital for benthic organisms to conduct metabolic processes and sustain their physiological functions. Persistent exposure to environments with low dissolved oxygen content posed significant constraints on the life activities and behaviors of benthic organisms (Chan et al., 2008). Many benthic species could not thrive in oxygen-depleted waters, and those that managed to survive have experienced diminished growth rates, reproductive failures, and heightened vulnerability to diseases (Hyvärinen et al., 2022; Briggs et al., 2021). Furthermore, the decline in species diversity resulting from diminishing oxygen levels could have triggered cascading impacts on marine ecosystems, leading to the loss of food sources and disruptions in nutrient cycling (Sun et al., 2022). Singh et al. (2021) documented a positive correlation between the diversity index of *Hanzawaia concentrica*, *Globocassidulina subglobosa*, and *Cancris sagra* and dissolved oxygen levels in aquatic environments, underscoring the crucial role of dissolved oxygen in sustaining the survival and diversity of benthic communities (Singh et al., 2021).

3.3.2 pH levels

According to Henry's law, the solubility of gases in water decreases as temperature rises, so higher temperatures reduce the solubility of carbon dioxide. In regions with warm ambient water, thermal discharge from power plants can increase pH levels (Jebure and Meshjel, 2019). However, in other areas, thermal discharge may lower seawater pH (Table 2). The impact of power plant discharges on water bodies is influenced by both the discharge volume and the temperature difference from ambient water. Larger discharge volumes and higher temperature differences can significantly elevate local water temperatures, affecting wider areas of the water body (Raptis et al., 2016; Issakhov and Zhandaulet, 2021). In semi-enclosed bodies, like estuaries and bays with limited water exchange, thermal discharges can impact the entire system, as poor circulation exacerbates temperature retention and affects local ecosystems more extensively (Raptis et al., 2016). Similarly, cold discharges with large volumes and high temperature differences have greater effects, determining the extent of cooling and the area impacted (Issakhov and Zhandaulet, 2021).

Changes in pH can alter the chemical properties of the water and directly affect the physiology, behavior, and distribution of marine organisms (Table 3). Kroeker et al. (2013) comprehensively analyzed the results of 228 studies examining the biological effects of ocean acidification. Their results suggest that acidification leads to decreased survival, calcification, growth, reproduction and development in a wide range of marine organisms, as well as significant character-mediated variation between taxa and enhanced sensitivity to early life history stages. In addition, their results indicate that mollusks are significantly sensitive to acidification, especially during the larval stage, and that vulnerability to acidification increases with simultaneous exposure of multiple organisms to elevated sea temperature.

pH levels can impact the availability of dissolved minerals and nutrients that are essential for the growth and reproduction of benthic

TABLE 3 Summary of effects of acidification among key taxonomic groups.

Taxa	pH change	Experimental period	Calcification rate	Abundance	Survival rate	Reference
Benthic herbivorous grazers	-1~0.2	≤ 5 d	–	–	-87%	Busch and McElhany, 2016
Bivalves	-1~0.2	7~30 d	–	–	-77%	Busch and McElhany, 2016
Shallow benthic filter feeders	-1~0.2	7~30 d	–	–	-48%	Busch and McElhany, 2016
Carnivorous infauna	-1~0.2	7~30 d	–	–	-34%	Busch and McElhany, 2016
Deposit feeders	-1~0.2	7~30 d	–	–	-32%	Busch and McElhany, 2016
Coral	-0.5	≤10 d	-39%	-33%	–	Kroeker et al., 2010
Mollusks	-0.5	≤10 d	95% CI overlaps 0	95% CI overlaps 0	95% CI overlaps 0	Kroeker et al., 2010
Echinoderms (Juvenile)	-0.5	≤10 d	95% CI overlaps 0	-33%	95% CI overlaps 0	Kroeker et al., 2010
Crustacea (Adult)	-0.5	≤10 d	10.5%	95% CI overlaps 0	-32%	Kroeker et al., 2010
Coral	-0.54	53 y	-14.9%	–	–	Kang et al., 2021
Coral	-0.38	2 mos	-47%	–	-73-90%	Crook et al., 2012
Lymnaea auricularia	-2.0	10 w	–	-83.85%	–	Al-Yaquob, 2011
Lymnaea auricularia	-1.0	10 w	–	-27.7%	–	Al-Yaquob, 2011
Lymnaea auricularia	0	10 w	–	0	–	Al-Yaquob, 2011
Lymnaea auricularia	1.0	10 w	–	+20%	–	Al-Yaquob, 2011
Phorcus sauciatus	-0.2 – -0.4	long-term	-37.63 ± 9.26%	ns	–	Viotti et al., 2019
Phorcus sauciatus	-0.54 – -1.05	long-term	-39.01 ± 10.81%	ns	–	Viotti et al., 2019
Nassarius nitidus	-0.5	3 mos	-47.7%	–	–	Chatzinikolaou et al., 2017
Columbella rustica	-0.5	3 mos	-30%	–	–	Chatzinikolaou et al., 2017

organisms. Additionally, high or low pH levels can directly affect the acidity or alkalinity of the water, which can be harmful to benthic organisms if it exceeds their tolerance range (Fabricius et al., 2014).

The pH tolerance range of benthic organisms has been extensively studied, with research defining specific thresholds that delineate conditions for optimal health and survival across various taxa (Feugere et al., 2021; Dong et al., 2020). Benthic macroinvertebrates, particularly sensitive to pH fluctuations, generally experience adverse effects when pH levels fall below 5 or exceed 9 (Yuan, 2004). The pH of a fluid is positively correlated with the concentration of carbonate, bicarbonate, and other related salts in the aquatic environment. Calcifying invertebrates, such as corals, gastropods, and bivalves, rely on calcium carbonate for structural formation. Ocean acidification, by reducing the availability of carbonate ions necessary for calcification, weakens these structures, often increasing mortality rates (Hoegh-Guldberg et al., 2017; Beesley et al., 2008; Vargas et al., 2015). When the pH value of seawater decreases below 7, it can have severe impacts on marine organisms such as shrimp, snails, and bivalves with calcium carbonate shells, which experience difficulties in surviving. Additionally, if the pH value drops below 6.5, the benthic population will degrade, and their reproductive capacity will be significantly reduced (Busch and McElhany, 2016). Dong et al. (2020) investigated the growth, development, and community structure changes of various types of foraminifera (hyaline, porcelaneous, and agglutinated) in different pH environments. The study revealed that the species richness and individual growth of hyaline and porcelaneous foraminifera were positively correlated with pH, while the agglutinated foraminifera exhibited a negative correlation (Dong et al., 2020).

In a key experimental study, Kroeker et al. (2011) specifically investigated pH tolerance among invertebrates, conducting a controlled trial on Castello Aragonese d'Ischia, a small island, in May and September. By releasing carbon dioxide at a depth of 0.5–3 meters around the site, the researchers adjusted pH levels and assessed species abundances near the vents, sampling over 15,000 individuals across 82 taxonomic families. This study quantified suitable pH ranges for different invertebrate taxa, finding that a pH of 8.1 ± 0.1 was optimal for 4% of gastropods, 22% of decapods, 10% of amphipods, 29% of tanaids, 38% of isopods, 47% of polychaetes, and 75% of sipunculids. For 26% of gastropods, 30% of bivalves, 39% of decapods, 7% of amphipods, and 38% of isopods, a broader pH range of 7.8 ± 0.3 to 8.1 ± 0.1 was suitable, while amphipods, 29% of tanaids, 13% of isopods, and 7% of polychaetes tolerated a range of 6.6 ± 0.5 to 8.1 ± 0.1.

From the above, the impact of pH on the benthic community is contingent upon several factors, including the extent of pH fluctuations, the type of pre-existing benthic community, and the ecological backdrop of the ecosystem.

3.3.3 Bottom material

The process of piping large quantities of cooling water from power plants into the ocean contributes to the transport of coastal sediment (Venugopalan et al., 2011; Wither et al., 2012). Bozorgchenani et al. (2018) conducted a parallel investigation, which revealed a prevailing dominance of clay and silt in the sediment composition at both discharge outlets of power plants. This observation was derived from year-round monitoring of sediment particle sizes. In contrast, the control group exhibited a prevailing dominance of sand. Furthermore, Bozorgchenani et al. (2018) noted a marked elevation in the total organic matter (TOM) content at the discharge point in comparison to the control point. In tandem, studies have substantiated that the elevated temperatures at the thermal discharge points played a pivotal role in fostering an increase in organic matter content. Interestingly, in certain regions, there was a notable increase in organic matter content during summer compared to winter. This phenomenon is attributed to the augmented primary production resulting from higher temperatures (Cheng et al., 2004; Sarkar et al., 2005). The impact of power plant discharge extended significantly to sediment composition.

3.4 Mitigation measures

To effectively address hazards to marine ecology, various management strategies have been employed. These include marine spatial planning (Ehler, 2008), adaptive management (Williams, 2011), and risk retirement, which involves reducing or eliminating potential environmental risks associated with marine activities to safeguard marine ecosystems (Copping et al., 2020). These strategies encompass a range of actions, including siting, permitting, monitoring, and, when necessary, mitigating potential risks (O'Hagan, 2020; Jansujwicz and Johnson, 2015). When selecting mitigation measures, priority was given to the location of outfalls and the placement of energy equipment to minimize environmental impact while ensuring safety for shipping and fishing activities. Mitigation measures aimed at preventing and controlling the adverse effects of power plant effluent on marine benthos are detailed in Table 4.

Cold discharge from Ocean Thermal Energy Conversion (OTEC) systems can significantly impact the marine ecological environment. Distributed discharge serves as an effective mitigation strategy for managing cold discharge water. By dispersing cold, nutrient-rich deep seawater over a broader area, this approach minimizes localized environmental impacts, such as excessive fertilization of surface waters, which can lead to harmful algal blooms (Giraud et al., 2019). Research suggests that strategically placing discharge outlets at optimal depths—generally below the mixed layer—enhances nutrient dilution and reduces potential ecological effects (Viviani et al., 2011; Comfort and Vega, 2011). For example, positioning discharge outlets where light penetration is limited, ideally at depths of 90 meters or below, can further mitigate risks to phytoplankton communities (Jia et al., 2012).

In contrast, the discharge of high-temperature water can pose additional risks to marine ecosystems. To mitigate these impacts, strategies such as thermal plume modeling and controlled mixing with ambient seawater can be employed. The discharge temperature should be carefully monitored to ensure it remains within acceptable limits to prevent thermal shock to marine life (Liu et al., 2023). Additionally, using cooling towers or heat exchangers can help reduce the temperature of the discharged water before it enters the marine environment (Kumar and Sharma, 2020). However, these technologies often result in increased initial and operating costs, which should be considered in the overall assessment of their effectiveness and feasibility (Ayoub et al., 2018; Castro et al., 2000).

Pre-experimental assessments could be conducted on-site to evaluate potential impacts on the marine ecological environment. For instance, Giraud et al. (2019) investigated the potential impacts of discharging cold, nutrient-rich deep seawater on the phytoplankton community residing in warm, oligotrophic surface waters. This study, conducted before the installation of the pilot

TABLE 4 List of mitigation measures to prevent hazards to marine benthos from power plant discharge.

Discharge type	Recommendation	Reference
Thermal discharge	Improving the recovery and utilization rate of waste heat from power plants, such as advanced heat recovery systems, heat pump technologies, and so on.	Jouhara et al., 2018
	Refrain from employing power plants in regions characterized by high biodiversity or heat-sensitive ecosystems.	Keshavmurthy et al., 2012
	Establishing an adequate clearance between the pipeline and the seabed.	LLC, Honolulu Seawater Air Conditioning, 2014
	Minimize the use of chlorine-containing decontamination agents.	ÇETİN and Adem, 2022
	Conducting long-term continuous detection and promptly adjusting equipment distribution to minimize environmental impacts.	Martínez et al., 2021
Cold discharge	Utilizing chilled nutrient-rich water for aquaculture, municipal, or agricultural purposes in open-cycle OTEC systems, guided by water quality indicators.	Pelc and Fujita, 2002
	The discharge point is situated within an area characterized by the highest levels of biological productivity, spanning approximately 90 to 200 meters below sea level.	Comfort and Vega, 2011
	Avoid the use of toxic decontamination agents including chlorine.	ÇETİN and Adem, 2022
	Conducting long-term continuous detection and promptly adjusting equipment distribution to minimize environmental impacts.	Martínez et al., 2021

plant, determined the optimal outlet depth to minimize adverse effects. Cold emissions from OTEC power plants are designed to prevent excessive fertilization of surface seawater; thus, it is crucial that the plume settlement area is situated below the mixed layer. It is recommended that the discharge pipe be positioned in conditions where only 1% of light penetrates. Based on data from the ALOHA station and model predictions, the optimal depth for the discharge pipe is at or below 90 meters (Viviani et al., 2011). This recommendation considers that certain phytoplankton can still absorb nutrients from the descending plume at higher levels within the water column. Conservative estimates for emission depths suggest that discharges should occur at 120 meters or below (Comfort and Vega, 2011).

Jia et al. (2012) found that cold discharge results in the formation of a layer characterized by nearly uniform temperature, salinity, and density at depths ranging from 150 to 200 meters. As the plume approaches this homogeneous layer, its downward momentum allows it to penetrate the layer and migrate into deeper, denser regions. Additionally, tidal currents can create short-circuiting effects on the water intake. Consequently, it is recommended that the discharge outlet be positioned above this uniform layer to optimize environmental outcomes (Jia et al., 2012).

Martínez et al. (2021) underscored the importance of long-term management and monitoring of environmental conditions, including physicochemical parameters and marine biological attributes, as essential complements to mitigation measures during and post-installation of energy devices. However, it was noted that very few project sites possess long-term datasets persistently monitored for marine environmental conditions, encompassing physicochemical parameters and marine biological attributes such as abundance, distribution, and behavior across various temporal scales (daily, seasonal, annual, or multi-annual) and spatial scales (local, regional) (Kolar et al., 2013; Williamson et al., 2017; O'Carroll et al., 2017). Such comprehensive data was imperative for understanding the interactions between biotic and abiotic components and their feedback into energy devices (McClure et al., 2010).

Of particular concern is the absence of environmental standards for the impact of deep-sea water discharge, emphasizing the critical need for implementing rigorous monitoring measures for marine biocommunities, biogeochemical parameter distribution, and water column stratification during and after the ongoing operation of Ocean Thermal Energy Conversion (OTEC) systems.

3.5 Framework for managing thermal discharge

Regarding the regulatory context, it is important to highlight that there is currently no universally established environmental standard defining the threshold level of temperature change resulting from Ocean Thermal Energy Conversion (OTEC) deep seawater discharge. This gap in regulation is concerning, as the absence of a consensus can lead to varied practices that may undermine marine ecosystems globally. Existing studies primarily reference the 3°C temperature difference limit at the edge of the initial mixing dilution zone, as recommended by the International Finance Corporation (2007), which underscores the necessity for careful monitoring to prevent adverse ecological impacts. However, this recommendation may not sufficiently capture the complexities of thermal discharges, particularly in diverse marine environments.

In addition to this, various national regulations concerning thermal emissions from power plants typically focus on the quality of effluents, encompassing critical parameters such as temperature, dissolved oxygen, and pH levels. For instance, Egypt's environmental law stipulates that the maximum absolute water temperature due to effluent discharge should not exceed 35°C, while also mandating that the temperature outside the mixing zone must not exceed 5°C above the ambient water temperature (Egypt Government, 2009). Such regulatory measures reflect an awareness of the need to protect marine biodiversity and ecosystem functionality.

Furthermore, the Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) has consistently emphasized the importance of maintaining ecological integrity in marine environments. They recommend that temperature differentials near power plants should not exceed 7°C in subtropical waters and 5°C in tropical waters (GESAMP, 1984). These guidelines are critical in safeguarding sensitive marine organisms that are particularly vulnerable to temperature fluctuations, as extensive research has demonstrated that even minor deviations from natural temperature ranges can lead to significant disruptions in marine ecosystems (Jawad, 2021; Przeslawski et al., 2008).

Moreover, the inconsistency in regulations across different countries raises concerns regarding the potential for cumulative impacts of thermal discharges, as emphasized by several studies which call for a more unified approach to managing thermal pollution (Issakhov and Zhandaulet, 2021; Baram, 1972). This lack of harmonization not only complicates enforcement efforts but also hampers global initiatives aimed at preserving marine biodiversity in the face of climate change and other anthropogenic pressures.

Thus, local regulations governing the construction and operation of marine outfalls, discharge locations, and effluent quality limitations (including temperature and chemical substances) are essential for managing the environmental impact of these discharges. However, tracking the diverse environmental laws applicable to each power plant across different countries and regions can be challenging. Therefore, this paper focuses on analyzing changes in water and sediment quality indicators and their effects on benthic organisms following discharge from power plants.

4 Conclusion

In this study, a comprehensive database about the effects of power plant discharge on benthic organisms is curated through the screening of literature sourced from Scopus, PubMed, and the Web of Science. CiteSpace software is employed to analyze and visualize

the selected literature, thereby elucidating the spatial and temporal distribution of research on this topic and identifying research hotspots across different periods. Emerging areas of interest encompassed issues such as the impact of coastal power plant discharge on macrobenthos and coral community structure.

The study confirms a significant negative correlation between the temperature differential at the influence site and the control site, as well as ambient temperature, and variations in benthic abundance. Furthermore, apart from temperature fluctuations, other environmental factors, including dissolved oxygen, pH, chlorophyll-a, phaeopigment, conductivity, clay, and organic content exhibit varying degrees of alteration. It is noteworthy that the interplay among these factors appears to be more influential than the impact of any single factor alone. Changes in benthic organisms have the potential to induce alterations in the dynamics of coastal marine ecosystems. These findings underscore the importance of considering relevant information in environmental policy formulation aimed at mitigating the potential impacts of thermal and cold effluents on marine biodiversity.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

QL: Data curation, Investigation, Methodology, Visualization, Writing – original draft. FY: Conceptualization, Funding acquisition, Investigation, Supervision, Writing – review & editing. KR: Data curation, Investigation, Supervision, Writing – review & editing. NZ: Formal analysis, Supervision, Validation, Writing – review & editing. MH: Investigation, Software, Visualization, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. The authors would like to express their gratitude to Universiti Putra Malaysia (UPM) for supporting this project through the Science Start Scholarship (GP-IPS/2023/9768600). We also extend our thanks to the Japan Science and Technology Agency (JST), the Japan International Cooperation Agency (JICA), and the Ministry of Higher Education Malaysia (MoHE) for their contributions through the Science and Technology Research Partnership for Sustainable Development (SATREPS) Program. This initiative, titled "Development of Advanced Hybrid Ocean Thermal Energy Conversion (OTEC) Technology for a Low Carbon Society and Sustainable Energy System: First Experimental OTEC Plant of Malaysia," has been instrumental in our research.

Acknowledgments

The authors would like to express their appreciation to the reviewers for their valuable suggestions aimed at enhancing the quality of the manuscript. The author(s) declare that Generative AI was used in the creation of this manuscript. Authors used ChatGPT 4.0 to improve the language.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2024.1465289/full#supplementary-material

References

Ahamed, M. S., Durairaj, G., Suresh, K., and Nair, K. V. K. (1992). Effect of power plant heated effluent on distribution of sedentary fauna and flora. *Indian J. Mar. Sci.* 21, 188–191.

Alden Iii, R. W. (1979). Effects of a thermal discharge on the mortality of copepods in a subtropical estuary. *Environ. pollut. (1970)* 20 (1), 3–19. doi: 10.1016/0013-9327(79)90049-1

Ali, M. F., Salman, A. H., Guda, M. A., Abojassim, A. A., and Almayabi, B. (2020). The hydroclimatic effects of the thermal pollution on surface waters in Iraq and its biological effects. *Prensa Med. Argent* 106, 189–196. doi: 10.47275/0032-745X-189

Al-Yaquob, A. J. (2011). Effect of salinity and pH on hatchability and survival of the snails *Lymnaea auricularia*. *Marsh Bull.* 6, 62–72.

Arai, R., Nukazawa, K., Kazama, S., and Takemon, Y. (2015). Variation in benthic invertebrate abundance along thermal gradients within headwater streams of a temperate basin in Japan. *Hydrobiologia* 762, 55–63. doi: 10.1007/s10750-015-2336-8

Arieli, R. N., Almogi-Labin, A., Abramovich, S., and Herut, B. (2011). The effect of thermal pollution on benthic foraminiferal assemblages in the Mediterranean shoreface adjacent to Hadera power plant (Israel). *Mar. pollut. Bull.* 62, 1002–1012. doi: 10.1016/j.marpolbul.2011.02.036

Attrill, M. J., and Thomas, R. M. (1996). Long-term distribution patterns of mobile estuarine invertebrates (Ctenophora, Cnidaria, Crustacea: Decapoda) in relation to hydrological parameters. *Mar. Ecol. Prog. Ser.* 143, 25–36.

Ayoub, A., Gjorgiev, B., and Sansavini, G. (2018). Cooling towers performance in a changing climate: Techno-economic modeling and design optimization. *Energy* 160, 1133–1143. doi: 10.1016/j.energy.2018.07.080

Bacouillard, L., Baux, N., Dauvin, J. C., Desroy, N., Geiger, K. J., Gentil, F., et al. (2020). Long-term spatio-temporal changes of the muddy fine sand benthic community of the Bay of Seine (eastern English Channel). *Mar. Environ. Res.* 161, 105062. doi: 10.1016/j.marenvres.2020.105062

Baldanzi, S., McQuaid, C. D., Cannicci, S., and Porri, F. (2013). Environmental domains and range-limiting mechanisms: testing the Abundant Centre Hypothesis using Southern African sandhoppers. *PloS One* 8, e54598. doi: 10.1371/journal.pone.0054598

Bamber, R. N. (1990). Power station thermal effluents and marine crustaceans. *J. thermal Biol.* 15 (1), 91–96. doi: 10.1016/0306-4565(90) 90054-L

Baram, M. S. (1972). The legal and regulatory framework for thermal discharge from nuclear power plants. *Envtl. Aff.* 2, 505.

Beesley, A., Lowe, D. M., Pascoe, C. K., and Widdicombe, S. (2008). Effects of CO2-induced seawater acidification on the health of Mytilus edulis. *Climate Res.* 37 (2-3), 215–225. doi: 10.3354/cr00765

Bensoussan, N., Romano, J. C., Harmelin, J. G., and Garrabou, J. (2010). High resolution characterization of northwest Mediterranean coastal waters thermal regimes: to better understand responses of benthic communities to climate change. *Estuar. Coast. Shelf Sci.* 87, 431–441. doi: 10.1016/j.ecss.2010.01.008

Billman, E. J., Wagner, E. J., and Arndt, R. E. (2006). Effects of temperature on the survival and growth of age-0 least chub (Iotichthys phlegethontis). *Western North Am. Nat.* 66, 434–440. doi: 10.3398/1527-0904(2006)66[434:EOTOTS]2.0.CO;2

Bozorgchenani, A., Seyfabadi, J., and Shokri, M. R. (2018). Effects of thermal discharge from Neka power plant (southern Caspian Sea) on macrobenthic diversity and abundance. *J. Thermal Biol.* 75, 13–30. doi: 10.1016/j.jtherbio.2018.05.002

Breitburg, D., Levin, L. A., Oschlies, A., Grégoire, M., Chavez, F. P., Conley, D. J., et al. (2018). Declining oxygen in the global ocean and coastal waters. *Science.* 359, eaam7240. doi: 10.1126/science.aam7240

Briggs, M. A., Albertson, L. K., Lujan, D. R., Tronstad, L. M., Glassic, H. C., Guy, C. S., et al. (2021). Carcass deposition to suppress invasive lake trout causes differential mortality of two common benthic invertebrates in Yellowstone Lake. *Fundam. Appl. Limnol.* 194, 285–295. doi: 10.1127/fal/2020/1352

Bryan, N. J., Moorhead, D. L., and Crail, T. D. (2014). Habitat characteristics of a unionid refuge in the thermal plume of a power plant in western Lake Erie. *J. Great Lakes Res.* 40 (3), 699–704. doi: 10.1016/ j.jglr.2014.05.015

Burton, D. T., Richardson, L. B., Margrey, S. L., and Abell, P. R. (1976). Effects of low ΔT powerplant temperatures on estuarine invertebrates. *J. (Water pollut. Control Federation)* 48 (10), 2259–2272. Available at: http://www.jstor.org/stable/25040024.

Busch, D. S., and McElhany, P. (2016). Estimates of the direct effect of seawater pH on the survival rate of species groups in the California current ecosystem. *PloS One* 11, e0160669. doi: 10.1371/journal.pone.0160669

Cai, L., Rao, Y., Zhao, X., Yang, D., Zhou, X., Wang, D., et al. (2023). Spatial and seasonal distributions of ten species of benthic macrofauna and twelve water environmental factors in a subtidal zone near the Daya Bay nuclear power plant. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.1093468

Caputi, N., Kangas, M., Chandrapavan, A., Hart, A., Feng, M., Marin, M., et al. (2019). Factors affecting the recovery of invertebrate stocks from the 2011 Western Australian extreme marine heatwave. *Front. Mar. Sci.* 6. doi: 10.3389/fmars.2019.00484

Cardoso-Mohedano, J. G., Bernardello, R., Sanchez-Cabeza, J. A., Ruiz-Fernández, A. C., Alonso-Rodriguez, R., and Cruzado, A. (2015). Thermal impact from a thermoelectric power plant on a tropical coastal lagoon. *Water Air Soil pollut.* 226, 1–11. doi: 10.1007/s11270-014-2202-8

Castro, M. M. D., Song, T. W., and Pinto, J. M. (2000). Minimization of operational costs in cooling water systems. *Chem. Eng. Res. Design* 78, 192–201. doi: 10.1205/026387600527220

ÇETİN, Y., and Adem, A. C. I. R. (2022). Decontamination applications in primary circuit equipment of nuclear power plants. *Int. J. Energy Stud.* 7, 195–216. doi: 10.58559/ijes.1178889

Chan, H. Y., Xu, W. Z., Shin, P. K. S., and Cheung, S. G. (2008). Prolonged exposure to low dissolved oxygen affects early development and swimming behaviour in the gastropod Nassarius festivus (Nassariidae). *Mar. Biol.* 153, 735–743. doi: 10.1007/s00227-007-0850-6

Chatzinikolaou, E., Grigoriou, P., Keklikoglou, K., Faulwetter, S., and Papageorgiou, N. (2017). The combined effects of reduced pH and elevated temperature on the shell density of two gastropod species measured using micro-CT imaging. *ICES J. Mar. Sci.* 74, 1135–1149. doi: 10.1093/icesjms/fsw219

Chavan, P., Kumar, R., Kirubagaran, R., and Venugopalan, V. P. (2017). Comparative toxicological effects of two antifouling biocides on the marine diatom Chaetoceros lorenzianus: Damage and post-exposure recovery. *Ecotoxicol. Environ. Saf.* 144, 97–106. doi: 10.1016/j.ecoenv.2017.06.001

Cheng, I., Ko, P. C., Hu, S. I., Hu, C. P., and Wei, T. P. (2004). Nearshore macrobenthic communities of two nuclear power plants in northern Taiwan. *J. Mar. Sci. Technol.* 12, 5. doi: 10.51400/2709-6998.2260

Chou, Y., Lin, T. Y., Chen, C. T. A., and Liu, L. L. (2004). Effects of Nuclear Power Plant thermal effluent on marine sessile invertebrate communities in southern Taiwan. *J. Mar. Sci. Technol.* 12 (5), 448–452. doi: 10.51400/ 2709-6998.2267

Chuang, Y. L., Yang, H. H., and Lin, H. J. (2009). Effects of a thermal discharge from a nuclear power plant on phytoplankton and periphyton in subtropical coastal waters. *J. Sea Res.* 61, 197–205. doi: 10.1016/j.seares.2009.01.001

Colella, M. A., Ruzicka, R. R., Kidney, J. A., Morrison, J. M., and Brinkhuis, V. B. (2012). Cold-water event of January 2010 results in catastrophic benthic mortality on patch reefs in the Florida Keys. *Coral Reefs* 31, 621–632. doi: 10.1007/s00338-012-0880-5

Comfort, C. M., and Vega, L. (2011). "Environmental assessment for ocean thermal energy conversion in Hawaii: Available data and a protocol for baseline monitoring," in *OCEANS'11 MTS/IEEE KONA* (Kona, Hawaii, USA: IEEE), 1–8. doi: 10.23919/OCEANS

Copping, A. E., Freeman, M. C., Gorton, A. M., and Hemery, L. G. (2020). Risk retirement-decreasing uncertainty and informing consenting processes for marine renewable energy development. *J. Mar. Sci. Eng.* 8, 172. doi: 10.3390/jmse8030172

Crema, R., and Pagliai, A. B. (1980). The structure of benthic communities in an area of thermal discharge from a coastal power station. *Mar. pollut. Bull.* 11 (8), 221–224. doi: 10.1016/0025-326X(80)90410-5

Crook, E. D., Potts, D., Rebolledo-Vieyra, M., Hernandez, L., and Paytan, A. (2012). Calcifying coral abundance near low-pH springs: implications for future ocean acidification. *Coral Reefs* 31, 239–245. doi: 10.1007/BF00334344

Dallas, L. J., Bean, T. P., Turner, A., Lyons, B. P., and Jha, A. N. (2016). Exposure to tritiated water at an elevated temperature: Genotoxic and transcriptomic effects in marine mussels (M. *galloprovincialis). J. Environ. radioactivity* 164, 325–336. doi: 10.1016/j.jenvrad.2016.07.034

Dalpadado, P., Roxy, M. K., Arrigo, K. R., van Dijken, G. L., Chierici, M., Ostrowski, M., et al. (2024). Rapid climate change alters the environment and biological production of the Indian Ocean. *Sci. Total Environ.* 906, 167342. doi: 10.1016/j.scitotenv.2023.167342

Deabes, E. A. (2020). The impact of thermal power stations on coastline and benthic fauna: Case study of El-Burullus power plant in Egypt. *Results Eng.* 7, 100128. doi: 10.1016/j.rineng.2020.100128

Deldicq, N., Langlet, D., Delaeter, C., Beaugrand, G., Seuront, L., and Bouchet, V. M. (2021). Effects of temperature on the behaviour and metabolism of an intertidal foraminifera and consequences for benthic ecosystem functioning. *Sci. Rep.* 11, 4013. doi: 10.1038/s41598-021-83311-z

Dong, Z. G., Chen, Y. H., Ge, H. X., Li, X. Y., Wu, H. L., Wang, C. H., et al. (2018). Response of growth and development of the Pacific oyster (Crassostrea gigas) to thermal discharge from a nuclear power plant. *BMC Ecol.* 18 (1), 1–11. doi: 10.1186/s12898-018-0191-y

Dong, S., Lei, Y., Li, T., and Jian, Z. (2020). Response of benthic foraminifera to pH changes: Community structure and morphological transformation studies from a microcosm experiment. *Mar. Micropaleontol.* 156, 101819. doi: 10.1016/j.marmicro.2019.101819

Egyptian Government. (2009). *Protection of Environment (Law No. 9)* (Egypt: Ministry of Environment of Egypt).

Ehler, C. (2008). Conclusions: benefits, lessons learned, and future challenges of marine spatial planning. *Mar. Policy* 32, 840–843. doi: 10.1016/j.marpol.2008.03.014

Ellingsen, K., and Gray, J. S. (2002). Spatial patterns of benthic diversity: is there a latitudinal gradient along the Norwegian continental shelf? *J. Anim. Ecol.* 71, 373–389. doi: 10.1046/j.1365-2656.2002.00606.x

Everall, N. C., Johnson, M. F., Wilby, R. L., and Bennett, C. J. (2015). Detecting phenology change in the mayfly E phemera danica: responses to spatial and temporal water temperature variations. *Ecol. Entomol.* 40, 95–105. doi: 10.1111/een.12164

Fabricius, K. E., De'ath, G., Noonan, S., and Uthicke, S. (2014). Ecological effects of ocean acidification and habitat complexity on reef-associated macroinvertebrate communities. *Proc. R. Soc. B: Biol. Sci.* 281, 20132479. doi: 10.1098/rspb.2013.2479

Falfushynska, H. I., Gnatyshyna, L. L., Golubev, A. P., and Stoliar, O. B. (2012). Main partitioning criteria for the characterization of the health status in the freshwater mussel Anodonta cygnea from spontaneously polluted area in western ukraine. *Environ. Toxicol.* 27 (8), 485–494. doi: 10.1002/tox.20663

Farshchi, M., Nasrolahi, A., and Shokri, M. R. (2020). Variability in benthic invertebrate community structure near warm water effluents of a power plant in the southern Caspian Sea. *Regional Stud. Mar. Sci.* 40, 101507. doi: 10.1016/j.rsma.2020.101507

Feugere, L., Angell, L., Fagents, J., Nightingale, R., Rowland, K., Skinner, S., et al. (2021). Behavioural stress propagation in benthic invertebrates caused by acute pH drop-induced metabolites. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.773870

Florin, A. B., Mo, K., Svensson, F., Schagerström, E., Kautsky, L., and Bergström, L. (2013). First records of Conrad´ s false mussel, *Mytilopsis leucophaeata* (Conrad 1831) in the southern Bothnian Sea, Sweden, near a nuclear power plant. *BioInvasions Records* 2, 303–309. doi: 10.3391/bir.2013.2.4.02

Gall, M. L., Holmes, S. P., Campbell, H., and Byrne, M. (2021). Effects of marine heatwave conditions across the metamorphic transition to the juvenile sea urchin (Heliocidaris erythrogramma). *Mar. pollut. Bull.* 163, 111914. doi: 10.1016/j.marpolbul.2020.111914

Gangur, A. N., and Marshall, D. J. (2020). Facultative feeding in a marine copepod: effects of larval food and temperature on performance. *Mar. Ecol. Prog. Ser.* 652, 33–47. doi: 10.3354/meps13470

Gao, Y., Xie, Z., Qian, J., Tu, Z., Yang, C., Deng, Y., et al. (2023). Effects of diel-cycling hypoxia and salinity on lipid metabolism and fatty acid composition of the oyster Crassostrea hongkongensis. *Mar. Environ. Res.* 191, 106124. doi: 10.1016/j.marenvres.2023.106124

Garcia-Soto, C., Cheng, L., Caesar, L., Schmidtko, S., Jewett, E. B., Cheripka, A., et al. (2021). An overview of ocean climate change indicators: Sea surface temperature, ocean heat content, ocean pH, dissolved oxygen concentration, arctic sea ice extent, thickness and volume, sea level and strength of the AMOC (Atlantic Meridional Overturning Circulation). *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.642372

Giraud, M., Garçon, V., de la Broise, D., L'Helguen, S., Sudre, J., and Boye, M. (2019). Potential effects of deep seawater discharge by an Ocean Thermal Energy Conversion plant on the marine microorganisms in oligotrophic waters. *Sci. Total Environ.* 693, 133491. doi: 10.1016/j.scitotenv.2019.07.297

Golmen, L. G., Masutani, S. M., and Ouchi, K. (2005). "Ocean thermal energy conversion and the next generation fisheries," in *World Renewable Energy Congress (WREC 2005)*. Eds. M. S. Imbabi and C. P. Mitchell (UK: The World Renewable Energy Congress), 789–795.

Górska, B., Grzelak, K., Kotwicki, L., Hasemann, C., Schewe, I., Soltwedel, T., et al. (2014). Bathymetric variations in vertical distribution patterns of meiofauna in the surface sediments of the deep Arctic Ocean (HAUSGARTEN, Fram strait). *Deep Sea Res. Part I: Oceanogr. Res. Papers* 91, 36–49. doi: 10.1016/j.dsr.2014.05.010

Guimarães, L. S. F., de Carvalho-Junior, L., Façanha, G. L., da Silva Resende, N., Neves, L. M., and Cardoso, S. J. (2023). Meta-analysis of the thermal pollution caused by coastal nuclear power plants and its effects on marine biodiversity. *Mar. pollut. Bull.* 195, 115452. doi: 10.1016/j.marpolbul.2023.115452

Hamilton, H. J., and Gosselin, L. A. (2020). Ontogenetic shifts and interspecies variation in tolerance to desiccation and heat at the early benthic phase of six intertidal invertebrates. *Mar. Ecol. Prog. Ser.* 634, 15–28. doi: 10.3354/meps13189

Heip, C., and Craeymeersch, J. A. (1995). Benthic community structures in the North Sea. *Helgoländer Meeresuntersuchungen* 49, 313–328. doi: 10.1007/BF02368359

Hillebrand, H., Soininen, J., and Snoeijs, P. (2010). Warming leads to higher species turnover in a coastal ecosystem. *Global Change Biol.* 16, 1181–1193. doi: 10.1111/j.1365-2486.2009.02045.x

Hoegh-Guldberg, O., Poloczanska, E. S., Skirving, W., and Dove, S. (2017). Coral reef ecosystems under climate change and ocean acidification. *Front. Mar. Sci.* 4. doi: 10.3389/fmars.2017.00158

Hoglund, J., and Thomas, K. (1992). The black goby Gobius niger as a potential paratenic host for the parasitic nematode Anguillicola crassus in a thermal effluent of the Baltic. *Dis. OF Aquat. ORGANISMS* 13 (3), 175–180. doi: 10.3354/dao013175

Hussain, K. J., Mohanty, A. K., Satpathy, K. K., and Prasad, M. V. R. (2010). Abundance pattern of wedge clam Donax cuneatus (L.) in different spatial scale in the vicinity of a coastal nuclear power plant. *Environ. Monit. Assess.* 163, 185–194. doi: 10.1007/s10661-009-0826-8

Hwang, J. S., Tu, Y. Y., Tseng, L. C., Fang, L. S., Souissi, S., Fang, T. H., et al. (2004). Taxonomic composition and seasonal distribution of copepod assemblages from waters adjacent to nuclear power plant I and II in northern Taiwan. *J. Mar. Sci. Technol.* 12 (5), 380–391. doi: 10.51400/ 2709-6998.2259

Hyvärinen, H. S., Sjönberg, T., Marjomäki, T. J., and Taskinen, J. (2022). Effect of low dissolved oxygen on the viability of juvenile Margaritifera margaritifera: Hypoxia tolerance *ex situ*. *Aquat. Conserv.: Mar. Freshw. Ecosyst.* 32, 1393–1400. doi: 10.1002/aqc.3859

IEA. (2024). IEA world energy balances. Available online at: https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances (accessed May 20, 2024).

IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP). (1984). *Thermal Discharges in the Marine Environment (No. 24)*. Rome: Food and Agriculture Organisation of the United Nations.

Ingels, J., Tchesunov, A. V., and Vanreusel, A. (2011). Meiofauna in the Gollum Channels and the Whittard Canyon, Celtic Margin—how local environmental conditions shape nematode structure and function. *PloS One* 6, e20094. doi: 10.1371/journal.pone.0020094

International Finance Corporation (IFC) (2007). *Environmental, Health, and Safety Guidelines for Liquefied Natural Gas (LNG) Facilities* (Washington, D.C., USA: World Bank Group).

Islam, S. S., Samanta, S., Mahato, S., Bhattacharya, S., and Midya, S. (2024). "Diversity of meiobenthic fauna in costal environment: As a bioindicator," in *Spatial Modeling of Environmental Pollution and Ecological Risk* (Cambridge, UK: Woodhead Publishing), 275–299. doi: 10.1016/B978-0-323-95282-8.00029-8

Issakhov, A., and Zhandaulet, Y. (2021). Thermal pollution zones on the aquatic environment from the coastal power plant: Numerical study. *Case Stud. Thermal Eng.* 25, 100901. doi: 10.1016/j.csite.2021.100901

Jansujwicz, J. S., and Johnson, T. R. (2015). Understanding and informing permitting decisions for tidal energy development using an adaptive management framework. *Estuar. Coasts* 38, 253–265. doi: 10.1007/s12237-013-9678-0

Jawad, L. A. (2021). "The effects of thermal pollution on the aquatic life in the southern marshes of Iraq," in *Southern IRAQ's Marshes: Their Environment and Conservation* (Springer International Publishing, Cham). , 559–571.

Jebakumar, J. P. P., Nandhagopal, G., Babu, B. R., Ragumaran, S., and Ravichandran, V. (2018). Impact of coastal power plant cooling system on planktonic diversity of a polluted creek system. *Mar. pollut. Bull.* 133, 378–391. doi: 10.1016/j.marpolbul.018.05.053

Jebure, H. A., and Meshjel, M. H. (2019). Impact of Wasit power plant effluents on biodiversity of benthic fauna in Tigris river, province Wasit/Iraq. *Iraqi J. Agric. Sci.* 50 (3), 960–971.

Jenner, H. A., Taylor, C. J. L., Van Donk, M., and Khalanski, M. (1997). Chlorination by-products in chlorinated cooling water of some European coastal power stations. *Mar. Environ. Res.* 43, 279–293. doi: 10.1016/S0141-1136(96)00091-8

Jia, Y., Nihous, G. C., and Richards, K. J. (2012). Effects of ocean thermal energy conversion systems on near and far field seawater properties—A case study for Hawaii. *J. Renewable Sustain. Energy* 4 (6), 063104. doi: 10.1063/1.4766820

Jones, S. J., Lima, F. P., and Wethey, D. S. (2010). Rising environmental temperatures and biogeography: poleward range contraction of the blue mussel, Mytilus edulis L., in the western Atlantic. *J. Biogeogr.* 37, 2243–2259. doi: 10.1111/j.1365-2699.2010.02386.x

Jouhara, H., Khordehgah, N., Almahmoud, S., Delpech, B., Chauhan, A., and Tassou, S. A. (2018). Waste heat recovery technologies and applications. *Thermal Sci. Eng. Prog.* 6, 268–289. doi: 10.1016/j.tsep.2018.04.017

Kalimuthu, K., Hamli, H., Engan, M. T., Rasidi, J. B., Rabullah, M., Ismail, J., et al. (2022). Diversity of fish and macrobenthos at the coastal area of Tanjung Kidurong Power Plant (TKPP), Sarawak, Malaysia. *Egyptian J. Aquat. Biol. Fisheries* 26 (1), 585–607. doi: 10.21608/EJABF.2022.226426

Kang, H., Chen, X., Deng, W., Wang, X., Cui, H., Liu, X., et al. (2021). Skeletal growth response of porites coral to long-term ocean warming and acidification in the South China Sea. *J. Geophys. Res.: Biogeosci.* 126, e2021JG006423. doi: 10.1029/2021JG006423

Kastendiek, J., Schroeter, S. C., and Dixon, J. (1981). The effect of the seawater cooling system of a nuclear generating station on the growth of mussels in experimental populations. *Mar. pollut. Bull.* 12 (12), 402–407. doi: 10.1016/0025-326X(81)90155-7

Keshavmurthy, S., HSU, C. M., KUO, C. Y., MENG, P. J., WANG, J. T., and Chen, C. A. (2012). Symbiont communities and host genetic structure of the brain coral Platygyra verweyi, at the outlet of a nuclear power plant and adjacent areas. *Mol. Ecol.* 21, 4393–4407. doi: 10.1111/j.1365-294X.2012.05704.x

Kim, J. H., Jeong, S. Y., Kim, P. J., Dahms, H. U., and Han, K. N. (2017). Bio-effect-monitoring of long-term thermal wastes on the oyster, Crassostrea gigas, using heat shock proteins. *Mar. pollut. Bull.* 119, 359–364. doi: 10.1016/j.marpolbul.2017.04.035

Kimmerer, W., and Weaver, M. J. (2013). Vulnerability of estuaries to climate change. (Oxford, UK: CRC Press), 277–289. doi: 10.1016/B978-0-12-384703-4.00438-X

Kolar, H. R., McKeown, E. P., Purcell, M. E., Gaughan, P. J., Westbrook, A. G., Barry, M. G., et al. (2013). "The design and deployment of a real-time wide spectrum acoustic monitoring system for the ocean energy industry," in *2013 MTS/IEEE OCEANS-Bergen* (Bergen, Norway: IEEE), 1–4. doi: 10.1109/OCEANS-Bergen. 2013.6608126

Kolehmainen, S. E., Martin, F. D., and Schroeder, P. B. (1974). *Thermal studies on tropical marine ecosystems in Puerto Rico (No. CONF-740820-1; SM-187/14)* (Mayaguez: Puerto Rico Nuclear Center).

Krepski, T., Pilecka-Rapacz, M., Czerniawski, R., and Domagała, J. (2014). Analysis of benthic macroinvertebrate communities from the lower sections of large river in relation to different environmental factors. *Open Life Sci.* 9, 1037–1047. doi: 10.2478/s11535-014-0346-6

Kroeker, K. J., Kordas, R. L., Crim, R. N., Hendriks, I. E., Ramajo, L., Singh, G. S., et al. (2013). Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. *Global Change Biol.* 19, 1884–1896. doi: 10.1111/gcb.12179

Kroeker, K. J., Kordas, R. L., Crim, R. N., and Singh, G. G. (2010). Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms. *Ecol. Lett.* 13, 1419–1434. doi: 10.1111/j.1461-0248.2010.01518.x

Kroeker, K. J., Micheli, F., Gambi, M. C., and Martz, T. R. (2011). Divergent ecosystem responses within a benthic marine community to ocean acidification. *Proc. Natl. Acad. Sci.* 108, 14515–14520. doi: 10.1073/pnas.1107789108

Kumar, A., and Sharma, R. (2020). Mitigation of thermal pollution from industrial discharges. *Environ. Manage.* 65, 123–136.

Lamadrid-Rose, Y., and Boehlert, G. W. (1988). Effects of cold shock on egg, larval, and juvenile stages of tropical fishes: Potential impacts of ocean thermal energy conversion. *Mar. Environ. Res.* 25, 175–193. doi: 10.1016/0141-1136(88)90002-5

Lan, W. R., Huang, X. G., Lin, L. X., Li, S. X., and Liu, F. J. (2020). Thermal discharge influences the bioaccumulation and bioavailability of metals in oysters: Implications of ocean warming. *Environ. pollut.* 259. doi: 10.1016/j.envpol.2019.113821

Lardicci, C., Rossi, F., and Maltagliati, F. (1999). Detection of thermal pollution: variability of benthic communities at two different spatial scales in an area influenced by a coastal power station. *Mar. pollut. Bull.* 38 (4), 296–303. doi: 10.1016/S0025-326X(98)00149-0

Li, Z., Xing, Y., Liu, Z., Chen, X., Jiang, X., Xie, Z., et al. (2020). Seasonal changes in metacommunity assembly mechanisms of benthic macroinvertebrates in a subtropical river basin. *Sci. Total Environ.* 729, 139046. doi: 10.1016/j.scitotenv.2020.139046

Li, X., and Xu, Y. (2021). 3.4 macrobenthos. *PICES Sci. Rep.* 62), 255–284.

Lin, J., Zou, X. Q., and Huang, F. M. (2018). Effects of the thermal discharge from an offshore power plant on plankton and macrobenthic communities in subtropical China. *Mar. pollut. Bull.* 131, 106–114.

Loi, T., and Wilson, B. J. (1979). Macroinfaunal structure and effects of thermal discharges in a mesohaline habitat of Chesapeake Bay, near a Nuclear Power Plant. *Mar. Biol.* 55 (1), 3–16. doi: 10.1007/BF00391711

Liu, C. C. (2018). Ocean thermal energy conversion and open ocean mariculture: The prospect of Mainland-Taiwan collaborative research and development. *Sustain. Environ. Res.* 28, 267–273. doi: 10.1016/j.serj.2018.06.002

Liu, H., Li, J., Wang, H., Huang, H., Xie, F., and Song, X. (2023). High-temperature thermal discharge inhibits plankton community metabolism in a partly eutrophicated bay in China. *Front. Mar. Sci.* 9, 1016074. doi: 10.3389/fmars.2022.1016074

LLC, Honolulu Seawater Air Conditioning (2014). *Final environmental impact statement for the proposed Honolulu Seawater Air Conditioning project, Honolulu, Hawai'i*. Ed. Engineers USA Co, (Honolulu, HI: Cardno TEC, Inc.), 834.

Macias, D., Hong, S., Yang, K. M., Kim, J., and Kim, J. H. (2024). Variability of marine epifauna assemblages in response to the microhabitat type and thermal stress. *Regional Stud. Mar. Sci.* 71. doi: 10.1016/j.rsma.2024.103392

Mariu, A., Chatha, A. M. M., Naz, S., Khan, M. F., Safdar, W., and Ashraf, I. (2023). Effect of temperature, pH, salinity and dissolved oxygen on fishes. *J. Zool. Syst.* 1, 1–12. doi: 10.56946/jzs.v1i2.198

Martin, J., and Planque, B. (2006). Variability in the onset of hatching of Maja brachydactyla Bals(Brachyura: Majidae) in the English Channel in relation to sea temperature. *Invertebrate Reprod. Dev.* 49 (3), 143–150. doi: 10.1080/07924259.2006.9652205

Martínez, M. L., Vázquez, G., Pérez-Maqueo, O., Silva, R., Moreno-Casasola, P., Mendoza-González, G., et al. (2021). A systemic view of potential environmental impacts of ocean energy production. *Renewable Sustain. Energy Rev.* 149, 111332. doi: 10.1016/j.rser.2021.111332

Masilamoni, J. G., Nandakumar, K., Jesudoss, K. S., Azariah, J., Satapathy, K. K., and Nair, K. V. K. (2002). Influence of temperature on the physiological responses of the bivalve Brachidontes striatulus and its significance in fouling control. *Mar. Environ. Res.* 53, 51–63. doi: 10.1016/S0141-1136(01)00109-X

Masutani, S. M., and Takahashi, P. K. (2001). Ocean thermal energy conversion (OTEC). *Oceanography* 22, 625. doi: 10.1006/rwos.2001.0031

Mazik, K., Hitchman, N., Quintino, V., Taylor, C. J., Butterfield, J., and Elliott, M. (2013). Sublethal effects of a chlorinated and heated effluent on the physiology of the mussel, Mytilus edulis L.: A reduction in fitness for survival? *Mar. pollut. Bull.* 77, 123–131. doi: 10.1016/j.marpolbul.2013.10.020

McClure, R., Acker, T., and Dawson, J. (2010). "Environmental assessment and monitoring of ocean energy sites—A rapid, proven, and economical approach," in *OCEANS 2010 MTS/IEEE SEATTLE* (Piscataway, New Jersey, USA: IEEE), 1–5. doi: 10.1109/OCEANS.2010.5664110

McIntyre, A. D. (1969). Ecology of marine meiobenthos. *Biol. Rev.* 44, 245–288. doi: 10.1111/j.1469-185X.1969.tb00828.x

Michie, L. E., Thiem, J. D., Boys, C. A., and Mitrovic, S. M. (2020). The effects of cold shock on freshwater fish larvae and early-stage juveniles: implications for river management. *Conserv. Physiol.* 8, coaa092. doi: 10.1093/conphys/coaa092

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., and Petticrew, M. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst. Rev.* 4, 1–9. doi: 10.1186/2046-4053-4-1

Møller, B., and Dahl-Madsen, K. I. (1983). Biological Monitoring of Thermal Effects of Cooling Water Discharges from Danish Power Plants. *Water Sci. Technol.* 15 (10), 89–99. doi: 10.2166/wst.1983.0058

Murugesan, P., Muniasamy, M., Muthuvelu, S., Vijayalakshmi, S., and Balasubramanian, T. (2011). Utility of benthic diversity in assessing the health of an ecosystem. *Indian J. Geo Marine Sci.* 40, 783–793.

Muthukumar, C., Balasubramaniyan, S., Garlapati, D., Bharathi, M. D., Kumar, B. C., James, R. A., et al. (2022). Impact of untreated sewage and thermal effluent discharges on the air-sea CO_2 fluxes in a highly urbanized tropical coastal region. *Mar. pollut. Bull.* 175, 113166. doi: 10.1016/j.marpolbul.2021.113166

Myers, E. P., Hoss, D. E., Matsumoto, W. M., Peters, D. S., Seki, M. P., Uchida, R. N., et al. (1986). *The potential impact of ocean thermal energy conversion (OTEC) on fisheries*. (U.S. Department of Commerce: National Oceanic and Atmospheric Administration).

Nayak, A., Equbal, J., Rout, S. S., Dash, B., Thiruchitrambalam, G., Bhadury, P., et al. (2022). Macrobenthic community of an anthropogenically influenced mangrove associated estuary on the East coast of India: An approach for ecological assessment. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.1008912

Nicastro, A., and Bishop, M. J. (2013). Weak and habitat-dependent effects of nutrient pollution on macrofaunal communities of southeast Australian estuaries. *PloS One* 8, e65706. doi: 10.1371/journal.pone.0065706

O'Carroll, J. P. J., Kennedy, R. M., and Savidge, G. (2017). Identifying relevant scales of variability for monitoring epifaunal reef communities at a tidal energy extraction site. *Ecol. Indic.* 73, 388–397. doi: 10.1016/j.ecolind.2016.10.005

O'Hagan, A. M. (2020). *Supplement. Marine Spatial Planning and Marine Renewable Energy* (Richland, WA (United States: Pacific Northwest National Lab. (PNNL). doi: 10.2172/1633205

Oh, J. H., Kug, J. S., An, S. I., Jin, F. F., McPhaden, M. J., and Shin, J. (2024). Emergent climate change patterns originating from deep ocean warming in climate mitigation scenarios. *Nat. Climate Change* 14, 260–266. doi: 10.1038/s41558-024-01928-0

Oshimi, R., Tabeta, S., and Mizuno, K. (2021). Water quality modeling in subtropical shallow waters to predict environmental impacts of ocean thermal energy conversion. *J. Mar. Sci. Technol.*, 335–347. doi: 10.1007/s00773-021-00837-7

Osman, A. I., Chen, L., Yang, M., Msigwa, G., Farghali, M., Fawzy, S., et al. (2023). Cost, environmental impact, and resilience of renewable energy under a changing climate: a review. *Environ. Chem. Lett.* 21, 741–764. doi: 10.1007/s10311-022-01532-8

Padhi, R. K., Subramanian, S., Mohanty, A. K., and Satpathy, K. K. (2019). Monitoring chlorine residual and trihalomethanes in the chlorinated seawater effluent of a nuclear power plant. *Environ. Monit. Assess.* 191, 1–13. doi: 10.1007/s10661-019-7611-0

Pan, S. Y., Snyder, S. W., Packman, A. I., Lin, Y. J., and Chiang, P. C. (2018). Cooling water use in thermoelectric power generation and its associated challenges for addressing water-energy nexus. *Water Energy Nexus* 1, 26–41. doi: 10.1016/j.wen.2018.04.002

Pelc, R., and Fujita, R. M. (2002). Renewable energy from the ocean. *Mar. Policy* 26, 471–479. doi: 10.1016/S0308-597X(02)00045-3

Przeslawski, R., Ahyong, S., Byrne, M., Woerheide, G., and Hutchings, P. A. T. (2008). Beyond corals and fish: the effects of climate change on noncoral benthic invertebrates of tropical reefs. *Global Change Biol.* 14, 2773–2795. doi: 10.1111/j.1365-2486.2008.01693.x

Pusceddu, A., Gambi, C., Corinaldesi, C., Scopa, M., and Danovaro, R. (2014). Relationships between meiofaunal biodiversity and prokaryotic heterotrophic production in different tropical habitats and oceanic regions. *PloS One* 9, e91056. doi: 10.1371/journal.pone.0091056

Qiao, L., Ren, C., Sun, X., Li, T., Gui, F., and Zhao, A. (2023). Benthic foraminiferal community structure and diversity in intertidal zone near China resources wenzhou power plant. *Appl. Ecol. Environ. Res.* 21, (4), 3177–3192. doi: 10.15666/aeer/2104_31773192

Rajagopal, S., Venugopalan, V. P., van der Velde, G., and Jenner, H. A. (2003). Comparative chlorine and temperature tolerance of the oyster Crassostrea madrasensis: Implications for cooling system fouling. *Biofouling* 19, 115–124. doi: 10.1080/0892701021000028497

Rao, Y., Cai, L., Chen, X., Zhou, X., Fu, S., and Huang, H. (2021). Responses of functional traits of macrobenthic communities to human activities in Daya Bay (A subtropical semi-enclosed bay), China. *Front. Environ. Sci.* 9. doi: 10.3389/fenvs.2021.766580

Raptis, C. E., van Vliet, M. T., and Pfister, S. (2016). Global thermal pollution of rivers from thermoelectric power plants. *Environ. Res. Lett.* 11 (10), 104011. doi: 10.1088/1748-9326/11/10/104011

R Core Team. (2023). R: A language and environment for statistical computing. Available online at: http://www.R-project.org/ (accessed July 06, 2023).

Ridall, A., and Ingels, J. (2021). Suitability of free-living marine nematodes as bioindicators: status and future considerations. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.685327

Riera, R., Núñez, J., and Martín, D. (2011). Effects of thermal pollution on the soft-bottoms surrounding a power station in the Canary Islands (NE Atlantic Ocean). *Oceanology* 51, 1040–1046. doi: 10.1134/S0001437011060142

Saraswat, R., Nigam, R., and Pachkhande, S. (2011). Difference in optimum temperature for growth and reproduction in benthic foraminifer Rosalina globularis: Implications for paleoclimatic studies. *J. Exp. Mar. Biol. Ecol.* 405, 105–110. doi: 10.1016/j.jembe.2011.05.026

Sarkar, S. K., Bhattacharya, A., Giri, S., Bhattacharya, B., Sarkar, D., Nayak, D. C., et al. (2005). Spatiotemporal variation in benthic polychaetes (Annelida) and relationships with environmental variables in a tropical estuary. *Wetlands Ecol. Manage.* 13, 55–67. doi: 10.1007/s11273-003-5067-y

Sasikumar, N., Azariah, J., and Nair, K. V. K. (1993). Changes in the composition of a tropical marine fouling community at a power plant discharge. *Biofouling* 6, 221–234. doi: 10.1080/08927019309386225

Schiel, D. R., Steinbeck, J. R., and Foster, M. S. (2004). Ten years of induced ocean warming causes comprehensive changes in marine benthic communities. *Ecology* 85, 1833–1839. doi: 10.1890/03-3107

Schratzberger, M., Danovaro, R., Ingels, J., Montagna, P. A., Rohal Lupher, M., Semprucci, F., et al. (2023). "Hidden players—Meiofauna mediate ecosystem effects of anthropogenic disturbances in the ocean," in *New Horizons in Meiobenthos Research: Profiles, Patterns and Potentials* (Springer International Publishing, Cham), 175–255. doi: 10.1007/978-3-031-21622-0_7

Schratzberger, M., and Ingels, J. (2018). Meiofauna matters: the roles of meiofauna in benthic ecosystems. *J. Exp. Mar. Biol. Ecol.* 502, 12–25. doi: 10.1016/j.jembe.2017.01.007

Schroeter, S. C., Dixon, J. D., Kastendiek, J., Smith, R. O., and Bence, J. R. (1993). Detecting the ecological effects of environmental impacts: a case study of kelp forest invertebrates. *Ecol. Appl.* 3 (2), 331–350. doi: 10.2307/ 1941836

Simard, M. A., Paquet, A., Jutras, C., Robitaille, Y., Blier, P. U., Courtois, R., et al. (2012). North American range extension of the invasive Asian Clam in a St. Lawrence River power station thermal plume. *Aquat. Invasions* 7 (2). doi: 10.3391/ai. 2012.7.1.009

Singh, D. P., Saraswat, R., and Nigam, R. (2021). Untangling the effect of organic matter and dissolved oxygen on living benthic foraminifera in the southeastern Arabian Sea. *Mar. pollut. Bull.* 172, 112883. doi: 10.1016/j.marpolbul.2021.112883

Sivaperumal, P., Khot, M., Chakraborty, S. K., Pawase, A., and Jaiswar, A. K. (2022). Diversity of intertidal macrobenthic fauna around Ratnagiri and Sindhudurg districts of Maharashtra, west coast of India. *Indian J. Geo.-Mar. Sci. (IJMS)* 51 (01), 56–66. doi: 10.56042/ijms.v51i01.65900

Smith, K. E., Burrows, M. T., Hobday, A. J., King, N. G., Moore, P. J., Sen Gupta, A., et al. (2023). Biological impacts of marine heatwaves. *Annu. Rev. Mar. Sci.* 15, 119–145. doi: 10.1146/annurev-marine-032122-121437

Snelgrove, P. V. (1998). The biodiversity of macrofaunal organisms in marine sediments. *Biodivers. Conserv.* 7, 1123–1132. doi: 10.1023/A:1008867313340

Snoeijs, P. J. M. (1989). Effects of increasing water temperatures and flow rates of epilithic fauna in a cooling-water discharge basin. *J. Appl. Ecol.* 26 (3), 935-956. doi: 10.2307/2403703

Steinbeck, J. R., Schiel, D. R., and Foster, M. S. (2005). Detecting long-term change in complex communities: A case study from the rocky intertidal zone. *Ecol. Appl.* 15 (5), 1813–1832. doi: 10.1890/04-1046

Sun, X., Li, Z., Ding, X., Ji, G., Wang, L., Gao, X., et al. (2022). Effects of algal blooms on phytoplankton composition and hypoxia in coastal waters of the northern Yellow Sea, China. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.897418

Suresh, K., Ahamed, M. S., Durairaj, G., and Nair, K. V. K. (1993). Impact of power plant heated effluent on the abundance of sedentary organisms, off Kalpakkam, East coast of India. *Hydrobiologia* 268, 109–114. doi: 10.1007/BF00006881

Suresh, K., Durairaj, G., and Nair, K. V. K. (1996). Harpacticoid copepod distribution on a sandy shore in the vicinity of a power plant discharge, at Kalpakkam, along the east coast of India. *Indian J. Mar. Sci.* 25, 307–311.

Taylor, C. J. (2006). The effects of biological fouling control at coastal and estuarine power stations. *Mar. pollut. Bull.* 53, 30–48. doi: 10.1016/j.marpolbul.2006.01.004

Teixeira, T. P., Neves, L. M., and Araújo, F. G. (2009). Effects of a nuclear power plant thermal discharge on habitat complexity and fish community structure in Ilha Grande Bay, Brazil. *Mar. Environ. Res.* 68 (4), 188–195. doi: 10.1016/j.marenvres.2009.06.004

Teixeira, T. P., Neves, L. M., and Araújo, F. G. (2012). Thermal impact of a nuclear power plant in a coastal area in Southeastern Brazil: effects of heating and physical structure on benthic cover and fish communities. *Hydrobiologia* 684, 161–175. doi: 10.1007/s10750-011-0980-1

Thieltges, D. W., Strasser, M., van Beusekom, J. E., and Reise, K. (2004). Too cold to prosper—winter mortality prevents population increase of the introduced American slipper limpet Crepidula fornicata in northern Europe. *J. Exp. Mar. Biol. Ecol.* 311, 375–391. doi: 10.1016/j.jembe.2004.05.018

Titelboim, D., Almogi-Labin, A., Herut, B., Kucera, M., Schmidt, C., Hyams-Kaphzan, O., et al. (2016). Selective responses of benthic foraminifera to thermal pollution. *Mar. pollut. Bull.* 105, 324–336. doi: 10.1016/j.marpolbul.2016.02.002

Urban-Malinga, B. (2014). Meiobenthos in marine coastal sediments. *Geol. Society London Special Publications* 388, 59–78. doi: 10.1144/SP388.9

Vaquer-Sunyer, R., and Duarte, C. M. (2008). Thresholds of hypoxia for marine biodiversity. *Proc. Natl. Acad. Sci.* 105, 15452–15457. doi: 10.1073/pnas.0803833105

Vargas, C. A., Aguilera, V. M., Martín, V. S., Manríquez, P. H., Navarro, J. M., Duarte, C., et al. (2011). Temperature effects on oxygen thresholds for hypoxia in marine benthic organisms. *Global Change Biol.* 17 (5), 1788–1797. doi: 10.1111/j.1365-2486.2010.02343.x

Venugopalan, V. P., Rajagopal, S., and Jenner, H. A. (2011). Operational and environmental issues relating to industrial cooling water systems: an overview. *Operational Environ. Consequences Large Ind. Cooling Water Syst.*, 1–12. doi: 10.1007/978-1-4614-1698-21

Viotti, S., Sangil, C., Hernández, C. A., and Hernández, J. C. (2019). Effects of long-term exposure to reduced pH conditions on the shell and survival of an intertidal gastropod. *Mar. Environ. Res.* 152, 104789. doi: 10.1016/j.marenvres.2019.104789

Viviani, D. A., Bjorkman, K. M., Karl, D. M., and Church, M. J. (2011). Plankton metabolism in surface waters of the tropical and subtropical Pacific Ocean. *Aquat. Microb. Ecol.* 62 (1), 1-12. doi: 10.3354/ame01451

Wang, Y. S., Lou, Z. P., Sun, C. C., and Sun, S. (2008). Ecological environment changes in Daya Bay, China, from 1982 to 2004. *Mar. pollut. Bull.* 56, 1871–1879. doi: 10.1016/j.marpolbul.2008.07.017

Wang, Y. S., Sun, C. C., Lou, Z. P., Wang, H. L., Mitchell, B. G., Wu, M. L., et al. (2011). Identification of water quality and benthos characteristics in Daya Bay, China, from 2001 to 2004. *Oceanol. Hydrobiol. Stud.* 40, 82–95. doi: 10.2478/s13545-011-0009-4

Warwick, R. M., and Clarke, K. R. (1993). Increased variability as a symptom of stress in marine communities. *J. Exp. Mar. Biol. Ecol.* 172, 215–226. doi: 10.1016/0022-0981(93)90098-9

Wasti, A., Ray, P., Wi, S., Folch, C., Ubierna, M., and Karki, P. (2022). Climate change and the hydropower sector: A global review. *Wiley Interdiscip. Reviews: Climate Change* 13, e757. doi: 10.1002/wcc.757

West, A., Penk, M. R., Larney, R., and Piggott, J. J. (2021). Response of macroinvertebrates to industrial warm discharges: the River Shannon case study (Ireland). *Inland Waters* 11, 381–395. doi: 10.1080/20442041.2021.1904761

Williams, B. K. (2011). Adaptive management of natural resources—framework and issues. *J. Environ. Manage.* 92, 1346–1353. doi: 10.1016/j.jenvman.2010.10.041

Williamson, B. J., Fraser, S., Blondel, P., Bell, P. S., Waggitt, J. J., and Scott, B. E. (2017). Multisensor acoustic tracking of fish and seabird behavior around tidal turbine structures in Scotland. *IEEE J. Oceanic Eng.* 42, 948–965. doi: 10.1109/JOE.2016.2637179

Wither, A., Bamber, R., Colclough, S., Dyer, K., Elliott, M., Holmes, P., et al. (2012). Setting new thermal standards for transitional and coastal (TraC) waters. *Mar. pollut. Bull.* 64, 1564–1579. doi: 10.1016/j.marpolbul.2012.05.019

Wong, C. K., Hwang, J. S., and Chen, Q. C. (1998). Taxonomic composition and grazing impact of calanoid copepods in coastal waters near nuclear power plants in northern Taiwan. *ZOOLOGICAL Stud.* 37 (4), 330–339.

Xu, D., Wang, H., Han, D., Chen, A., and Niu, Y. (2021). Phytoplankton community structural reshaping as response to the thermal effect of cooling water discharged from power plant. *Environ. pollut.* 285, 117517. doi: 10.1016/j.envpol.2021.117517

Yang, Y., Yi, Y., Zhou, Y., Wang, X., Zhang, S., and Yang, Z. (2020). Spatio-temporal variations of benthic macroinvertebrates and the driving environmental variables in a shallow lake. *Ecol. Indic.* 110, 105948. doi: 10.1016/j.ecolind.2019.105948

Yanygina, L. V. (2015). Spatial distribution of Gmelinoides fasciatus Steb. *thermally polluted Water (Belovo Reservoir Southwest Siberia). Int. J. Environ. Res.* 9 (3), 877–884.

Ying, R., Cao, Y., Yin, F., Guo, J., Huang, J., Wang, Y., et al. (2020). Trophic structure and functional diversity reveal pelagic-benthic coupling dynamic in the coastal ecosystem of Daya Bay, China. *Ecol. Indic.* 113, 106241. doi: 10.1016/j.ecolind.2020.106241

Yuan, L. L. (2004). Assigning macroinvertebrate tolerance classifications using generalised additive models. *Freshw. Biol.* 49, 662–677. doi: 10.1111/j.1365-2427.2004.01206.x

Zeng, C., Rotllant, G., Giménez, L., and Romano, N. (2020). Effects of environmental conditions on larval growth and development. *Dev. Biol. Larval Ecol. Natural History Crustacea* 7, 195–222.

Zeppilli, D., Bongiorni, L., Cattaneo, A., Danovaro, R., and Santos, R. S. (2013). Meiofauna assemblages of the Condor Seamount (North-East Atlantic Ocean) and adjacent deep-sea sediments. *Deep Sea Res. Part II: Topical Stud. Oceanogr.* 98, 87–100. doi: 10.1016/j.dsr2.2013.08.009

Zeppilli, D., Sarrazin, J., Leduc, D., Arbizu, P. M., Fontaneto, D., Fontanier, C., et al. (2015). Is the meiofauna a good indicator for climate change and anthropogenic impacts? *Mar. Biodivers.* 45, 505–535. doi: 10.1007/s12526-015-0359-z

Zimina, L. M., Zimin, V. L., and Khayrutdinova, J. (1993). Some results of the long-time ecological monitoring of the Leningrad NPP cooling water body (Koporskaya bay, gulf of Finland). *Hydrological. Chem. Biol. Processes Transformation Transport Contaminants Aquat. Environments Proc. HYDROCHEMISTRY*, 137–146.

Zvyagintsev, A. Y., Korn, O. M., and Kulikova, V. A. (2004). Seasonal dynamics of pelagic larvae and settling of the fouling organisms in conditions of thermal pollution. *Russian J. Mar. Biol.* 30 (4), 266–277. doi: 10.1023/B: RUMB.0000039157.34031.ba

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 23 December 2024
DOI 10.3389/fmars.2024.1486894

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
University of International Business and Economics, China

REVIEWED BY
Yen-Chiang Chang,
Dalian Maritime University, China
Tony Press,
University of Tasmania, Australia

*CORRESPONDENCE
Yitong Chen
chenyitong@ouc.edu.cn

RECEIVED 27 August 2024
ACCEPTED 09 December 2024
PUBLISHED 23 December 2024

CITATION
Chen Y and Wu S (2024) Regulating unmanned aircraft systems in Antarctica: challenges and collaborative solutions. *Front. Mar. Sci.* 11:1486894. doi: 10.3389/fmars.2024.1486894

COPYRIGHT
© 2024 Chen and Wu. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Regulating unmanned aircraft systems in Antarctica: challenges and collaborative solutions

Yitong Chen* and Shu Wu

Law School, Ocean University of China, Qingdao, China

The increasing use of unmanned aircraft systems (UAS) globally presents significant opportunities and challenges for Antarctic governance, particularly in terms of operational safety and environmental protection. This study investigates the challenges faced by various stakeholders in regulating UAS operations in Antarctica and identifies collaborative solutions, employing both empirical and comparative research methodologies. Data on domestic UAS regulations and Antarctic-specific rules from Antarctic Treaty Consultative Parties (ATCPs) were obtained through their official civil aviation websites, while the involvement of non-state actors in the Antarctic Treaty Consultative Meeting (ATCM) was assessed using information provided by the Antarctic Treaty Secretariat. The findings reveal that ATCPs have developed guidelines, manuals, and other regulatory tools and contribute actively to ATCM discussions. Non-state actors, leveraging their interdisciplinary expertise and research capabilities, also play a critical role in shaping UAS regulatory frameworks. Nevertheless, current rules governing UAS operations in Antarctica remain fragmented, underscoring the need for a more cohesive and comprehensive regulatory framework. As UAS regulations in Antarctica continue to evolve, effective rulemaking will require collaboration among diverse actors, integrating practical expertise, global regulatory standards, and the unique operational conditions of the Antarctic region. A comprehensive legally binding Measure or at least a resolution adopted by ATCM may be good start for this integrated regulatory process.

KEYWORDS

Antarctic Treaty Consultative Parties (ATCPs), non-state actors, regulation, unmanned aircraft systems (UAS), Antarctica

1 Introduction

Technological advancements have driven the global expansion of unmanned aircraft systems (UAS) usage. Current applications and existing legal regulations for UAS provide a valuable research framework for shaping UAS regulation in Antarctica. Although universal UAS regulations are lacking and legal frameworks differ significantly across states, the

relatively comprehensive and well-established regulations outside of Antarctica offer useful references for developing robust legal standards for UAS operations within the Antarctic region.

Originally developed as training aids for targeting practice during World War II, UAS have since evolved into highly sophisticated systems with various forms of ground control and pre-programming capabilities (Heverly, 2015). The term "drone" is widely used by the media, industry, and the general public. However, states and private entities often employ alternative terminology, such as Unmanned Aerial Vehicles (UAV) (The Canadian Aviation Regulations, 2016), Remotely Piloted Aircraft Systems (RPAS) (ATCM40 WP20, 2017), and Remotely Piloted Aerial Vehicles (RPAV) (ENAC, 2018). In 2015, the International Civil Aviation Organization (ICAO) published a Manual on Remotely Piloted Aircraft Systems to facilitate the integration of UAS regulations into the existing civil aviation framework (ICAO, 2015). As RPAS has emerged as the most internationally accepted term, it has been adopted by numerous national aviation agencies and is frequently used in guidelines and discussions at the Antarctic Treaty Consultative Meeting (ATCM) in recent years.

ICAO currently differentiates between UAS that can be accommodated within airspace and those capable of integration with manned aircraft (ICAO, 2024). The ICAO encourages states to support the development of UAS regulations by contributing experience-based insights (ICAO, 2011). This study adheres to the ICAO's current model standards and predominantly uses the term UAS, while also retaining the term RPAS in alignment with terminology commonly used in international governance platform publications.

To assess the current state of research on UAS in Antarctica, this study conducted a search in the Web of Science database (Web of Science, 2024) using keywords such as "Antarctica," "drones," "Unmanned Aerial Vehicle," "Unmanned Aircraft System," and "Remotely Piloted Aircraft System" for the period spanning 2012 to 2023. Figure 1 illustrates the search results. Over the past decade, there has been a marked increase in studies focusing on UAS in Antarctica. While the number of published papers fluctuated between 2012 and 2016, a consistent upward trend has been observed since 2016.

The findings indicate that the United States, the United Kingdom, China, Australia, Germany, Spain, and New Zealand have published more research on UAS usage in Antarctica than other Antarctic Treaty Consultative Parties (ATCPs). Figure 2 presents these search results. Greater utilization of UAS in Antarctica has allowed these states to accumulate significant practical experience, resulting in a higher volume of research publications. Leveraging this practical experience and research knowledge, these states have enhanced their governance capacity in regulating UAS activities within Antarctica, increasing their influence in Antarctic governance. Additionally, these countries have submitted national proposals for discussion at the ATCM and the Committee for Environmental Protection (CEP), receiving strong engagement and support. This active participation has initiated the regulatory process for UAS activities under a state-led approach within the broader international Antarctic governance framework.

To deepen understanding of Antarctica, states have increasingly focused on researching and applying new technologies and equipment for polar exploration. The use and regulation of UAS have become prominent topics within the Antarctic Treaty Consultative Meeting (ATCM). The growing volume of research publications on Antarctic UAS highlights states' attention to such innovations in polar research. This rising trend in UAS applications underscores the need for more robust legal regulations governing their use in the region.

In polar research, states closely monitor advancements in technology and equipment. The unique characteristics of Antarctica make enhanced regulation of UAS essential. First,

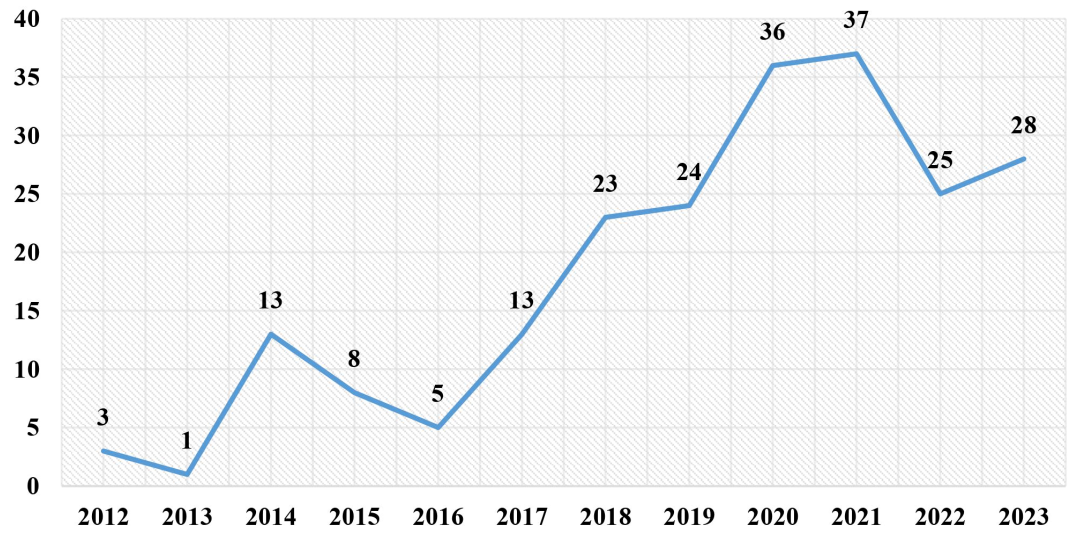


FIGURE 1
Trend in the number of papers related to UAS in Antarctica in the Web of Science Database (2012-2023). Source: Web of Science Database. https://www.webofscience.com/wos/alldb/summary/9dcee866-a1e7-4e31-8552-8d39fa9a2de1-98e3eb44/relevance/1. The figure is made by the author.

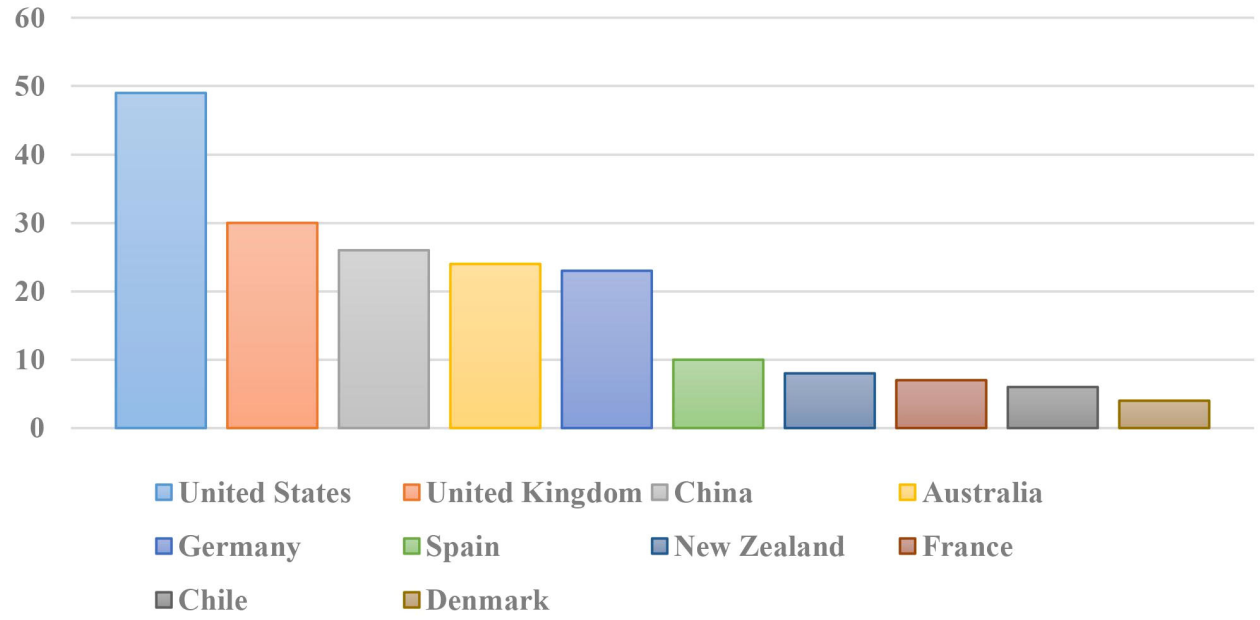


FIGURE 2
The number of papers related to UAS in Antarctica by various states in the Web of Science Database (2012-2023). Source: Web of Science Database. https://www.webofscience.com/wos/alldb/summary/9dcee866-a1e7-4e31-8552-8d39fa9a2de1-98e3eb44/relevance/1. The figure is made by the author.

Antarctica's environment is highly fragile, and UAS operations may disrupt or damage local wildlife and ecosystems. Second, as a key region for scientific study, UAS activities must be carefully coordinated with ongoing research to prevent mutual interference. Third, as an international public domain, UAS operations must be adhered strictly to established rules to ensure the region's peaceful use. Overall, UAS operations in Antarctica call for unified regulatory standards.

Beyond Antarctica's unique characteristics, it is crucial to standardize UAS regulations in the region. ATCPs and non-state actors have collaboratively developed a soft law framework for UAS operations in Antarctica, grounded in scientific and practical experience. The ATCM adopted the "Environmental Guidelines for Operation of Remotely Piloted Aircraft Systems in Antarctica" (ATCM41 Final Report Environmental Guidelines, 2018). Additionally, the Council of Managers of National Antarctic Programs (COMNAP) published the Antarctic UAS Operator's Handbook (Handbook, 2022), while the International Association of Antarctica Tour Operators (IAATO) introduced the IAATO Policies on the Use of Unmanned Aerial Vehicles in Antarctica (ATCM38 IP88 IAATO Policies, 2015). The existing UAS regulations in Antarctica are fragmented and lack systematic coherence. It is insufficient for states and non-state actors to independently design and follow their own UAS guidelines. To ensure orderly UAS operations and safeguard the Antarctic environment, it is essential to establish unified regulations as a minimum standard. Various actors, at multiple levels, should take the initiative in developing collaborative solutions for effective UAS governance in Antarctica.

Therefore, this study analyzes the domestic policies and regulations of ATCPs, relevant ATCM documents, normative guidelines from associated organizations, and scholarly literature, utilizing both comparative and empirical research methods. The remainder of the paper is organized as follows: Section 2 examines the practical applications of UAS; Section 3 reviews ATCPs' domestic UAS regulations and their involvement in Antarctic UAS governance; Section 4 analyzes the role of non-state actors in Antarctic UAS regulation; Section 5 offers recommendations for improving UAS regulation in Antarctica; and Section 6 concludes the discussion.

2 Applications and challenges of UAS

UAS were initially developed for military purposes. By the early 21st century, advancements in technologies such as global satellite positioning facilitated the gradual expansion of UAS applications in the civilian sector. Much like the transformative impact of manned aircraft on civil aviation, UAS are now revolutionizing this field (Fiallos, 2016). Their civilian applications parallel those in Antarctica, where their flexibility and cost-effectiveness have led to increased usage. However, UAS operations in Antarctica also pose challenges and risks to the fragile Antarctic environment. Consequently, the regulation of UAS is emerging as a critical issue on the Antarctic governance agenda. This section examines conventional civilian UAS applications and explores their uses and associated challenges in Antarctica to inform the development of effective UAS regulatory frameworks.

2.1 Conventional civilian applications of UAS

Over recent decades, UAS have advanced rapidly, becoming integral to civilian applications such as remote sensing, logistics, emergency rescue, environmental monitoring, and precision agriculture. Their advantages—accuracy, efficiency, and flexibility—make UAS well-suited for these diverse uses (Hayat et al., 2016). To provide a clear overview of UAS applications, this section examines their role in the civilian sector across three key areas: remote sensing, logistics, and emergency rescue.

2.1.1 Remote sensing

UAS-based remote sensing provides automated, intelligent, and specialized capabilities for rapidly acquiring spatial information on land, resources, environmental conditions, and specific events. It integrates advanced technologies, including unmanned aerial vehicle systems, remote sensing sensors, telemetry and telecontrol, communication systems, and GPS differential positioning to enable real-time data processing, modeling, analysis, and actionable insights (Li and Li, 2014). UAS remote sensing applications encompass meteorological monitoring (Sziroczak et al., 2022), environmental observation (Zhang and Zhu, 2023), maritime information infrastructure, and disaster forecasting (Mohd Daud et al., 2022).

For instance, during the monitoring of Antarctic glaciers in 2017, a collapse event occurred at the Darke Glacier near Zhongshan Station, forming a new ice-pit landform. UAS remote sensing was deployed for emergency aerial imaging, surveying the ice surface from Eagle's Nest Rock to the inland departure base and conducting three-dimensional modeling and data processing. This operation provided valuable high-resolution UAS remote sensing data essential for studying ice-pit landforms (Zhang et al., 2019).

As an innovative remote sensing tool, UAS overcomes limitations inherent in traditional satellite remote sensing, manned aerial sensing, and ground-based monitoring. UAS remote sensing images offer a resolution as fine as 0.1 meters—significantly higher than satellite images—and flight endurance exceeding 16 hours. With high mobility, cost-effectiveness, and efficiency, UAS remote sensing is poised to become a vital information source for the dynamic monitoring and management of national marine areas in the future (Li and Li, 2014).

2.1.2 Logistics

The rapid growth of e-commerce has driven increasing demand for UAS in logistics and distribution, with the potential to revolutionize logistics systems. Amazon was one of the first e-commerce companies to utilize UAS for paid deliveries, launching Prime Air in 2015. Prime Air's advanced detection and avoidance system allows it to fly longer distances without a visual observer, while safely avoiding other aircraft, people, pets, and obstacles (Amazon, 2022). In contrast to Amazon's delivery drones, WING employs a unique system that lowers packages to the ground via a tether without the need to land (Wing, 2021). JD.com, capitalizing on its global logistics and warehousing network, is developing a "feeder and terminal" drone logistics ecosystem. This system covers all logistics orders within a 500-kilometer radius and establishes an intelligent "skyway network" (JD, 2024).

In addition to safety and flexibility, the cost of drone delivery is a crucial factor in logistics. Drone delivery costs approximately $0.30 per parcel, which is one-third or less of the cost of traditional ground transportation (Sudbury and Hutchinson, 2016). In 2019, Air Cargo Canada and Drone Delivery Canada partnered to use UAS for air cargo transport, planning 150,000 drone transport routes. These drone-based air transport services are expected to offer cost-effective solutions for cargo delivery, especially in reaching remote communities across Canada. This agreement is also likely to advance the development of regular international air transport operations for UAS (DDC, 2019).

In logistics applications, the advantages of UAS in terms of safety, flexibility, and low cost are fully realized. UAS are commonly used to transport daily necessities and work equipment for scientific expeditions in Antarctica, proving highly effective in logistics support. The experience gained from UAS applications in logistics can offer valuable insights for their use in Antarctica. For instance, optimizing cargo transportation routes can reduce costs, allowing scientific research funds to be allocated more effectively to other key areas of research.

2.1.3 Medical and rescue

States with underdeveloped infrastructure have a high demand for UAS in medical supply delivery and rescue operations. In areas with limited transportation options, such as mountainous regions, traditional methods can be hindered by infrastructure challenges, leading to delayed medical deliveries and missed rescue opportunities. In contrast, UAS are not impacted by such limitations. Their versatility and maneuverability make them ideal for emergency situations. Since 2016, Zipline, a drone operator, has saved lives in Rwanda by delivering medical supplies, including blood, via drones (Zipline, 2018a). While traditional transportation can take hours to deliver medical supplies, Zipline's drones can transport blood samples to hospitals within 75 kilometers of Rwanda's Muhanga distribution center in just 30 minutes, reducing delivery time by at least four hours (Zipline, 2018b).

Geographic dispersion and limited medical services in the Caribbean pose significant challenges for timely medical emergency responses. UAS are increasingly being used in the region to deliver critical medical supplies, such as intravenous injections, sodium chloride infusions, hypertonic solutions, antiepileptic drugs, antihypertensive medications, painkillers, sedatives, and blood products (Ramsewak et al., 2022). Additionally, UAS utilize advanced computer vision technologies for dynamic monitoring (Mishra et al., 2020). For instance, rescue drones are deployed for coastal monitoring and search-and-rescue operations (Del-Real and Díaz-Fernández, 2021), offering timely and efficient assistance to individuals stranded on beaches.

UAS applications contribute to public welfare by stimulating economic growth and enhancing social benefits (Intelsat, 2024). Their high safety, flexibility, and low cost make them valuable not only for daily operations but also for scientific research and exploratory activities in Antarctica. UAS have become increasingly

essential for Antarctic scientific research, logistical support, and emergency search-and-rescue operations.

2.2 UAS applications in Antarctica

UAS offer significant advantages in the harsh and sparsely populated conditions of Antarctica, which present unique challenges compared to other regions of the world. Currently, UAS are widely used in Antarctica for scientific research, logistical support, tourism, and journalism.

In scientific research, UAS have been utilized to gather data on the impacts of climate change, monitor sea ice, track penguin populations, map fine-scale vegetation, study ecosystem functioning (ATCM40 WP20, 2017), monitor marine mammals (ATCM40 IP75, 2017), and conduct surveys of Antarctic Specially Protected Areas (ATCM40 IP86, 2017). These applications align with UAS use in remote sensing. For logistical support, UAS are employed to transport scientific equipment and small items to designated locations (ATCM38 IP22, 2015), a role similar to their function in general logistics.

Travel agents and tourists can also use UAS for Antarctic tours, with proper permissions. In the future, UAS could play key roles in various emergency situations, such as search and rescue, firefighting, medical assistance, and the rapid detection of crevasses in sea ice and glaciers, similar to their applications in medical rescue. Furthermore, UAS are revolutionizing conservation efforts and enabling more informed management decisions (Jesús and Mulero-Pázmány, 2019). They can address environmental issues that threaten biodiversity in protected areas by providing continuous monitoring of environmental biophysical indicators. Traditionally, conservation actions combine field visits with satellite remote sensing, but these methods can disrupt the environment in protected areas. UAS offer a less invasive, non-disruptive, and reliable alternative for monitoring species abundance and distribution, as well as documenting wildlife behavior and health status (Jewell, 2013).

Under the harsh conditions of Antarctica, UAS offer several advantages (Li et al., 2021). First, they are cost-effective, with lower acquisition, training, and operational expenses. Second, UAS are highly flexible, lightweight, portable, and easy to operate. Third, they enhance safety by eliminating the risks associated with onboard personnel. Finally, UAS have a minimal impact on wildlife and the environment (ATCM41 WP29, 2018). Excessive human activity in Antarctica can disrupt wildlife habitats and disturb the ecological balance, significantly impacting the local ecosystem. Compared to manned aircraft, UAS are less intrusive when collecting data and conducting missions, making them a more environmentally friendly option for protecting the Antarctic region.

The aforementioned characteristics of UAS allow for the overcoming of human limitations, enabling the collection of scientific data across a wide range of natural conditions and scenarios, while minimizing environmental impact in Antarctica. This significantly enhances the effectiveness of scientific research in the region.

2.3 Challenges of UAS in Antarctica

However, the extreme and complex geography of Antarctica presents significant challenges for UAS operations. First, risks such as extremely low temperatures, strong winds, and rugged terrain can impede UAS flights, leading to potential damage or loss due to accidents, system failures, or unplanned landings. Additionally, UAS may collide with other aircraft or infrastructure, posing safety risks to personnel (ATCM38 IP22, 2015). Second, UAS operations can impact Antarctic wildlife, causing collisions, injuries, or even fatalities (ATCM37 WP51, 2014). The fragile vegetation and soil on the Antarctic surface can take years to recover from damage. Finally, UAS can threaten Antarctic wilderness values and protected areas, potentially harming unique ecosystems, as well as special areas such as Antarctic Specially Protected Areas, Antarctic Specially Managed Areas, and Historical Sites and Monuments (Secretariat of the Antarctic Treaty, 2024a). Thus, UAS operations in Antarctica pose both safety risks and potential environmental harm.

These concerns have not been adequately addressed by existing international regulations, including the Antarctic Treaty, the Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol) (Madrid Protocol, 1991), and its accompanying annexes. Given its urgency, the regulation of UAS is swiftly becoming a key issue on the Antarctic governance agenda.

In summary, while the applications of UAS in Antarctica offer significant benefits, they also present substantial challenges. Many states have incorporated UAS into their Antarctic programs as part of their logistical and operational plans for scientific research, and non-governmental organizations and individuals are increasingly using UAS in the region. To fully harness the advantages of UAS and ensure safe operations while safeguarding the environment, it is essential to establish and enhance regulatory frameworks for UAS activities in Antarctica.

3 Engagement of ATCPs in regulating UAS operations in Antarctica

Advancements in science and technology have significantly expanded human understanding of Antarctica and have had a profound impact on its governance. The development of UAS regulations in Antarctica is a prime example of this influence. Currently, UAS operations in the region are governed by a set of frameworks, including the *Environmental Guidelines*, the *Handbook*, and the *IAATO Policies*. These regulations have been shaped through collaboration between ATCPs and non-state actors. According to Article 38 of the Statute of the International Court of Justice (Statute of the International Court of Justice, 1946), states are the principal subjects of international lawmaking. As such, states remain central to the creation of UAS regulations in Antarctica (Rebecca and Saleem, 2015), while non-state actors, such as non-governmental organizations (NGOs), play complementary and interdependent roles (Sands et al., 2012).

There is currently no universally accepted, harmonized regulatory standard for UAS, and national regulatory practices differ significantly. However, the domestic technical practices and regulatory experiences of the ATCPs provide valuable models for UAS regulation in Antarctica. Based on their existing UAS practices, ATCPs have assessed the operational benefits, potential risks, and environmental impacts of UAS. The ATCM, the primary deliberative platform of the Antarctic Treaty System (ATS), facilitates the participation of signatories in Antarctic governance through active involvement, speaking opportunities, and the submission of meeting documents (ATCM Rules, 2022). Some ATCPs, drawing on their domestic regulatory experience and high-quality proposals, have made substantial contributions to shaping the UAS regulatory agenda within Antarctic governance. This section examines the domestic UAS regulations of ATCPs and their application to UAS in Antarctica, offering a comparative analysis of UAS regulations both within and outside the Antarctic region (Tsiamis et al., 2019).

3.1 Comparison of domestic UAS regulations in ATCPs

This section analyzes the domestic regulatory documents of 29 ATCPs to provide a comprehensive understanding of UAS regulations. By examining the varied regulatory practices among ATCPs, this study seeks to draw valuable insights and lessons for the development of UAS regulations in Antarctica.

National civil aviation or transport authorities are responsible for establishing UAS regulations to ensure safe operations and the organized development of the aviation sector. The data for this section were primarily sourced from the official websites of national government departments, civil aviation authorities, and the global drone regulations database (Global Drone Regulations Database, 2024). Table 1 presents the ATCPs and the relevant agencies responsible for regulating UAS. The national UAS regulations discussed in this section were published before March 2024, with the understanding that regulations are part of an evolving legislative process, and new updates are likely to emerge.

An analysis of UAS regulations across various ATCPs reveals that most countries have established specific criteria, including registration requirements, flight distance limitations, weight classifications, restrictions on flying over sensitive areas, proximity to airports, flight prohibitions in densely populated regions, flight time limits, and safety insurance mandates. In addition, some ATCPs emphasize additional factors such as pilot qualifications, age limits, weather conditions for UAS flights, and privacy regulations. Upon reviewing the domestic UAS regulations of 29 ATCPs, it is evident that these criteria appear frequently, indicating a level of commonality across the regulations. This study summarizes these twelve key criteria in Table 2. The black dots in the table indicate the presence of these criteria in the respective ATCPs' regulations, while a slash signifies their absence.

In the left column of Table 2, the ATCPs are listed in alphabetical order. The horizontal header presents the legislative criteria, ranked in descending order based on the number of ATCPs that govern them. All ATCPs regulate UAS registration and flight distance limitations, while only about half address weather conditions and privacy guidelines. This suggests that registration and flight distance limitations are fundamental aspects of UAS operations. The next section will further analyze these two elements.

TABLE 1 Authorities of UAS regulations in ATCPs.

State	Authority
Argentina	National Common Aeronautics Organization of Argentina
Australia	Civil Aviation Safety Authority
Belgium	Civil Aviation Authority
Brazil	National Civil Aviation Agency
Bulgaria	Bulgarian Air Traffic Services Authority
Chile	Directorate General of Civil Aviation
China	Civil Aviation Administration of China
Czech Republic	Civil Aviation Authority of Czech Republic
Ecuador	General Directorate of Civil Aviation of Ecuador
Finland	Finnish Transport Safety Agency
France	Ministry of Ecological and Solidarity Transition
Germany	Federal Minister of Justice and Consumer Protection of Germany
India	Directorate General of Civil Aviation (DGCA) Site for RPAS
Italy	The Italian Civil Aviation Authority
Japan	The Ministry of Land, Infrastructure, Transport and Tourism of Japan
Korea	Ministry of Land, Infrastructure and Transport of South Korea
Netherlands	The State Secretary for Transport, Public Works and Water Management of Netherlands
New Zealand	The Civil Aviation Authority of New Zealand
Norway	The Civil Aviation Authority of Norway
Peru	Peru's Directorate General of Civil Aeronautics
Poland	The Civil Aviation Office of Poland
Russian Federation	Russian Federal Space Agency
South Africa	South African Civil Aviation Authority
Spain	The Safety Aviation Agency of Spain
Sweden	The Transport Agency of Sweden
Ukraine	State Aviation Administration of Ukraine
United Kingdom	Civil Aviation Authority of United Kingdom
United States	Federal Aviation Administration of United States
Uruguay	National Directorate of Civil Aviation and Aeronautical Infrastructure of Uruguay

The table was made by the author based on the official website data from UAS authorities of ATCPs.

TABLE 2 Main legislative criteria in the national legal regulations.

State	Registration	Flight distance limitation	Weight classification	Sensitive area restriction	Distance from the airport	Security Insurance	Prosperous areas Restrictions	Flight time	Pilot qualification	Age limitation	Privacy	Climatic condition	Total
Argentina	•	•	•	•	•	•	•	•	•	•	•	•	12
Australia	•	•	•	•	•	•	•	•	•	•	•	•	12
Belgium	•	•	•	•	•	•	•	•	•	•	•	•	12
Brazil	•	•	•	•	/	•	/	/	•	•	/	/	7
Bulgaria	•	•	•	•	•	•	•	•	•	•	•	•	12
Chile	•	•	•	•	•	•	/	•	•	•	•	•	11
China	•	•	•	•	•	•	•	•	•	•	•	•	12
Czech Republic	•	•	•	•	•	•	•	•	•	/	•	•	11
Ecuador	•	•	•	•	•	•	/	•	•	•	•	•	11
Finland	•	•	•	•	•	•	•	•	•	•	/	/	10
France	•	•	•	•	•	•	•	•	•	•	/	•	11
Germany	•	•	•	•	•	•	•	•	•	/	•	•	11
India	•	•	•	•	•	•	•	•	•	•	/	/	10
Italy	•	•	•	•	•	•	•	•	•	•	•	/	11
Japan	•	•	•	•	•	•	•	•	•	/	/	/	9
Korea	•	•	•	•	•	•	•	•	/	/	•	•	10
Netherlands	•	•	•	•	•	•	•	•	•	•	•	•	12
New Zealand	•	•	•	•	•	•	•	•	•	/	/	/	9
Norway	•	•	•	•	•	•	•	•	•	•	/	/	10
Peru	•	•	•	•	•	/	•	•	/	/	•	/	8
Poland	•	•	•	•	•	•	•	•	•	•	•	•	12
Russian Federation	•	•	•	•	•	•	•	•	/	/	•	•	10
South Africa	•	•	/	/	•	/	/	•	•	•	•	•	8
Spain	•	•	•	•	•	•	•	•	•	•	•	•	12
Sweden	•	•	•	•	•	•	•	•	•	•	•	•	12
Ukraine	•	•	•	•	•	/	•	/	/	/	/	/	6
United Kingdom	•	•	•	•	/	•	•	/	•	•	/	/	8
United States	•	•	•	•	•	/	•	•	/	•	/	/	8
Uruguay	•	•	•	/	/	•	•	/	/	/	/	/	5
Total	29	29	28	27	26	25	25	25	23	20	18	17	

The table is made by the author based on the domestic UAS regulations of ATCPs.

In addition to the total number of criteria, Table 2 outlines the primary legislative criteria for domestic UAS regulations in the ATCPs. Figure 3, created using data from Table 2, provides a graphical representation of ATCPs' UAS regulations at the domestic law level. It illustrates the global distribution of ATCPs, with different colors representing varying numbers of criteria. States depicted in dark blue, such as Australia, have 12 criteria, while those in light blue, such as the United States, have 11 criteria. States shown in green, like Finland, possess 10 criteria; those in yellow, such as Japan, have 9 criteria; and states in orange, like Peru, have 8

criteria. States with skin tones, like Brazil, utilize 7 criteria, while those in red, such as Ukraine, have 6. States depicted in brown, such as Uruguay, possess 5 criteria. Figure 3 thus serves as a graphical representation of the data presented in Table 2.

ATCPs with comprehensive domestic UAS regulations have gained substantial experience in UAS scientific experiments and regulatory frameworks. By combining domestic legislative developments with international rules in Antarctica, it becomes evident that ATCPs with well-established UAS regulations are playing an active role in shaping the Antarctic UAS regulatory agenda. This highlights the fact that domestic experience provides a technical and regulatory foundation for the application of UAS by ATCPs in Antarctica. While the domestic practices and experiences of ATCPs cannot be directly applied to Antarctica due to its unique geography and special governance structure, they offer valuable lessons and insights. The following section compares and analyzes the main legislative criteria of ATCPs, explores their similarities and differences, and investigates how ATCPs' domestic regulations can be adapted for use in Antarctica.

UAS registration is a crucial criterion in the domestic regulations of all ATCPs and should be an essential component of the Antarctic UAS rules. Under Article 17 of the Chicago Convention, aircraft are assigned the nationality of the state in which they are registered (Chicago Convention, 1944). The state of registration bears several responsibilities concerning the aircraft under its jurisdiction. As Professor Cooper notes, "each State has a reciprocal responsibility for the international behavior of an aircraft having its nationality" (Cooper, 1965).

For example, in Argentina, the registration process for all unmanned aerial vehicles (UAVs) purchased from domestic suppliers must be initiated by the buyers (UAV regulations in Argentina, 2020). In Japan, the Civil Aviation Law mandates the registration of UAS weighing over 100 grams (Flight rules in Japan, 2024). Similarly, China's Interim Regulations on the Administration of Unmanned Aerial Vehicle Flights require owners to register their UAS under their real name, with penalties for operating without proper registration (UAS regulations in China, 2024).

The registration of UAS has become a global trend, facilitating both domestic management and adherence to international aviation regulations. Registration ensures that UAS operations are subject to government oversight and the legal framework of the state of registration, offering an effective mechanism for ensuring safe operations. This principle is equally applicable to UAS in Antarctica. Given that the airspace above Antarctica is considered international public airspace, registration is essential for establishing aircraft ownership and assigning responsibilities. UAS operating in Antarctica should be registered to maintain order and stability in the Antarctic airspace and ensure compliance with the regulations and standards of their respective states.

Additionally, all ATCPs' domestic regulations impose restrictions on flying distances, though the specific limits vary between states. Figure 4 illustrates the data on maximum vertical and horizontal distance limits in the domestic UAS regulations of the 29 ATCPs.

For vertical distance, most ATCPs regulate flight ceilings, with limits ranging from 50 meters to 150 meters. Notably, 66% of ATCPs, including countries such as Australia and the United States, specify a maximum height of 120 meters. However, Japan, Italy, South Korea, and Peru permit flights up to 150 meters, while

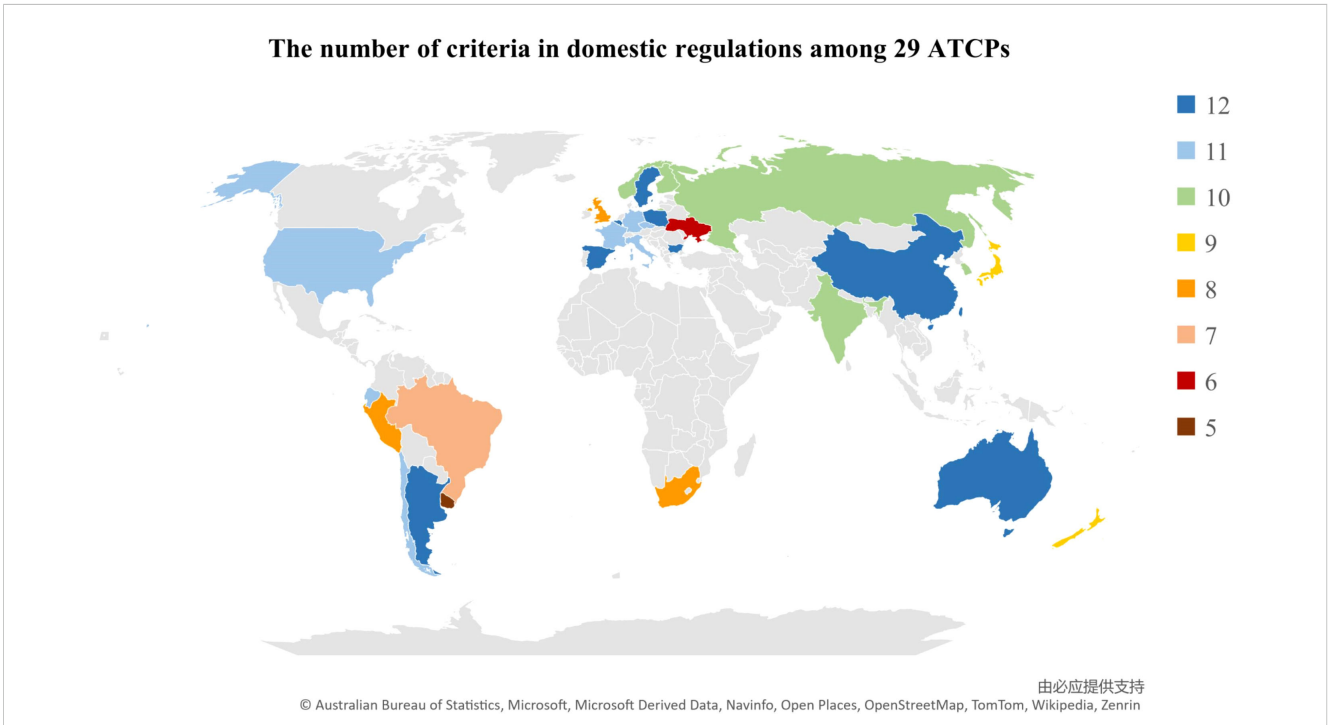


FIGURE 3
The number of criteria in domestic regulations among 29 ATCPs. The figure is made by the author based on the domestic UAS regulations of ATCPs.

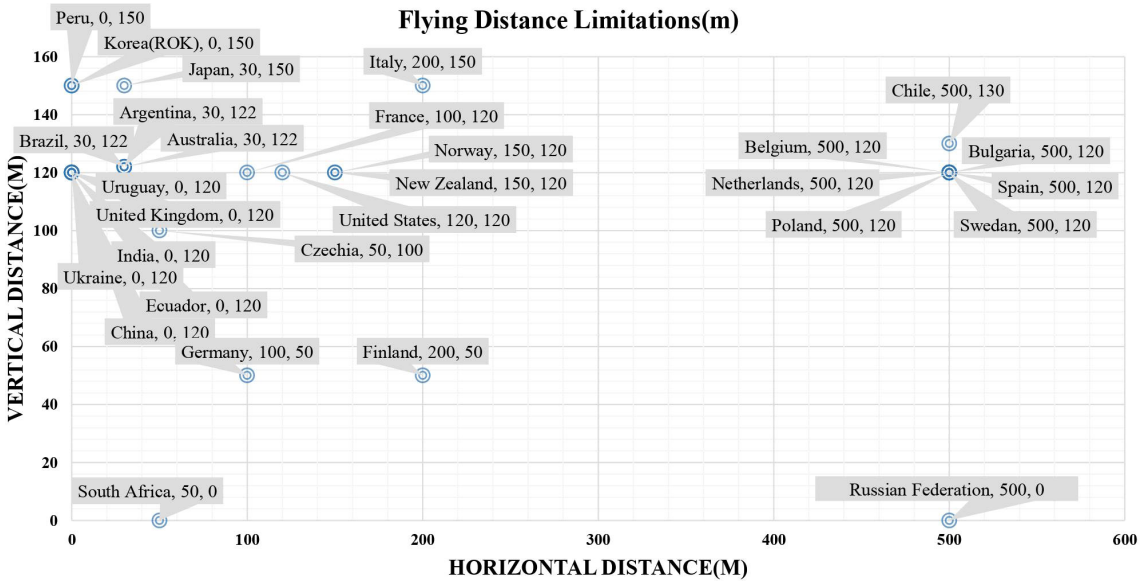


FIGURE 4
Limitations on the vertical and horizontal distance of UAS in the domestic regulations of ATCPs. The figure is made by the author based on the domestic UAS regulations of ATCPs.

Germany and Finland enforce a minimum flight height of 50 meters. By contrast, South Africa and the Russian Federation do not currently regulate maximum vertical distances.

In contrast to vertical distance regulations, the maximum horizontal distance permitted for UAS operations varies significantly among ATCPs, ranging from 30 meters to 500 meters. As shown in Figure 4, eight states, including Russia and Spain, have established a maximum horizontal distance of 500 meters, representing the higher end of the spectrum. Conversely, many other ATCPs impose stricter limits, allowing UAS to operate within a horizontal distance of less than 200 meters. Additionally, eight states, including China and the United Kingdom, do not define a specific horizontal distance but instead require that UAS remain within the visual line of sight (VLOS) of the operator. This approach emphasizes the operator's direct control and situational awareness during flight, potentially enhancing safety.

The emphasis on flight distance limitations in ATCPs' domestic regulations reflects a commitment to multiple priorities: ensuring flight safety, avoiding collisions with other aircraft or ground facilities, minimizing interference with the natural environment and wildlife, and protecting Antarctica's delicate ecosystems. For instance, both the United States and New Zealand extend their domestic standards to Antarctic operations, requiring UAS to operate strictly within the VLOS. Furthermore, they mandate a maximum flight altitude of 120 meters, aligning with safety and environmental protection principles. These measures stem from their broader domestic regulatory frameworks and demonstrate how established national practices can influence Antarctic governance (US Antarctic Program, 2016; ATCM40 ATT36, 2017).

The *Environmental Guidelines* explicitly mandate that UAS pilots and observers maintain operations within the VLOS and uphold constant communication unless explicitly authorized by a competent authority. Additionally, the guidelines emphasize keeping UAS at a precautionary distance from wildlife to minimize disturbances (ATCM41 WP29, 2018). These stipulations highlight the priority of flight distance limitations within the Antarctic UAS regulatory framework (Harris et al., 2019). However, a significant challenge persists: the lack of uniformity in the specific distance rules across ATCPs. For instance, while all ATCPs emphasize flight distance limitations domestically, the permitted distances vary widely.

Regarding the distance from airports during UAS operations (see Figure 5), Brazil, the United Kingdom, and Uruguay currently lack specific regulations, while the remaining 26 ATCPs mandate distances ranging from 1 km to 15 km. Among these, 72% require a minimum distance of 5 km or more. Most regulations fall within the 5–8 km range, with seven states stipulating distances exceeding 8 km. Generally, UAS are prohibited from approaching airports, particularly near take-off and landing paths, to ensure safety and reduce the risk of interfering with manned aircraft operations.

If UAS distances from airports are not effectively regulated, they can disrupt aviation operations, interfere with flight schedules, and even lead to aviation accidents. This issue is equally relevant in Antarctica, where aviation bases are vital infrastructure. Incomplete statistics indicate that over 50 airports exist in and around Antarctica, with more than 40 assigned ICAO airport codes (CAAC News, 2018). The region's unusually complex magnetic fields can cause compass errors, affecting aircraft navigation. The operation of UAS introduces an additional layer of complexity to Antarctic aviation. To ensure aviation safety, UAS should comply with distance limitations from airports, tailored to the unique conditions of Antarctica for safe and effective operations.

Flight time and weather conditions are critical factors influencing UAS operations. For instance, ATCPs like Australia

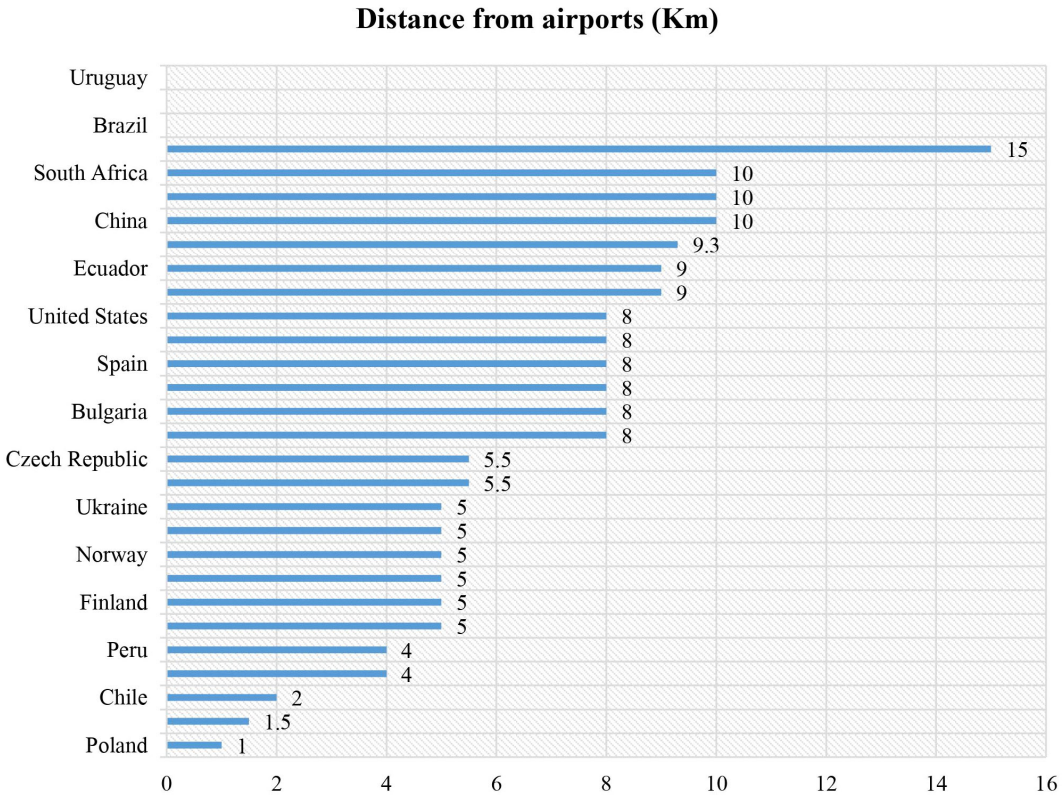


FIGURE 5
Limitations on the distance from airports. The figure is made by the author based on the domestic UAS regulations of ATCPs.

and New Zealand restrict UAS flights to daylight hours, explicitly prohibiting night flights. Conversely, the United States allows UAS to operate at night under certain conditions, such as the absence of exposed rotors and the use of anti-collision lights (Federal Aviation Administration, 2021). Restrictions on night flights are primarily due to reduced visibility, which hinders operators' ability to track UAS trajectories accurately and respond effectively to emergencies. Additionally, adverse weather conditions pose significant risks to UAS performance and safety, underscoring the need for clear regulatory provisions to ensure safe and effective operations.

Most ATCPs mandate that UAS operate only under favorable weather conditions. In Australia, for example, UAS flights are prohibited, unless approved by the Civil Aviation Safety Authority, in adverse conditions such as under clouds, in thick fog, at night, or with visibility less than 5 km. All drones are subject to environmental factors like wind and temperature and must adhere to the manufacturer's operational limits (CASR Part 101, 2023). Similarly, China's regulations have evolved, initially restricting UAS operations to daytime and continuous visual line-of-sight unaffected by weather. Recent updates now permit night flights or operations within the legal line of sight, provided the lighting system is activated (UAS regulations in China, 2024).

As technology advances, UAS are expected to adapt to increasingly complex scenarios, leading to the gradual relaxation of regulations concerning flight time and weather conditions. However, Antarctica's distinctive environment—marked by extreme cold, vast ice caps, frequent blizzards, and unpredictable weather—continues to present substantial challenges to UAS operations. To ensure safety, it is imperative to establish stringent regulations on flight time and weather conditions in Antarctica, mitigating economic losses and minimizing environmental risks.

Finally, security insurance and pilot qualifications are crucial factors influencing UAS operations. With the exceptions of Peru, South Africa, Ukraine, and the United States, all ATCPs have established insurance mechanisms to manage UAS-related accidents. Insurance requirements differ by state, with some regulations mandating coverage while others make it voluntary. For example, Brazil requires insurance for non-recreational UAS weighing ≥ 250 g (ANAC Resolution 419, 2017). In Australia, while public liability insurance is not mandatory, operators may face substantial financial liability in case of damage or injury, making liability insurance highly advisable (CASR Part 101, 2023). Some states, such as Argentina, have a mix of mandatory and voluntary insurance requirements. Operators of class C, D, and E recreational UAS must have liability insurance for damages caused by their operations, while those operating class A and B UAS are exempt but remain liable under general liability rules (UAV regulations in Argentina, 2020). Given the varying approaches, liability insurance should be considered for UAS operations to cover potential damage and accidents.

It is essential to address the issue of civil liability for damages caused by UAS operations (Konert and Kotliński, 2020). Insurance serves to protect UAS operators from accidental damage or liabilities incurred during flight activities. Given the harsh

Antarctic environment and the unpredictable nature of UAS operations in this region, mandatory insurance for UAS operations in Antarctica is crucial. This requirement would provide financial compensation for losses in the event of an accident, ensuring that operators are protected and that responsibilities are clearly defined.

Qualifications and age limits for UAS pilots are critical for ensuring the safe operation of UAS. Remote pilots must be trained, experienced, and competent, with their qualifications verified by the licensing authority in the state of registration, akin to the requirements for manned aircraft pilots (Pazmiño, 2021). According to Annex 2 of the Rules of the Air, remote pilots bear the same responsibilities as pilots of manned aircraft (Annexes of the Chicago Convention, 1944).

Statistically, 24 ATCPs have established requirements for UAS pilot qualifications. For instance, Japan (Flight rules in Japan, 2024) and Poland (Konert and Kotlinski, 2018) mandate that UAS pilots be certified, demonstrating the necessary skills, knowledge, and competence to operate UAS safely. Furthermore, 25 states have set age requirements for pilots. Argentina and Australia stipulate a minimum age of 16, while Brazil, Italy, South Africa, and Spain require pilots to be at least 18 years old.

China has classified personnel requirements for operating UAS based on their size and type. Operators of small, medium, or large civil UAS must possess full legal capacity, complete safe operation training, pass a civil aviation authority assessment, and have no medical history or record of drug abuse that could impair their ability to operate drones (UAS regulations in China, 2024). These requirements ensure that UAS pilots are adequately equipped to handle the responsibilities and challenges of UAS operations, thereby improving safety and reliability.

Individuals with a certain level of cognitive ability and knowledge are permitted to operate UAS. Overall, more than 83% of ATCPs have specific regulations for UAS pilots, highlighting the importance of operator proficiency in ensuring the safety of UAS operations. The challenging natural environment of Antarctica imposes even greater demands on pilots. Therefore, the competence of UAS operators must be thoroughly assessed to ensure their knowledge, skills, and age are suitable for Antarctic conditions, ensuring the safe and effective deployment of UAS in this harsh and unpredictable environment.

After an in-depth analysis of the domestic UAS regulations of ATCPs, this section finds that many ATCPs have already established relatively comprehensive UAS management systems. The regulations and practices of these states can serve as valuable references for the legal regulation of UAS in Antarctica. By drawing on the diverse domestic practices and expertise of ATCPs, Antarctic UAS regulations could benefit from more standardized and refined criteria. These practices can provide a foundation for harmonizing operational safety and environmental protection measures in the unique context of Antarctic governance. Given Antarctica's distinctive natural environment, it is likely to impose more stringent restrictions on UAS than other regions. Therefore, international regulation of UAS in Antarctica could build on the domestic regulations of ATCPs to establish more rigorous flight access regimes and operational rules. The next section will continue to examine UAS regulation practices of some ATCPs in Antarctica to inform the regulation of UAS activities in the region.

3.2 ATCPs' UAS regulations in Antarctica

To ensure compliance with the Antarctic Treaty, Article 7 establishes an inspection mechanism. This allows ATCPs to designate observers who are authorized to carry out inspections across all areas of Antarctica. These inspections encompass stations, installations, and equipment, as well as ships and aircraft involved in the disembarkation or embarkation of cargo and personnel. Additionally, aerial observations can be conducted at any time over any area of Antarctica by any Contracting Party authorized to designate observers.

In a joint report on Antarctic Treaty inspections conducted by the United Kingdom, Australia, and Peru, helicopters were identified as the primary tool for inspections, though their limitations were also highlighted. The report noted that most inspections were carried out using two Lynx helicopters, which facilitated flexible and efficient logistics, enabling more inspections to be completed within the available timeframe. However, during these inspections, five unoccupied stations were only overflown by helicopter but not visited due to the presence of large numbers of penguins or fur seals around the stations. Landing the helicopter in these areas would have caused significant disturbance to wildlife, violating Annex II of the Environmental Protocol (Antarctic Treaty inspections, 2005). In contrast, UAS are less invasive to the environment and can be used in situations where helicopter landings would be impractical or disruptive. This underscores a clear trend toward UAS being increasingly employed by ATCPs to fulfill their inspection obligations under the Antarctic Treaty System.

Supporting scientific research is the primary use of UAS in Antarctica, with ATCPs regulating UAS activities mainly through regulations established by their National Antarctic Programs (NAPs). A survey by COMNAP revealed that, as of March 31, 2017, 26.4% of the 30 member states had UAS regulations specifically applicable to the Antarctic region. Additionally, 56.7% of these states were in the process of developing national UAS guidelines, regulations, or manuals.

As illustrated in Table 3, there are commonalities across the UAS regulations of several ATCPs in Antarctica. These regulations are managed by the relevant Antarctic authorities in each state, which have established approval and licensing procedures. While UAS regulations in Antarctica are largely based on the domestic UAS frameworks of each ATCP, they are also adapted to account for the unique environmental conditions of the continent.

However, there are distinct differences in the form of regulation, scope of application, and specific content. Firstly, the types of normative documents issued by ATCPs to govern UAS in Antarctica vary across states. These include both non-binding instruments, such as operational manuals, guidelines, and usage policies, as well as legally binding measures that involve formal approval and licensing procedures.

Secondly, in terms of the scope of application, some states, such as the United States (US Antarctic Program, 2016), Germany

(ATCM40 IP38, 2017), New Zealand (ATCM40 ATT36, 2017), Australia (Australian Antarctic Program, 2016), and the United Kingdom, have extended their regulations to cover all activities conducted in Antarctica, including non-scientific activities. In contrast, countries like Spain (ATCM39 IP28, 2016) and Poland (ATCM40 IP46, 2017) have limited their regulations to specific categories of UAS activities.

Finally, regarding regulatory content, the regulations issued by the United States and New Zealand are the most systematic and comprehensive. They cover various aspects, including UAS operations and environmental rules, pilot qualification and licensing, drone airworthiness certification, application-approval mechanisms for drone activities, operation plans, risk assessment and management, liability, and specific operational requirements and restrictions for the Antarctic environment. In contrast, Germany, Australia, the United Kingdom, Spain, and Poland have only partially addressed the issues covered by the United States and New Zealand in their regulations.

In summary, the regulation of UAS in Antarctica has increasingly garnered attention from the ATCPs. In addition to their own national Antarctic UAS regulations, ATCPs submit proposals in the form of working papers, sharing their domestic practices and regulatory experiences on the ATCM and CEP platforms. This process has initiated a driven approach to regulating UAS activities within the Antarctic governance framework, with national precedents paving the way for international governance efforts.

TABLE 3 Regulations of UAS in Antarctica from some ATCPs.

State	Authority	Formality
United States	Office of Polar Programs, U.S. National Science Foundation	Air Operations Manual
New Zealand	Antarctica New Zealand	Antarctica New Zealand Unmanned Aerial System Operations Manual
Australia	Australian Antarctic Program	Unwritten operational requirements and environmental policies
Germany	German Environment Agency	Use of UAVs in Antarctica
Spain	Spanish Polar Commission	Regulations
Poland	Polish Antarctic Program	Criterion
United Kingdom	British Antarctic Survey	unwritten rules

Source: Antarctic Treaty Database. https://www.ats.aq/devAS/ToolsAndResources/AntarcticTreatyDatabase?lang=e; (ATCM, 2024).
The table is made by the author.

4 The role of non-state actors in the regulations of UAS in Antarctica

The ATS plays a crucial role in maintaining peace and stability in the region while fostering international scientific cooperation. Since the Antarctic Treaty entered into force in 1961, 57 states, including 29 ATCPs, have acceded (Secretariat of the Antarctic Treaty, 2024b). As illustrated in Figure 6, both ATCPs and non-state actors collaborate in shaping the Antarctic UAS regulatory agenda. With the expanding use of UAS in Antarctica, ATCPs have actively participated in agenda-setting, drawing from their national experience in UAS operations and regulation.

Currently, the international framework for UAS operations in Antarctica includes the *Environmental Guidelines*, the *Handbook*, and *IAATO Policies*, all of which contribute to a soft law regime governing UAS activities. The development of formal international legal regulations for UAS in Antarctica has been largely driven by the proactive involvement of ATCPs. Furthermore, non-state actors have become increasingly influential in shaping international legislation, thereby complementing the traditional role of states in the regulatory process.

"Non-state actors" typically refer to entities other than sovereign states that play an independent role in international

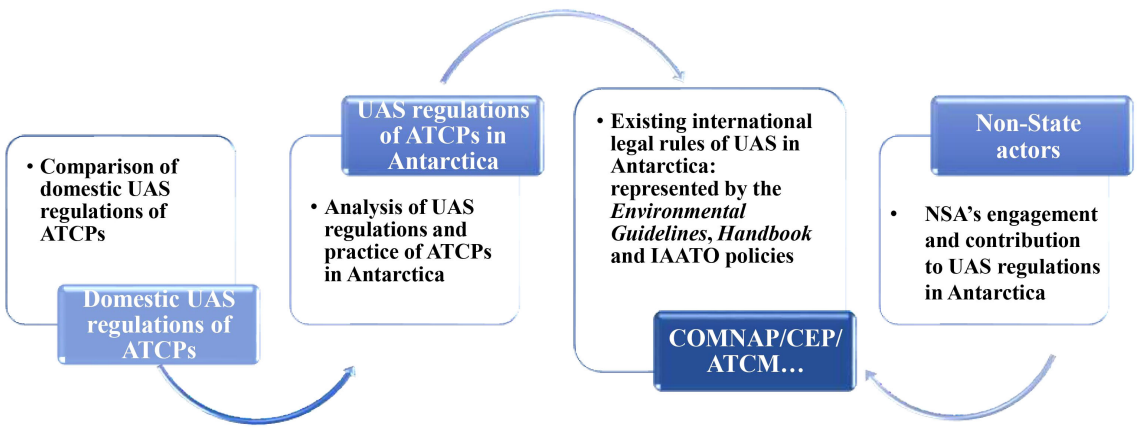


FIGURE 6
Joint engagement in the Antarctic UAS regulations agenda of ATCPs and Non-state actors. The figure is made by the author.

affairs and contribute to global governance through unified actions. These actors include civil society organizations, NGOs, and transnational entities (Naghmeh et al., 2016). In the context of UAS regulation in Antarctica, non-state actors have made substantial contributions. Their involvement has been particularly influential in agenda-setting and rule-setting processes, helping shape the evolving framework for UAS operations in the region.

4.1 Modalities of non-state actors' participation in the regulation of UAS in Antarctica

4.1.1 Through ATCM and CEP

The ATCM serves as the primary platform for deliberation within the ATS. According to the ATCM Rules of Procedure, Antarctic Treaty Contracting Parties, Observers, and invited experts from international organizations with scientific or technical interests in Antarctica are entitled to participate in Antarctic governance by submitting documents for consideration (ATCM Rules, 2022). Key document types include Working Papers (WPs), which propose substantive discussions and actions, and Information Papers (IPs), which offer supporting materials for these proposals. The content of WPs and IPs is often incorporated into legally binding measures or non-binding but influential soft laws. The conference papers submitted by ATCPs offer insight into their priorities and engagement in Antarctic matters (Chen, 2023).

As shown in Figure 7, from 2011 to 2023, the four non-state actors most actively involved in Antarctic governance were the Scientific Committee on Antarctic Research (SCAR), the Antarctic and Southern Ocean Coalition, IAATO, and COMNAP. Notably, the top three of these non-state actors submitted more proposals than France, one of the Antarctic territorial claimants, and Russia, a state that retains territorial claim rights. This underscores the significant role that non-state actors play in Antarctic governance. These organizations have effectively applied their expertise in science, technology, and environmental protection to influence proposals submitted to the ATCM/CEP, addressing specific governance issues, advancing the governance agenda, and providing recommendations for future resolutions.

The number and nature of documents submitted by non-state actors on the ATCM/CEP platform reflect both their willingness and capacity to contribute to Antarctic governance. A study of UAS-related issues at the ATCM (Table 4) reveals that ATCPs have leveraged their scientific and technological strengths to enhance their deliberative capacity within the ATCM (Chen and Gao, 2022). While ATCPs have submitted 21 papers on UAS issues, non-state actors have contributed 8 papers. This demonstrates that although states continue to dominate agenda-setting, non-state actors, particularly those oriented toward scientific and technological concerns, have made significant contributions to the process of regulating UAS in Antarctica.

The Committee for Environmental Protection (CEP) plays a significant role in the regulatory process for UAS in Antarctica, and it is highly inclusive of non-state actors. The Madrid Protocol allows relevant scientific, environmental, and technical organizations that contribute to the CEP's work to participate as observers in its meetings. According to the CEP Rules of Procedure, organizations such as SCAR, CCAMLR, and COMNAP can submit Working Papers (WPs), while other observers are restricted to submitting

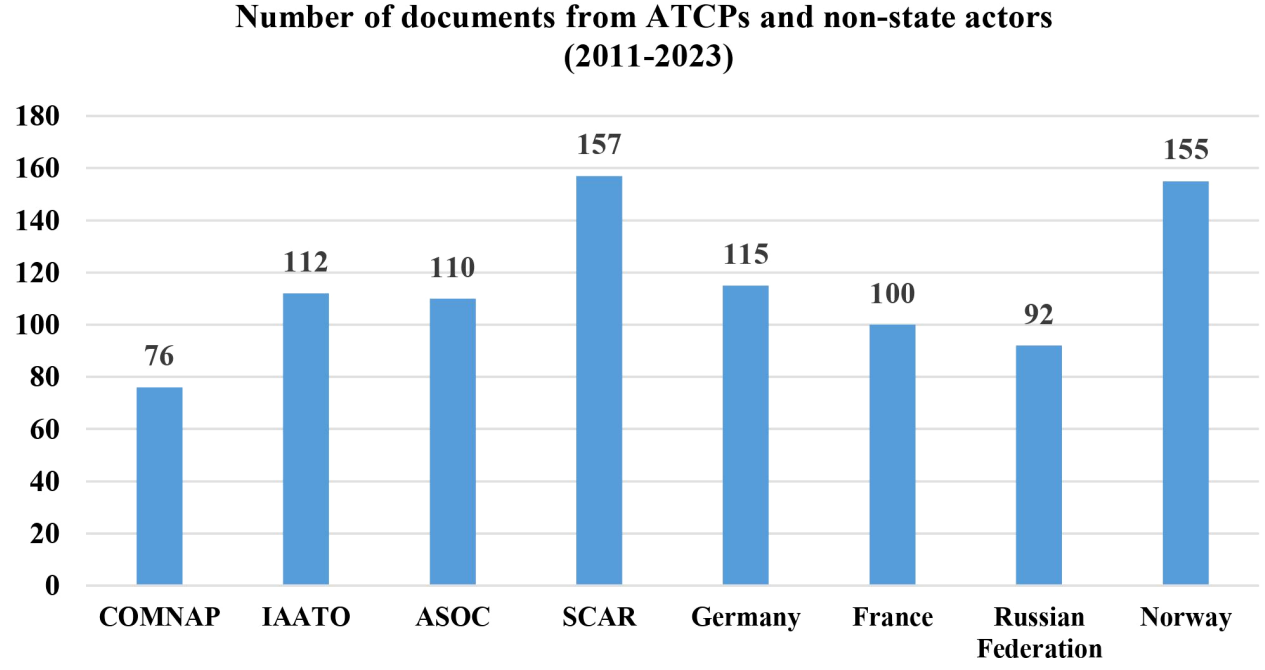


FIGURE 7
Number of documents from ATCPs and non-state actors (2011-2023). Source: Antarctic Treaty Database. https://www.ats.aq/devAS/ToolsAndResources/AntarcticTreatyDatabase?lang=e. The table is made by the author.

TABLE 4 Number of ATCM documents relating to the topic of UAS in Antarctica (2004-2023).

ATCPs/ Institutions	WP	IP
Germany	4	4
United States	1	3
Poland	1	4
New Zealand	0	2
South Africa	0	1
Spain	0	1
COMNAP	2	2
SCAR	2	0
IAATO	0	2

Source: Antarctic Treaty Database. https://www.ats.aq/devAS/ToolsAndResources/AntarcticTreatyDatabase?lang=e
The table is made by the author.

Information Papers (IPs). However, observers do not possess decision-making authority. Additionally, experts and consultants are welcome to participate and provide expert advice tailored to the Committee's needs (CEP Rules, 2022). These WPs and IPs from non-state actors can influence UAS regulation in Antarctica, thereby contributing to the regulatory framework.

In addition to the ATCM, the annual CEP meetings are a central forum for discussing UAS regulations. The CEP focuses on the environmental impact of UAS activities in Antarctica, and UAS was incorporated into its five-year plan (CEPXVII Report, 2014). One notable contribution of the CEP is its role in advancing the development of Environmental Guidelines for UAS operations. In 2018, at its 21st session, the CEP adopted the draft Environmental Guidelines developed by the German-led Intersessional Working Group. These guidelines were then submitted to the 41st session of the ATCM for further consideration and were subsequently adopted as a resolution (CEP XXI Report, 2018). This highlights the CEP's important role in shaping the environmental standards that govern UAS operations in the Antarctic region.

4.1.2 Through CCAMLR

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is a key law-making and decision-making body within the ATS, established under the Convention on the Conservation of Antarctic Marine Living Resources (CAMLR Convention, 1980). The CCAMLR includes a permanent Scientific Committee that provides scientific advice and programs to support its decision-making processes.

The CCAMLR's website features numerous studies on the use of UAS, reflecting their increasing importance in Antarctic research. For example, UAS have been identified as valuable tools for studying the distribution and abundance of predator populations, providing detailed data that would be difficult to obtain through traditional methods (WG-EMM-15, 2015). Additionally, UAS have become essential for wildlife monitoring, offering a less intrusive and more efficient way to track and observe wildlife in Antarctica without causing disruption to sensitive ecosystems (WG-EMM-2019, 2019). These developments demonstrate the growing role of UAS in advancing scientific research and environmental monitoring in Antarctica, which aligns with the broader goals of the CAMLR Convention and the protection of the region's marine and terrestrial ecosystems.

4.1.3 Through ICAO

As international legal frameworks for UAS continue to evolve, it is essential to monitor and integrate regulations established by global bodies such as the International Civil Aviation Organization (ICAO). The ICAO has made significant strides in the development of international UAS regulations, with a particular focus on ensuring the safe and coordinated use of drones worldwide.

In 2015, the ICAO introduced the Remotely Piloted Aircraft Systems Manual, which provides a comprehensive framework based on the latest drone technology. This manual addresses critical aspects such as drone airworthiness, technical requirements, operational limitations, and human resource qualifications (ICAO, 2015). The goal was to establish a standardized approach for the safe integration of UAS into global airspace.

Further accelerating the regulatory development process, the ICAO issued Model UAS Regulations in 2020. These guidelines, derived from the existing UAS regulations in countries like New Zealand, Australia, Canada, and the United States, also incorporate elements of international best practices. Although non-mandatory, these model regulations offer member states a standardized reference to guide the creation of their own national UAS regulations, providing flexibility while promoting international consistency (ICAO Model UAS Regulations, 2020). As these international standards evolve, they will likely influence the regulation of UAS in Antarctica, especially as the use of drones expands for scientific research, environmental monitoring, and logistical operations.

In recent years, the ICAO has made significant strides in UAS regulation. In 2021, the ICAO Council revised its Standards and Recommended Practices, improving international safety and interoperability of RPAS (ICAO News, 2021). In 2022, the ICAO launched the "Drone Enable" initiative, inviting innovative organizations from both the public and private sectors to contribute to advancements in drone airspace management and global UAS standards (ICAO News, 2022). As UAS regulations evolve, the ICAO is expected to amend the 19 annexes of the Chicago Convention to integrate UAS into the global aviation system in a safe and efficient manner.

UAS regulations in Antarctica are part of the broader framework of international UAS rules, and there are strong connections between them. Antarctic UAS regulations will not be entirely separate from global regulations and can therefore draw on the experiences of UAS regulation in other regions. In 2019, the ICAO presented a paper at the 42nd ATCM, suggesting that Antarctic UAS regulation could benefit from the Arctic's regulatory experiences (ATCM42 IP163, 2019). Given the faster pace of global UAS regulation compared to Antarctic developments,

the expertise and experience of the ICAO in regulating UAS can serve as a valuable reference for shaping UAS regulations in Antarctica.

4.2 Non-state actors' engagement of UAS regulation in Antarctica

Non-state actors play a key role in the agenda-setting and rule-making phases of UAS regulation in Antarctica. Their involvement is exemplified by the development of the *Environmental Guidelines*. As shown in Table 5, during the agenda-setting phase, COMNAP and SCAR contributed significantly by submitting proposals to the ATCM and CEP platforms. SCAR provided current scientific insights into the impacts of UAS on Antarctic wildlife, while COMNAP shared practical experience regarding the use of UAS in scientific research, logistics, and other Antarctic activities. This collective expertise enriched the understanding of UAS's environmental effects, ultimately facilitating consensus among ATCPs on the *Environmental Guidelines*.

At the specific rule-making stage, non-state actors, especially SCAR and COMNAP, played a significant role in shaping the content of the *Environmental Guidelines*. The working group referred to previous Working Papers (WPs) submitted by these organizations and also distributed a questionnaire to all ATCPs, observers, and experts on issues related to the rules' content. The feedback, including contributions from SCAR and COMNAP, informed the draft text. For instance, the issue of maintaining separation distances between UAS and Antarctic wildlife, addressed in the guidelines, can be traced back to a WP submitted by SCAR (ATCM41 WP29, 2018). This process illustrates how non-state actors have influenced the regulatory framework for UAS in Antarctica.

The documents adopted by the ATCM, COMNAP, and IAATO in addressing UAS governance in Antarctica exhibit varying effectiveness, as shown in Table 6. While each document plays a distinct role in different contexts, they also have shortcomings. One key issue is the lack of clear definitions for different categories of UAS activities. For instance, the *Environmental Guidelines* apply to all UAS activities, potentially allowing recreational ones, while the *IAATO Policies* explicitly prohibit recreational UAS operations. This creates a conflict, as the *Environmental Guidelines* and *IAATO Policies* are not aligned on the matter of recreational UAS. The inconsistencies in scope and application across these documents may lead to practical challenges and highlight a need for clearer, more cohesive regulations.

The three documents—*Environmental Guidelines, IAATO Policies*, and the *Handbook*—overlap in regulatory content, but each focus on different aspects. The *Environmental Guidelines* provide detailed environmental impact assessment procedures based on the Madrid Protocol and emphasize the protection of wildlife, ASPAs, and sensitive areas during UAS operations. The

TABLE 5 Process leading to the *Environmental Guidelines*.

Time of session	Subject of the proposal	Main elements of the motion	Outcome of ATCM discussions/considerations
37	Germany, Poland	(1) Recommended that establish an intersessional working group to advance the discussions and conduct further work; (2) Discuss the possibility of developing a guide for the operation of UAS in Antarctica; (3) COMNAP and SCAR review the safety risks and environmental impacts of UAS activities in Antarctica;	(1) Determine the potential environmental impacts of UAS in Antarctica; (2) Adopt the US proposal that request COMNAP and SCAR to report the utility and risks of UAS activities in Antarctica at the next meeting.
	The United States		
38	COMNAP	Recommended states and other operators to share information on UAS practices in Antarctica	(1) Consider to develop operational guidance on environment aspects of UAS in Antarctica; (2) Consider to establish an intersessional working group
	SCAR	Reported on the impacts of anthropogenic disturbance on Antarctic wildlife	
39	Germany	Recommended minimum distances between UAS and Antarctic wildlife	(1) Agreed to develop operational guidance on environment aspects of UAS in Antarctica; (2) Agreed to establish an intersessional working group
	COMNAP	Reported on the UAS Operator's Guide: The *Handbook*	
40	SCAR	Reported on the latest scientific knowledge on the response of Antarctic wildlife to UAS	Agreed to establish an intersessional working group led by Germany to develop operational guidance on environment aspects of UAS in Antarctica
41	Germany	Reported on the draft *Environmental Guidelines* developed by the German-led intersessional working group	Adopted *Environmental Guidelines* in the form of a resolution
44	Germany	(1) Improve the content and structure of the *Environmental Guidelines*	Agreed to revise the *Environmental Guidelines*

Source: Antarctic Treaty Database. https://www.ats.aq/devAS/ToolsAndResources/AntarcticTreatyDatabase?lang=e
The table is made by the author.

TABLE 6 Comparison of *Environmental Guidelines, Handbook, IAATO Policies*.

Name of the document	Scope of application	Content
Environmental Guidelines	All types of UAS activities	Environmental guidance
Handbook	Require that any deployment of drones in the Antarctic Treaty area is subject to notification. In fact, it applies mainly to drone activities of a scientific, logistical and operational nature that fall within the scope of COMNAP's responsibilities.	Operational guidelines, and environmental guidance
IAATO Policies	Apply to UAS activities in Antarctic tourism. Commercial and scientific UAS activities are conditionally permitted; recreational UAS activities are explicitly prohibited. In practice, there are also operational UAS activities in Antarctic.	Operational guidelines, with a small amount of environmental guidance

Source: Antarctic Treaty Database. https://www.ats.aq/devAS/ToolsAndResources/AntarcticTreatyDatabase?lang=e
The table is made by the author.

IAATO Policies address environmental concerns more briefly, particularly regarding UAS use near wildlife and in special areas like ASPAs. The *Handbook* offers both operational and environmental guidance, including procedures for communication, record-keeping, and pre-flight environmental assessments. However, this overlap raises the question of which document should serve as the primary reference for practical issues. Given the increasing frequency of UAS operations in Antarctica, it is crucial to resolve inconsistencies in these regulations to ensure effective and coherent governance.

Efforts by non-state actors to regulate drones in Antarctica have been ongoing. Since the release of the *Handbook* in 2016, COMNAP has regularly reviewed and updated it to reflect the latest developments in the Antarctic region. The most recent edition, the 8th edition, was released in December 2023. This update includes a document catalog that incorporates relevant content from the 2023 ATCM Resolution and CEP Recommendations. It also features a separate annex listing information shared by states on national Antarctic plans and operational programs, including details on the operation of large UAS over 25 kg and examples related to Beyond Visual Line of Sight (BVLOS) flights (COMNAP Handbook, 2022).

The international regulations for UAS in Antarctica are not yet comprehensive, and the decentralized rules lack clear and straightforward guidance for current and potential UAS users. Improvements in operational and environmental regulations continue to rely heavily on the involvement of non-state actors, primarily COMNAP, SCAR, and IAATO. While non-state actors play a crucial role as experts, their influence remains non-determinative in shaping the legal framework. Their interdisciplinary expertise, scientific research capabilities, and long-term field experience provide essential input for the formulation of policies and the achievement of legally accepted outcomes (Secretariat of the Antarctic Treaty, 2024b). Submissions from non-state actors are often incorporated into binding measures or non-legally binding resolutions. This study argues for strengthening the interaction between ATCPs and non-state actors to enhance current UAS regulations and establish a more comprehensive, detailed, and operational regulatory system for UAS in Antarctica. This collaborative approach would help create a more cohesive and effective framework for UAS operations in this unique and sensitive environment.

5 Strengthening collaboration among multiple actors for a comprehensive UAS regulatory framework in Antarctica

Currently, the domestic operating standards and technical specifications for UAS among ATCPs are not fully harmonized. The number of ATCPs using UAS in Antarctica remains limited, resulting in insufficient practical experience in drone operations. Regulations by non-state actors are fragmented, lacking universality and certainty. The process of international lawmaking for UAS in Antarctica is still in the agenda-setting phase, with most relevant rules primarily taking the form of soft law. As the demand for UAS increases, the lack of uniform regulation will create uncertainty for their application in the region. ATCPs and non-state actors must promote the integration of technology and legal regulation for UAS in Antarctica. Based on existing UAS practices, the Environmental Guidelines should be revised. To establish a preliminary legal regulatory system, a comprehensive legally binding Measure, or at least a resolution adopted by the ATCM, could serve as a strong starting point for this integrated regulatory framework. As the principal international forum for Antarctic affairs, the ATCM is uniquely positioned to harmonize the interests of all parties, facilitate the development of minimum UAS standards, and establish a consistent regulatory framework for all stakeholders.

5.1 Promote the integration of technology and legal regulation of UAS

UAS regulations in Antarctica are evolving in tandem with advancements in UAS technology. As UAS technology continues to develop, operational standards and procedures are also subject to change. Legal regulation of UAS in Antarctica should be grounded in practical experience at the current level of scientific and technological development. It should also incorporate information on UAS operations and certifications from the ATCPs' National Antarctic Programs, as well as insights from existing Antarctic documents. This approach will ensure that the regulations are both relevant and responsive to the fast-paced changes in UAS

technology while maintaining alignment with the unique environmental and operational context of Antarctica.

Firstly, ATCPs and non-state actors should prioritize innovation and collaboration in UAS technology development. For instance, advancing sense-and-avoid technology to ensure safe drone operations and improving battery technology for cold-weather adaptability are key areas for progress (Sharma, 2019). These technological advances offer a crucial scientific foundation for legal regulations. By integrating the latest UAS technology into Antarctic operations, practical experience can be accumulated to inform the regulatory framework. Non-state actors, through their expertise, research, and perspectives, can significantly contribute to the regulatory process. Their scientific input can enhance the decision-making process, helping shape UAS regulations in Antarctica more effectively (Chen and Liu, 2023). In turn, ATCPs should foster greater exchange of cutting-edge UAS technology with non-state actors, taking into account Antarctica's unique environmental conditions.

Secondly, multiple actors should collaborate to establish an Antarctic UAS database to consolidate operational experience. We recommend adding an Antarctic UAS module to the official website of the Antarctic Treaty Secretariat. This database could categorize UAS in Antarctica into five types: scientific research, environmental protection, emergency rescue, commercial use, and recreational use. Each UAS operation would be registered, with flight details submitted before and after operations, ensuring compliance with environmental protection standards and flight restrictions in Antarctica (Jesús and Mulero-Pázmány, 2019). Such a database would promote transparency in UAS technology and operations, providing valuable data to inform the development of more effective legal regulations.

Finally, a robust science-policy communication mechanism should be established in Antarctica. Multiple actors must stay informed about the latest developments in UAS regulations, both in Antarctica and globally. This includes monitoring the ATCM and CEP's priorities regarding UAS issues, as well as changes in international UAS regulations. Through deliberative platforms such as the ATCM, CEP, and CCAMLR, actors can actively submit proposals and share scientific, technical, and regulatory expertise. Such collaborative exchanges would help drive the process of UAS legal regulation in Antarctica, ensuring a more coordinated and informed approach.

In general, the interaction between technology and regulations promotes polar research. The coordinated use of UAS enhances ongoing scientific activities, minimizing interference and ensuring the uninterrupted progress of crucial studies. This leads to more efficient and productive polar research. Additionally, the establishment of an Antarctic UAS database and a science-policy communication mechanism would strengthen international cooperation. Such collaboration in regulating Antarctic UAS would facilitate a unified approach, supporting the peaceful and sustainable use of UAS in the region.

5.2 Revising the *Environmental Guidelines* and establishing a preliminary legal regulatory system for UAS in Antarctica

At the 44th ATCM, Germany proposed improvements to the content and structure of the *Environmental Guidelines*, recommending the establishment of an informal international coordination group to revise them promptly. Germany also encouraged the Parties to gather data on the impacts of UAS on Antarctic wildlife. After deliberation, the ATCM agreed that the *Environmental Guidelines* should be revised but did not reach a consensus on the immediate revision. The Parties were urged to continue discussions during the intersessional period (ATCM44 Final Report, 2022).

The revision of UAS environmental rules should be grounded in the latest scientific and technological advancements regarding their environmental impacts on Antarctica. To facilitate this process, all Parties can exchange and share relevant information through proposals at the ATCM, based on the data collected on UAS' environmental effects in the region.

Additionally, as a deliberative platform, the ATCM should enhance efforts to promote awareness and deepen the scientific understanding of UAS' environmental impact in Antarctica among multiple actors. This could involve organizing workshops, distributing research findings, and sharing expertise through various channels. Based on this improved scientific knowledge, the ATCM should drive the updating of environmental rules for UAS in the region.

The global legal regulation of UAS is progressing toward greater uniformity but remains in an evolving state. Thus, the international legal framework for UAS in Antarctica will necessarily develop gradually, not through immediate comprehensive solutions. Both global UAS regulations and existing Antarctic regulatory experiences can provide useful references for this process. For instance, establishing an intersessional working group on Antarctic UAS, similar to the one led by Germany, could bring together UAS technology experts, environmental scientists, and legal professionals to manage Antarctic UAS operations, conduct environmental impact assessments, and refine legal frameworks. Strengthening cooperation and interaction among states and organizations in Antarctica is essential for advancing these regulatory efforts.

By integrating existing UAS regulations, a more comprehensive, detailed, and operational regulatory framework can be developed, gradually establishing a legal system for UAS in Antarctica. Strengthening Antarctic UAS rules is crucial for environmental protection, flight safety, and regulatory compliance. Uniform standards would help minimize disturbances and damage to the delicate Antarctic ecosystem and wildlife caused by UAS operations, ensuring the preservation of the environment for scientific research and ecological conservation. Additionally, unified rules can reduce the risks associated with UAS flights in the harsh Antarctic climate, improving overall safety. In sum, a well-developed legal and regulatory system would provide a clear management framework for the sustainable use of UAS in Antarctica, guiding the operations of multiple actors in the region.

6 Conclusion

As States increasingly focus on advancing polar research through new technologies and equipment, there is growing

attention to the regulation of UAS activities in Antarctica. With the continued innovation and maturation of UAS technology, more states and non-state actors are likely to deploy UAS for scientific research and commercial activities. This increasing use of UAS could spur scientific and technological competition in Antarctica, potentially leading to more complex legal challenges and the need for stronger regulatory frameworks to manage these activities effectively.

Many states have successfully translated their scientific and technological innovation capabilities into agenda-setting and rule-making powers, significantly shaping the development of UAS regulations. Non-state actors, such as scientific organizations and experts, have also played a crucial role by contributing field experience and providing scientific advice. To improve air safety in Antarctica, the ATCM and COMNAP have organized collaborative efforts, bringing together various stakeholders to reach an agreement on the Antarctic Flight Information Manual (Air Safety in Antarctica, 2022). Both state and non-state actors are actively involved in the legal regulation of UAS in Antarctica, underscoring the importance of collective efforts in addressing the challenges of regulating emerging technologies in this unique and environmentally sensitive region.

Currently, the legal regulation of UAS in Antarctica remains fragmented, with no unified framework in place. Nevertheless, all actors are obliged to minimize the environmental impacts of their activities, including UAS operations, and they already bear the responsibility to regulate such activities under the ATS. Regulating and limiting UAS use is essential to the exercise of personal jurisdiction by Parties in fulfilling their ATS obligations. For instance, Article 13 of the Madrid Protocol mandates each Party to take appropriate measures within its jurisdiction to ensure compliance with the Protocol, including adopting relevant laws and regulations. Similarly, Article 21 of the CAMLR Convention obligates Contracting Parties to implement measures ensuring compliance with conservation provisions and measures adopted by the Commission.

Therefore, UAS regulations in Antarctica must be further developed and refined to safeguard areas of special environmental, scientific, historic, aesthetic, and wilderness significance. To ensure a more standardized and effective approach, all relevant actors, including states and non-state actors, must collaborate to create a comprehensive and cohesive legal framework for UAS regulation in Antarctica as a minimum standard. The concept of a minimum standard has been implemented in various international governance regimes. For instance, in the development of Environmental Impact Assessments mechanism related to Marine Biological Diversity in Areas beyond National Jurisdiction (BBNJ), the draft of BBNJ Agreement has attempted to establish a "global minimum standard" (Revised draft text of BBNJ Agreement, 2019). Similarly, the United Nations Convention on the Law of the Sea (UNCLOS) requires coastal State, under Article 61(3), to consider "any generally recommended international minimum standards, whether subregional, regional or global" when formulating conservation and management measures within their Exclusive Economic Zones. A notable precedent is the 1946 International Convention for the Regulation of Whaling (ICRW), which sets minimum standards for whale protection while allowing states to adopt stricter regulations within their jurisdiction which give additional protection to whales, provided they do not conflict with ICRW provisions (Proelss, 2017). Additionally, the Port State Measures Agreement (PSMA), the first legally binding international agreement to combat illegal, unreported, and unregulated (IUU) fishing, also provides minimum standards for port state measures while permitting states to implement more stringent measures (PMSA Agreement, 2009). The proposed unified legal framework for UAS regulation in Antarctica aligns with these examples, serving as an international minimum standard to guide governance while allowing for further tailored and stricter measures.

This study does not suggest that unified UAS regulations should be the sole framework for compliance in Antarctica. Instead, it acknowledges and respects the diverse regulatory efforts by multiple actors. These actors remain free to develop more specific and stringent rules. For instance, ATCPs can regulate UAS operations conducted by their nationals in Antarctica under the principle of personal jurisdiction and propose higher standards tailored to their technical capabilities and governance frameworks. Similarly, non-state actors, such as IAATO, could implement stricter measures to manage private UAS usage. Such collaborative approaches will contribute to enhancing the safety, efficiency, and environmental stewardship of UAS operations in this unique and sensitive region.

Author contributions

YC: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. SW: Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This research was funded by the National Social Science Fund of China, Grant No. 20CFX082.

Acknowledgments

The authors thank Gao Xiao for her preliminary groundwork.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Air Safety in Antarctica (2022). Available online at: https://www.ats.aq/devAS/ToolsAndResources/SearchAtd?from=1/1/1958&to=1/1/2158&cat=0&top=0&type=0&stat=0&txt=aviation&curr=0 (Accessed November 16, 2024).

Amazon (2022). *Amazon Prime Air prepares for drone deliveries*. Available online at: https://www.aboutamazon.com/news/transportation/amazon-prime-air-prepares-for-drone-deliveries (Accessed November 16, 2024).

ANAC Resolution 419 (2017). *General requirements for unmanned aircraft of civilian use*. Available online at: https://www.anac.gov.br/en/drones/files/rbac-e-no-94-amdt-00-english.pdf (Accessed November 16, 2024).

Annexes of the Chicago Convention (1944). *Annex 2, Rules of the Air*. Available online at: https://www.icao.int/safety/airnavigation/nationalitymarks/annexes_booklet_en.pdf (Accessed November 16, 2024).

Antarctic Treaty inspections (2005). *Report of Antarctic Treaty Inspections undertaken jointly by the United Kingdom, Australia and Perú in accordance with Article VII of the Antarctic Treaty and Article 14 of the Environmental Protocol*. Available online at: https://documents.ats.aq/ATCM28/att/ATCM28_att270_e.pdf (Accessed November 3, 2024).

ATCM (2024). *Meeting Document Archive in the Secretariat of the Antarctic Treaty*. Available online at: https://www.ats.aq/devAS/Meetings/DocDatabase?lang=e (Accessed August 1, 2024).

ATCM37 WP51 (2014). *Considerations for the use of unmanned aircraft systems (UAS) for research, monitoring, and observation in Antarctica*. Available online at: https://documents.ats.aq/ATCM37/wp/ATCM37_wp051_e.doc (Accessed November 16, 2024).

ATCM38 IP22 (2015). *UAV use in Antarctica-Risks and benefits*. Available online at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fdocuments.ats.aq%2FATCM38%2Fwp%2FATCM38_wp022_e.doc&wdOrigin=BROWSELINK (Accessed November 16, 2024).

ATCM38 IP88 (2015). *IAATO Policies on the Use of Unmanned Aerial Vehicles (UAVs) in Antarctica*. Available online at: https://iaato.org/wp-content/uploads/2024/09/ATCM38_ip088_e.pdf (Accessed October 31, 2024).

ATCM39 IP28 (2016). *Operación de UAV/RPAS en la Antártida: Normativa aplicada por España*. Available online at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fdocuments.ats.aq%2FATCM39%2Fip%2FATCM39_ip028_s.doc&wdOrigin=BROWSELINK (Accessed November 16, 2024).

ATCM40 ATT36 (2017). *Antarctica New Zealand Unmanned Aerial System (UAS) Operations Manual*. Available online at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fdocuments.ats.aq%2FATCM40%2Fatt%2FATCM40_att036_e.doc&wdOrigin=BROWSELINK (Accessed November 16, 2024).

ATCM40 IP38 (2017). *Use of UAVs in Antarctica A competent authority's perspective and lessons learnt*. Available online at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fdocuments.ats.aq%2FATCM40%2Fip%2FATCM40_ip038_e.doc&wdOrigin=BROWSELINK (Accessed November 16, 2024).

ATCM40 IP46 (2017). *UAV impact - problem of a safe distance from wildlife concentrations*. Available online at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fdocuments.ats.aq%2FATCM40%2Fip%2FATCM40_ip046_e.doc&wdOrigin=BROWSELINK (Accessed November 16, 2024).

ATCM40 IP75 (2017). *A Report on the Development and Use of UAS by the U.S. National Marine Fisheries Service for Surveying Marine Mammals*. Available online at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fdocuments.ats.aq%2FATCM40%2Fip%2FATCM40_ip075_e.doc&wdOrigin=BROWSELINK (Accessed November 16, 2024).

ATCM40 IP86 (2017). *Use of UAS for Improved Monitoring and Survey of Antarctic Specially Protected Areas*. Available online at: https://documents.ats.aq/ATCM40/ip/ATCM40_ip086_e.doc (Accessed November 16, 2024).

ATCM40 WP20 (2017). *State of Knowledge of Wildlife Responses to RPAS, A Working Paper submitted by SCAR*. Available online at: https://documents.ats.aq/ATCM40/wp/ATCM40_wp020_e.doc (Accessed November 16, 2024).

ATCM41 Final Report (2018). *Final Report of the Forty-first Antarctic Treaty Consultative Meeting*. Available online at: https://documents.ats.aq/ATCM41/fr/ATCM41_fr001_e.pdf (Accessed October 31, 2024).

ATCM41 WP29 (2018). *Report of the CEP Intersessional Contact Group to develop guidelines on the environmental aspects of the use of Unmanned Aerial Vehicles (UAVs)/ Remotely Piloted Aircraft Systems (RPAS) in Antarctica*. Available online at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fdocuments.ats.aq%2FATCM41%2Fwp%2FATCM41_wp029_e.doc&wdOrigin=BROWSELINK (Accessed November 16, 2024).

ATCM42 IP163 (2019). *Guidance for the Operation of Unmanned Aircraft Systems (UAS)*. Available online at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fdocuments.ats.aq%2FATCM42%2Fip%2FATCM42_ip163_e.doc&wdOrigin=BROWSELINK (Accessed November 16, 2024).

ATCM44 Final Report (2022). *Final Report of the Forty-fourth Antarctic Treaty Consultative Meeting*. Available online at: https://documents.ats.aq/ATCM44/fr/ATCM44_fr001_e.pdf (Accessed November 16, 2024).

ATCM Rules (2022). *Rules of Procedure of the Antarctic Treaty Consultative Meeting and the Committee for Environmental Protection*. Available online at: https://documents.ats.aq/atcm44/ww/ATCM44_ww019_e.pdf (Accessed October 31, 2024).

Australian Antarctic Program (2016). *Drone use set to rise in Antarctica*. Available online at: http://www.Antarctica.gov.au/magazine/2016-2020/issue-30-june-2016/technology/drone-use-set-to-rise-in-Antarctica (Accessed November 16, 2024).

CAAC News (2018). *Why a permanent airport in Antarctica*? Available online at: http://www.caacnews.com.cn/1/5/201811/t20181128_1261689.html (Accessed November 16, 2024).

CAMLR Convention (1980). *The Convention on the Conservation of Antarctic Marine Living Resources*. Available online at: https://www.ccamlr.org/en/organisation/camlr-convention-text (Accessed November 8, 2024).

CASR Part 101 (2023). *Micro Excluded Remotely Piloted Aircraft Operations*. Available online at: https://www.casa.gov.au/sites/default/files/2021-08/part-101-micro-excluded-rpa-operations-plain-english-guide.pdf (Accessed November 16, 2024).

CEP Rules (2022). *Rule 3 of the CEP Rules of Procedure*. Available online at: https://documents.ats.aq/atcm44/ww/ATCM44_ww019_e.pdf (Accessed November 16, 2024).

CEPXVII Report (2014). *Report of the Committee for Environmental Protection (CEP XVII)*. Available online at: https://documents.ats.aq/ATCM37/fr/ATCM37_fr001_e.pdf (Accessed November 2, 2024).

CEP XXI Report (2018). *Report of the Committee for Environmental Protection (CEP XXI)*. Available online at: https://documents.ats.aq/ATCM41/fr/ATCM41_fr001_e.pdf (Accessed November 2, 2024).

Chen, Y. T. (2023). China's role of bioprospecting in Antarctica and future prospects. *Chin. J. Environ. Law.* 7, 75–99. doi: 10.1163/24686042-12340098

Chen, Y. T., and Gao, X. (2022). Application of unmanned aircraft systems in Antarctica, legal regulation and China's response. *Polar Res.* 34, 329–339. doi: 10.13679/j.jdyj.20210042

Chen, Y. T., and Liu, Y. (2023). The contributions and constraints of NGOs in the arctic council: from a club theory perspective. *China Oceans Law Review*. 19, 192–221.

Chicago Convention (1944). Available online at: https://www.icao.int/publications/Documents/7300_orig.pdf (Accessed November 16, 2024).

COMNAP Handbook (2022). *COMNAP Antarctic Remotely Piloted Aircraft Systems (RPAS) Operator's Handbook*. Available online at: https://static1.squarespace.com/static/61073506e9b0073c7eaaf464/t/634763d712a5c627d0bc3e2e/1665623010304/COMNAP+RPAS+Handbook+15+October+2022.pdf (Accessed November 16, 2024).

Cooper, J. C. (1965). Backgrounds of international public air law. *Yearbook Air Space Law.*, 3–38.

DDC (2019). *Drone Delivery Canada Announces Commercial Agreement with Air Canada*. Available online at: https://dronedeliveryCanada.com/resources/drone-delivery-Canada-announces-commercial-agreement-with-air-Canada/ (Accessed November 16, 2024).

Del-Real, C., and Díaz-Fernández, A. M. (2021). Lifeguards in the sky: examining the public acceptance of beach-rescue drones. *Technol. Soc.* 64, 101502. doi: 10.1016/j.techsoc.2020.101502

ENAC (2018). *he ENAC issued regulations of Remotely Piloted Aerial Vehicles*. Available online at: https://www.enac.gov.it/sites/default/files/allegati/2018-Lug/Regulation_RPAS_Issue_2_Rev_4_eng.pdf (Accessed November 16, 2024).

Federal Aviation Administration (2021). *New rules allowing small drones to fly over people in U.S. take effect*. Available online at: https://www.faa.gov/newsroom/new-drone-rules-take-effect-today (Accessed November 16, 2024).

Fiallos, F. (2016). "The Applicability of the Public International Air Law Regime to the Operation of UAS," in *The Law of Unmanned Aircraft Systems: An Introduction to the Current and Future Regulation under National, Regional and International Law*, vol. 25 . Ed. B. I. Scott (Kluwer Law International, The Netherlands).

Flight rules in Japan (2024). Available online at: https://www.mlit.go.jp/en/koku/uas.htmlflightplan (Accessed November 16, 2024).

Global Drone Regulations Database (2024). Available online at: https://www.droneregulations.info/index.html (Accessed November 16, 2024).

Harris, C. M., Herata, H., and Hertel, F. (2019). Environmental guidelines for operation of Remotely Piloted Aircraft Systems (RPAS): Experience from Antarctica. *Biol. Conserv.* 236, 521–531. doi: 10.1016/j.biocon.2019.05.019

Hayat, S., Yanmaz, E., and Muzaffar, R. (2016). Survey on unmanned aerial vehicle networks for civil applications: A communications viewpoint. *IEEE Commun. Surveys Tuts. 4th Quart* 18, 2624–2661. doi: 10.1109/COMST.2016.2560343

Heverly, R. A. (2015). The state of drones: state authority to regulate drones. *Albany Govern. Law Review.* 8, 29–62.

ICAO (2011). *Unmanned Aircraft Systems*. Available online at: https://www.icao.int/Meetings/UAS/Documents/Circular%20328_en.pdf (Accessed November 16, 2024).

ICAO (2015). *Manual on Remotely Piloted Aircraft Systems.* Available online at: https://skybrary.aero/sites/default/files/bookshelf/4053.pdf (Accessed November 16, 2024).

ICAO (2024). *What is the difference between UAS and RPAS? Why can't we just call them all drones?* Available online at: https://www.icao.int/safety/UA/UASToolkit/Pages/FAQ.aspxQ1 (Accessed November 16, 2024).

ICAO Model UAS Regulations (2020). Available online at: https://www.icao.int/safety/UA/Documents/Model%20UAS%20Regulations%20-%20Parts%20101%20and%20102.pdf (Accessed November 16, 2024).

ICAO News (2021). *ICAO Council advances new standard for remotely piloted aircraft systems*. Available online at: https://www.icao.int/Newsroom/NewsDoc2021fix/COM.10.21.CH.pdf (Accessed November 16, 2024).

ICAO News (2022). *ICAO calls for innovation in drone airspace management*. Available online at: https://www.icao.int/Newsroom/NewsDoc2022fix/COM.26.22.CH.pdf (Accessed November 16, 2024).

Intelsat (2024). *Unmanned Aerial Systems Current Challenges and Future Opportunities for Governments Around the World*. Available online at: https://www.intelsat.com/wp-content/uploads/2022/01/intelsatgeneral-UAS-whitepaper.pdf (Accessed October 31, 2024).

JD (2024). *Smart delivery in JD*. Available online at: https://www.jdl.com/distribution/ (Accessed November 16, 2024).

Jesús, J. J., and Mulero-Pázmány, M. (2019). Drones for conservation in protected areas: present and future. *Drones* 3 (1), 10. doi: 10.3390/drones3010010

Jewell, Z. (2013). Effect of monitoring technique on quality of conservation science. *Conserv. biol.: J. Soc. Conserv. Biol.* 27, 501–508. doi: 10.1111/cobi.12066

Konert, A., and Kotlinski, M. (2018). Polish regulations on unmanned aerial vehicles. *Transport. Res. Procedia.* 35, 140–147. doi: 10.1016/j.trpro.2018.12.022

Konert, A., and Kotliński, M. (2020). U-Space – Civil Liability for damages caused by Unmanned Aircraft. *Transport. Res. Proc.* 51, 304–312. doi: 10.1016/j.trpro.2020.11.033

Li, D. R., and Li, M. (2014). Research progress and application prospect of UAV remote sensing system. *J. Wuhan Univ. (Information Sci. Edition).* 39, 505–513 + 540. doi: 10.13203/j.whugis20140045

Li, T., Zhang, B., Cheng, X., Hui, F., and Li, Y. (2021). Leveraging the UAV to support Chinese Antarctic expeditions: a new perspective. *Adv. Polar Sci.* 32, 67–74. doi: 10.13679/j.advps.2020.0018

Madrid Protocol (1991). *The Protocol on Environmental Protection to the Antarctic Treaty*. Available online at: https://www.ats.aq/e/protocol.html (Accessed November 8, 2024).

Mishra, B., Garg, D., Narang, P., and Mishra, V. (2020). Drone-surveillance for search and rescue in natural disaster. *Comput. Commun.* 156, 1–10. doi: 10.1016/j.comcom.2020.03.012

Mohd Daud, S. M. S., Mohd Yusof, M. Y. P., Heo, C. C., Khoo, L. S., Chainchel Singh, M. K., Mahmood, M. S., et al. (2022). Applications of drone in disaster management: A scoping review. *Sci. Justice* 62, 30–42. doi: 10.1016/j.scijus.2021.11.002

Naghmeh, N., Hjerpe, M., and Linnér, B. (2016). The roles of non-state actors in climate change governance: understanding agency through governance profiles. *Int. Environ. Agree.* 6, 109–126. doi: 10.1007/s10784-014-9243-8

Pazmiño, L. F. F. (2021). The international civil operations of unmanned aircraft systems under air law. *Aerospace Law Policy Series.* 19, 1–217.

PMSA Agreement (2009). *Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing*. Available online at: https://www.fao.org/fileadmin/user_upload/legal/docs/037t-e.pdf (Accessed November 26, 2024).

Proelss, A. (2017). *Exclusive Economic Zone, United Nations Convention on the Law of the Sea: A Commentary* (München: Nomos Verlagsgesellschaft), 480–524. doi: 10.5040/9781472561688.part-005

Ramsewak, D., Mohammed, N. S., and Sookram, N. (2022). Unoccupied aerial systems: a review of regulatory and legislative frameworks in the Caribbean. *Drones* 6, 170. doi: 10.3390/drones6070170

Rebecca, P., and Saleem, H. A. (2015). "Diplomacy on Ice: Energy and the Environment in the Arctic and Antarctic," in *Polar Environmental Governance and Non-state Actors*, vol. 1. (New Haven: Yale University Press), 13–40. doi: 10.12987/yale/9780300205169.003.0002

Revised draft text of BBNJ Agreement (2019). *Revised draft text of an agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction*. Available online at: https://documents.un.org/doc/undoc/gen/n19/372/88/pdf/n1937288.pdf (Accessed November 26, 2024).

Sands, P., Peel, J., Fabra, A., and MacKenzie, R. (2012). *Governance: states, international organisations and non-state actors. In Principles of International Environmental Law* (Cambridge: Cambridge University Press), 50–93.

Secretariat of the Antarctic Treaty (2024a). *Area Protection and Management/Historic Sites and Monuments*. Available online at: https://www.ats.aq/e/protected.html (Accessed November 16, 2024).

Secretariat of the Antarctic Treaty (2024b). *Parties of Secretariat of the Antarctica treaty*. Available online at: https://www.ats.aq/devAS/Parties?lang=e (Accessed October 31, 2024).

Sharma, J. B. (2019). *Applications of Small Unmanned Aircraft Systems: Best Practices and Case Studies. 1st ed* (Boca Raton: CRC Press).

Statute of the International Court of Justice (1946). Available online at: https://www.icj-cij.org/statute (Accessed August 1, 2024).

Sudbury, A. W., and Hutchinson, E. B. (2016). A cost analysis of amazon prime air (Drone delivery). *J. Econ. Educ.* 16, 1–12.

Sziroczak, D., Rohacs, D., and Rohacs, J. (2022). Review of using small UAV based meteorological measurements for road weather management. *Prog. Aerospace Sci.* 134, 1–16. doi: 10.1016/j.paerosci.2022.100859

The Canadian Aviation Regulations (2016). Available online at: https://tc.Canada.ca/en/aviation/reference-centre/exemptions-canadian-aviation-regulations-cars/exemption-sections-60241-60366-canadian-aviation-regulations-0 (Accessed November 16, 2024]).

Tsiamis, N., Efthymiou, L., and Tsagarakis, K. P. (2019). A comparative analysis of the legislation evolution for drone use in OECD countries. *Drones* 3 (4), 75. doi: 10.3390/drones3040075

UAS regulations in China (2024). *Interim Regulation on the Administration of the Flight of Unmanned Aircraft*. Available online at: https://www.gov.cn/gongbao/2023/issue_10586/202307/content_6893000.html (Accessed November 16, 2024).

UAV regulations in Argentina (2020). *UAV/SVANT Regulation and Regulatory Reference*. Available online at: https://www.Argentina.gob.ar/anac/vant-svant/reglamento-vant-svant (Accessed November 16, 2024).

US Antarctic Program (2016). *Interagency Air Operation Manual*. Available online at: https://www.usap.gov/logistics/documents/FY16_Air-Operation-Manual.pdf (Accessed November 16, 2024).

Web of Science database (2024). Available online at: https://www.webofscience.com/wos/alldb/summary/9dcee866-a1e7-4e31-8552-8d39fa9a2de1-98e3eb44/relevance/1 (Accessed November 16, 2024).

WG-EMM-15 (2015). *A small unmanned aerial system for estimating abundance and size of Antarctic predators*. Available online at: https://meetings.ccamlr.org/en/wg-emm-15/p06 (Accessed November 2, 2024).

WG-EMM-2019 (2019). *A drone-based Antarctic fur seal (Arctocephalus gazella) census of the St. Telmo Islands, South Shetland Archipelago*. Available online at: https://meetings.ccamlr.org/en/wg-emm-2019/65 (Accessed November 2, 2024).

Wing (2021). *Wing's drone delivery service hits 100,000 deliveries milestone*. Available online at: https://www.inceptivemind.com/wing-drone-delivery-service-hits-100000-deliveries-milestone/20797/ (Accessed November 16, 2024).

Zhang, B., Zhao, J., Ma, C., Li, T., Cheng, X., and Liu, L. (2019). UAV photogrammetric monitoring of Antarctic ice doline formation. *J. Beijing Normal Univ. (Natural Science).* 55, 19. doi: 10.16360/j.cnki.jbnuns.2019.01.003

Zhang, Z., and Zhu, L. (2023). A review on unmanned aerial vehicle remote sensing: platforms, sensors, data processing methods, and applications. *Drones* 7, no. doi: 10.3390/drones7060398

Zipline (2018a). *Zipline expands its medical delivery drones across East Africa*. Available online at: https://spectrum.ieee.org/zipline-expands-its-medical-delivery-drones-across-east-africa (Accessed November 16, 2024).

Zipline (2018b). *Zipline's new drone can deliver medical supplies at 79 miles per hour*. Available online at: https://www.cnbc.com/2018/04/02/zipline-new-zip-2-drone-delivers-supplies-at-79-mph.html (Accessed November 16, 2024).

frontiers | Frontiers in Marine Science

TYPE Perspective
PUBLISHED 23 December 2024
DOI 10.3389/fmars.2024.1478023

Check for updates

OPEN ACCESS

EDITED BY
Wen-Hong Liu,
National Kaohsiung University of Science and Technology, Taiwan

REVIEWED BY
Sílvia Gómez,
Autonomous University of Barcelona, Spain
Yi-Che Shih,
National Cheng Kung University, Taiwan

*CORRESPONDENCE
Anupa Asokan
anupaasokan@gmail.com

RECEIVED 09 August 2024
ACCEPTED 06 December 2024
PUBLISHED 23 December 2024

CITATION
Asokan A (2024) Marine protected areas as a tool for environmental justice.
Front. Mar. Sci. 11:1478023.
doi: 10.3389/fmars.2024.1478023

COPYRIGHT
© 2024 Asokan. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Marine protected areas as a tool for environmental justice

Anupa Asokan*

Independent Researcher, Los Angeles, CA, United States

Overfishing, destructive industrial practices, and climate change are the biggest drivers of biodiversity loss in the ocean. Marine Protected Areas (MPAs), including through nature conservation initiatives like "30x30" and "America the Beautiful," can be an effective solution to protect marine life and habitats, while making them more resilient to the pressures of extractive and destructive practices, as well as climate change impacts. There is general scientific consensus on the components that make MPAs ecologically effective, however, social context is often presented as burdensome—where protected spaces exclude communities from accessing nature. While this is a valid concern in top-down approaches to implementing protections around the world, under economic-driven systems of ocean management in countries like the United States, this narrative overlooks the potential opportunity of MPAs as a means to equity and environmental justice. In the U.S., the Magnuson-Stevens Fishery Conservation and Management Act (MSA) established a system that prioritizes the economic value of fisheries and centers power among Fishery Management Councils which are dominated by industry actors. Given this type of governance landscape, this perspective article presents MPAs as a step towards environmental justice in ocean management, whereby an MPA under the appropriate enabling conditions can be a tool to mitigate damage, distribute power, support other cultural value systems, and to advance our understanding of the ocean, climate change and diverse community impacts moving forward.

KEYWORDS

MPAs, policy reform, equity, ocean conservation, power dynamics, 30x30, fishery management

1 Introduction

A suite of ocean-related laws in the United States offer mechanisms to protect marine species, such as the Marine Mammal Protection Act (1972), the Endangered Species Act (1973), and the Magnuson-Stevens Fishery Conservation and Management Act of 1976 (MSA). The MSA is an important regulatory framework which supports the livelihoods of those that deliver wild caught seafood as a service to society. It is a tool designed to maintain commercially relevant natural resources and it is also, arguably, the most comprehensive governance framework for managing U.S. ocean waters. The law established a system of decision-making

power which is maintained through consistent federal agency resources and attention. Its extent covers the entire U.S. Exclusive Economic Zone and, though focused on specific marine fisheries, the biological consideration of habitats needed for long-term sustainability of those fisheries give decision-makers a broader purview than it may seem the law provides at surface level (NOAA Fisheries, 2007, 2024a). The result is that fishery management bodies are consulted and thus hold power in many fora for ocean decision-making (NOAA Fisheries, 2024b; NOAA, 2023).

Our planet and its climate are becoming less stable and increasingly less predictable (Wood et al., 2003; IPCC, 2019) and, post-2020, the intersection of these impacts with social injustices and systemic inequities are more prevalent in public discourse and harder to ignore in policy and decision-making (Schlosberg and Collins, 2014; Rowland-Shea et al., 2020). Climate change, the limitations of our governance to adapt management of marine resources to these changes, and the added pressures of new and emerging ocean industries warrant a deeper analysis of how environmental justice can be achieved in the United States with respect to the ocean.

Environmental justice is defined by the U.S. Federal Government as "the just treatment and meaningful involvement of all people regardless of income, race, color, national origin, Tribal affiliation, or disability, in agency decision-making and other Federal activities that affect human health and the environment." This goal will be achieved when everyone has "equitable access to a healthy, sustainable, and resilient environment in which to live, play, work, learn, grow, worship, and engage in cultural and subsistence practices." (Federal Register, 2023). Environmental in-justice exists from the unequal distribution of environmental burdens and benefits (Bennett et al., 2023). Thus, achieving environmental justice requires reparation, mitigation and prioritization of the needs and perspectives of, as well as impacts upon, those who have been marginalized.

For the ocean in particular, the recent White House Ocean Justice Strategy offers broad recommendations on achieving a more inclusive approach to decision-making and diversifying the communities involved in ocean use and management. Though tangible and actionable, integrating these approaches within existing systems will take time and consistent political will. The Strategy notes, "The diversity of advisory bodies, interagency coordination bodies, and decision-making groups is an important factor to achieving ocean justice." (The White House, 2023) The Fishery Management Council system lacks such diversity (Okey, 2003; NOAA Fisheries, 2023a), and given the exigent need to address biodiversity loss and climate change, a complementary and timely approach to conserving the marine environment is needed. Marine Protected Areas (MPAs) which are meaningful—i.e. well-designed, actively managed and monitored, and with high levels of protection—emerge as an important tool for environmental justice in our ocean. By meaningfully[1] protecting important habitats and the species and services these areas support, we have a mechanism to repair and mitigate the damage of commercial pursuits, support value systems that honor the intrinsic merit of what the ocean provides, and create an opportunity to better understand our ocean environment and how diverse communities value these areas and the benefits they offer.

2 Consequences and risks of U.S. fishery management

2.1 Economic priority

The MSA is predicated upon the concept of "maximum sustainable yield." As the term implies, the aim is to maximize profit from a fishery but only to the extent that enough of the population remains to reproduce and sustain the industry in future years (NOAA Fisheries, 2007, 2024c). The law's social and environmental guardrails extend its purview to the enabling conditions of a fishery, but also offer the caveat, "to the extent practicable," (NOAA Fisheries, 2023b) which is often used to further favor short-term economic interests at the expense of the longer-term health of habitat and other marine life. At the end of the day, "maximum sustainable yield" accounts for a limited suite of information on a species and its environmental conditions (NOAA, 2024), and it is an estimate. As environmental conditions and species interactions shift and become less predictable due to climate change, estimates of MSY will become more uncertain and further increase the potential risk to the health of a fishery (Roberts et al., 2017).

While shore-based and most subsistence take associated with the fishing activities of marginalized communities is done within state-level management schemes—separate but in coordination with, and often culturally similar to, federal-level management under MSA—this boundary is merely political (Hughes, 2015). Ecological boundaries are not static, and thus federal-level fishery management decisions can have implications on the near-shore catch for some species and hence, to the sustenance of low-income coastal communities. Commercial fishing activity impacts the quality, size and fishing effort needed by shore-based fishers. These local communities are often not considered or included in management decisions yet may be faced with catch limits and/or limited resource availability requiring greater effort for lesser and lower-quality catch (Cooper, 2024; Furman et al., 2023; Guiry et al., 2021).

2.2 Power asymmetry

Eight regional management bodies called Fishery Management Councils (Councils) are critical to the MSA's execution. While Council composition is intended to include diverse interests (U.S. Regional Fishery Management Councils, 2024), the system has come to exemplify the concept of regulatory capture,

1 In the context of this article, "meaningfully protected" or "meaningful MPAs" refer to the enabling conditions where MPAs are designed, implemented and managed in a way that is deemed effective according to literature and leading scientific information, such as the MPA Guide (Grorud-Colvert et al., 2021) and Edgar et al., 2014.

with Councils dominated by individuals from fishing industry sectors (Eagle et al., 2003).

A demonstration of this power asymmetry is evident in the establishment and management of National Marine Sanctuaries (Sanctuaries). As the ocean's equivalent of National Parks, Sanctuaries are community-borne efforts that should notionally support recreational use and offer a means to support intrinsic and other value systems in connecting with nature. Globally, fishing is the biggest driver of biodiversity loss in the ocean (IPBES, 2019) and only four of seventeen Sanctuaries—which are intended to protect areas of the marine environment due to a variety of qualities, including their ecological significance—have authority to regulate fishing within their boundaries[2] (NOAA, 2024; FKNMS, 1997; MNMS, 2024; ONMS, 2012; Federal Register, 2006). Bottom trawling, which is the most destructive form of commercial fishing, is allowed in most Sanctuaries (Jones, 2023; Mirza et al., 2021; Personal communication with NOAA ONMS staff, July 2024). Condition reports in the majority of Sanctuaries further point to fishing as a factor contributing to decline, yet updated management plans continually fail to address this significant threat (Gittings et al., 2013; Mirza et al., 2021). Guidance documents for new Sanctuary nominations recommend forgoing the authority of Sanctuary managers to regulate fishing in the management plan because Councils are given explicit privilege, by law, of consultation throughout the nomination and designation process, which is not necessarily granted to other communities and interests (NOAA, 2014; Greenly, 2023; NOAA, 2023). Thus, a Sanctuary nomination—intended to protect ecologically and/or culturally significant areas—is easily undermined by commercial interests through legally required Council consultation processes. As a result, most Sanctuaries are not meaningful MPAs, as they are minimally protected according to the MPA Guide (Sullivan-Stack et al., 2022).

Efforts to address population decline, habitat destruction and other significant environmental issues due to the limitations of the MSA are also often hindered by the power structure of the Fishery Management Councils. For example, the MSA does not mention climate change in its text, and while Councils continue to affirm that the nimble nature of their decision-making process can help them adapt to these unprecedented changes in the ocean, including to fish stocks, fishery management plans rarely account for stock shifts due to changing conditions (Otts et al., 2022). There is evidence that climate change will reduce productivity of some species in the coming years, and the impacts hold uncertainty (Free et al., 2019); these climate impacts and associated uncertainty will be compounded for the vast majority of marine species which have little or no data. Ninety-nine percent of documented ocean species in U.S. waters are not covered by this system (Fautin et al., 2010). This means species which may hold significance to other communities are unmanaged, likely at risk, and without a clear mechanism to understand, protect or restore their populations.

2.3 Limited knowledge

Even for those species that are managed under the fishery management system, information is limited. Fishery managers must still set thresholds and determine harvest levels with the information available. The process may be based on science and data however, decision-making is ultimately value-driven. This could result in a precautionary approach but more often leans toward economic incentive. For example, a stock that is found to be overfished (which relates to both extractive activities and degraded environmental conditions) requires a specific plan to rebuild the population, often with continued extraction of fishery stocks allowed to limit disruption to the livelihoods dependent on these fisheries. While this may be a helpful mechanism to recover commercially relevant species in the near-term, it also highlights the priority given to for-profit fishing interests over broader environmental and marine resource quality. Data is needed to trigger this effort to restore, but even for the 506 fish stocks managed under this system, nearly half do not even have a known overfished status and timely information is difficult to collect (NOAA Fisheries, 2024c). This allows for continued extractive activity despite long-term impacts, ultimately benefiting industry at the expense of ecosystem health.

Recent attempts to bring principles of equity and environmental justice into U.S. fishery management highlight gaps in representation in NOAA Fisheries and the Councils, as well as limitations in collecting and interpreting the demographic and social information needed to assess equity. Social science capacity and prioritization within the agency are also limiting factors in implementing and operationalizing NOAA Fisheries' EEJ Strategy (NOAA Fisheries, 2023a; NASEM, 2024). A National Academies Report on equity in fishery management notes, "Lack of capacity is not only a practical constraint, but also an epistemological one, reinforcing a culture within [NOAA Fisheries] that values particular kinds of science, data, and evidence." (NASEM, 2024). This cultural shift, plus the will and ability to identify gaps and gather necessary information on who is broadly impacted by fishery management decisions, though critical, will be a lengthy and resource intensive process.

2.4 Summary of consequences and risks

Thus, the most impactful and broadest mechanism for managing the U.S. ocean favors industry, and gives industry power in decision-making while failing to consider important values and ecosystem benefits to communities unrepresented in decision-making. This leads to further burden on vulnerable coastal

2 These four Sanctuaries are: Florida Keys, Monitor, Flower Garden Banks and Gray's Reef. Through section 304(a)(5) of the National Marine Sanctuaries Act (NOAA, 2023), the Channel Islands National Marine Sanctuary has Marine Reserves and Conservation Areas within its boundaries. These areas have limitations on fishing established through federal fishery management and state-level management processes (Federal Register, 2007). In 2020, the Monitor National Marine Sanctuary's prohibition on all fishing was clarified to only restrict trawling activities (Federal Register, 2020).

communities. Low-income subsistence fishers, often from communities of color, rely on near-shore fisheries for food security. These shore-based communities are not considered in fishery decision-making (Furman et al., 2023). Consequently, access to quality near-shore fisheries has declined over several generations, both in species type and condition (Miller et al., 2014; Poe et al., 2015). Fisheries that are now readily accessible from shore are often subject to health advisories (OEHHA, 2024; EPA, 2024) and are unsupported by management because there is little to no data on stock abundance (Furman et al., 2023), and a lack of recognition along with various other inequities. The examples and components of fishery management outlined above serve to establish conditions which should be mitigated as we seek environmental justice through future decision-making.

3 Opportunities and benefits of protected areas

If we accept that the system we have in place for U.S. ocean management benefits for-profit fishing interests at the burden of all others who find value in marine resources, Marine Protected Areas can emerge as a mechanism to reverse this injustice. On a global scale too, where high seas fishing activity is largely done by corporations (Carmine et al., 2020), open ocean protected areas have the potential to considerably reduce inequality in the distribution of fishery benefits among maritime countries (Sumaila et al., 2015). By limiting extractive activities, an MPA can shift the flow of benefits derived from the ocean away from industry by prioritizing the needs of diverse communities and value systems, and providing an opportunity to correct inequities in our current system of ocean management. This will, of course, require MPA design, implementation and management to be done meaningfully and with consideration of the various elements of social equity.

Building upon Bennett et al., 2021 examination of advancing social equity in marine conservation, the design and implementation of new MPAs and the management of existing protected areas can contribute to advancing all elements of equity outlined and, potentially, other elements beyond the scope of Bennett et al. (2021) analysis such as spatial and intergenerational equity. Core to this approach is an acceptance of diverse value systems and elevating these to, or beyond, the level enjoyed by the market-driven, economic-values approach that typically leads decision-making. At no point in our modern history has the overall state of our ocean become healthier (IPCC, 2019). The burden of this reality has and will impact already vulnerable communities most (Bennett et al., 2023). Meaningful MPAs can provide a place-based approach to reconnect communities with nature and the associated benefits of a healthier marine area, restore Tribal self-determination and Indigenous rights, and create a system where marginalized groups may find agency, safety and transparency in engaging with both the environment and its management.

Often described as an "insurance policy," MPAs can help mitigate the risks to ecosystem function associated with climate uncertainty (Jacquemont et al., 2022). By meaningfully protecting important habitat, MPAs can serve as a precautionary backstop to the uncertainties of fishery management associated with MSY and data limitations. These area-based protection efforts should be thoughtfully and deliberately sited to support communities and value systems marginalized across some or all of the elements of social equity. For example, shore-based fishing communities may directly benefit from partially protected areas on the margins of fully protected marine reserves, as there is evidence that socioeconomic advantages can be derived from limited and well-regulated uses in this type of protected area scheme (Zupan et al., 2018). Similarly, MPAs can be designed with downstream benefits to coastal access points in mind. In California, for example, piers and jetties do not require the purchase of a fishing license and are areas of concentrated subsistence fishing (Quimby et al., 2020) which could be enhanced by appropriately sited MPAs. Other non-consumptive ways of interacting with the ocean can and should be enhanced, as well, as there is a growing body of scientific literature relating ecosystem health and biodiversity to mental health and well-being (Bratman et al., 2019; Sandifer et al., 2015).

Hawaii's Community-Based Subsistence Fishing Areas (CBSFA) and California's Indigenous Marine Stewardship Areas (IMSAs) are two examples of existing MPA types that have, or have potential to, advance environmental justice. Hawaii's Hā'ena CBSFA is an example of a community-led stewardship effort to restore traditional systems of resource management. Local families with intergenerational ecological knowledge pre-dating colonization were key to this MPA's designation, offering an opportunity to continue traditional cultural practices and engage the community in enforcement and monitoring of the area, which has shown an increase in biodiversity since establishment (Collier, 2020). The IMSA is a relatively new MPA designation type in the state of California which can be established by Tribal governments. The Yurok-Tolowa Dee-ni' IMSA has been announced with co-management details still forthcoming (Tolowa Dee-ni' Nation, 2024). Assuming Tribal self-determination will be honored by the state, this offers another opportunity towards restoring both biodiversity and community stewardship of a marine area.

Any MPA designation requires political will and public support, so too does ensuring these areas are durably protected. Siting and boundaries will likely face resistance from the fishing industry, and moments for adaptive management could invite risk to MPA durability as much as opportunities to improve efficacy and service to communities. Political will may be the key enabling factor for an MPA to advance environmental justice, by placing priority on enhanced benefits for those marginalized over economic interests. Science shows that MPAs are an effective tool to invest in the future health of marine ecosystems and are themselves key to further scientific understanding of our marine ecosystems through the unknowns of changing conditions (Claudet et al., 2008; Lester et al., 2009; Marcos et al., 2021; O'Hara et al., 2021; Roberts et al., 2017). Our cultural acceptance and theories of practice as it relates to equity and environmental

justice principles are new and evolving. Marine Protected Areas, too, should be seen as an opportunity to understand the human connection to the ocean. Adaptive management is key to the efficacy of an MPA (Morris and Green, 2014; Tony, 2020). In addition to the management decisions that enhance ecological outcomes, adaptive management should also be an opportunity to learn and adapt for enhanced social outcomes, as well. As marginalized groups find safety and agency in decision-making processes, and our understanding of diverse perspectives becomes more robust, we can also build upon existing bodies of knowledge for more meaningful approaches to measuring and achieving equity in engaging with the ocean and its management.

4 Conclusion

Though there is opportunity for reform, the idealistic suggestion to fully upend existing systems of ocean management is not feasible. Given the current moment of opportunity, as different jurisdictions are examining how to reach 30x30 targets, new and strengthened MPAs—which should be ecologically effective and consider the dimensions of social equity—emerge as a pragmatic tool for progress in both addressing the biodiversity crisis and achieving environmental justice in U.S. ocean management, and perhaps other jurisdictions with similar management structures and inequities. State management schemes, Sanctuary designation and updated management plans, and/or establishment of Marine Monuments through the Antiquities Act are existing mechanisms that can and should be used with full authority in the U.S. It will be up to those respective decision-making bodies to look beyond the Council system. And the Council system itself could even choose to meaningfully, and durably, use area-based management opportunities under their purview. All of these potential efforts will require decision-makers to seek out and elevate the needs of those marginalized in ocean management, and meaningfully protect the ocean for everyone's benefit.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

AA: Conceptualization, Funding acquisition, Writing – original draft, Writing – review & editing.

Funding

The author declares financial support was received for the research, authorship, and/or publication of this article. Funding for this paper was solicited and awarded through the National Ocean Protection Coalition's small grant program; NOPC is fiscally sponsored by the Resources Legacy Fund.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Bennett, N. J., Alava, J. J., Ferguson, C. E., Blythe, J., Morgera, E., Boyd, D., et al. (2023). Environmental (in)justice in the anthropocene ocean. *Mar. Pol.* 147, 105383. doi: 10.1016/j.marpol.2022.105383

Bennett, N. J., Katz, L., Yadao-Evans, W., Ahmadia, G. N., Atkinson, S., Ban, N. C., et al. (2021). Advancing social equity in and through marine conservation. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.711538

Bratman, G. N., Anderson, C. B., Berman, M. G., Cochran, B., De Vries, S., Flanders, J., et al. (2019). Nature and mental health: An ecosystem service perspective. *Sci. Adv.* 5, 7. doi: 10.1126/sciadv.aax0903

California Office of Environmental Health and Hazard Assessment (OEHHA). (2024). Fish advisories. Available online at: https://oehha.ca.gov/fish/advisories (Accessed October 7, 2024).

Carmine, G., Mayorga, J., Miller, N. A., Park, J., Halpin, P. N., Ortuño Crespo, G., et al. (2020). Who is the high seas fishing industry? *One Ear.* 3, 730–738. doi: 10.1016/j.oneear.2020.11.017

Claudet, J., Osenberg, C. W., Benedetti-Cecchi, L., Domenici, P., García-Charton, J.-A., Pérez-Ruzafa, Á., et al. (2008). Marine reserves: size and age do matter. *Ecol. Lett.* 11, 481–489. doi: 10.1111/j.1461-0248.2008.01166.x

Collier, C. E. (2020). Enabling conditions for community-based comanagement of marine protected areas in the United States. *Mar. Pol.* 122, 104244. doi: 10.1016/j.marpol.2020.104244

Cooper, R. (2024). The predicament of subsistence fishing and seafood contaminants. Available online at: https://caseagrant.ucsd.edu/news/the-predicament-of-subsistence-fishing-and-seafood-contaminants (Accessed January 26, 2024).

Eagle, J., Newkirk, S., and Thompson, B. H. (2003). *Taking Stock of the Regional Fishery Management Councils*. Available online at: https://www.pewtrusts.org/-/media/legacy/uploadedfiles/wwwpewtrustsorg/reports/protecting_ocean_life/pewsciencetakingstockpdf.pdf (Accessed January 26, 2024).

Edgar, G., Stuart-Smith, R., Willis, T., Kininmonth, S., Baker, S., Banks, S., et al. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature* 506, 216–220. doi: 10.1038/nature13022

Environmental Protection Agency (EPA). (2024). Fish consumption advisories. Available online at: https://www.epa.gov/sfbay-delta/fish-consumption-advisories (Accessed October 7, 2014).

Fautin, D., Dalton, P., Incze, L. S., Leong, J.-A. C., Pautzke, C., Rosenberg, A., et al. (2010). An overview of marine biodiversity in United States waters. *PloS One* 5, e11914. doi: 10.1371/journal.pone.0011914

Federal Register. (2006). 15 CFR Part 922 Subpart I: Gray's Reef National Marine Sanctuary. Available online at: https://www.ecfr.gov/current/title-15/subtitle-B/chapter-IX/subchapter-B/part-922/subpart-I (Accessed February 6, 2024).

Federal Register. (2007). Establishment of Marine Reserves and a Marine Conservation Area Within the Channel Islands National Marine Sanctuary; Correction. Available online at: https://www.federalregister.gov/documents/2007/08/02/07-3754/establishment-of-marine-reserves-and-a-marine-conservation-area-within-the-channel-islands-national (Accessed July 17, 2024).

Federal Register. (2020). Clarification of Magnuson-Stevens Fishery Conservation and Management Act Regulation Regarding Monitor National Marine Sanctuary; Final Rulemaking. Available online at: https://www.federalregister.gov/documents/2020/03/18/2020-05649/clarification-of-magnuson-stevens-fishery-conservation-and-management-act-regulation-regarding (Accessed July 17, 2024).

Federal Register. (2023). *Executive Order 14096: Revitalizing Our Nation's Commitment to Environmental Justice for All*. Available online at: https://www.federalregister.gov/documents/2023/04/26/2023-08955/revitalizing-our-nations-commitment-to-environmental-justice-for-all (Accessed January 18, 2024).

Florida Keys National Marine Sanctuary (FKNMS). (1997). Florida keys national marine sanctuary regulations. Available online at: https://floridakeys.noaa.gov/regs/ (Accessed February 6,2024).

Free, C. M., Thorson, J. T., Pinsky, M. L., Oken, K. L., Wiedenmann, J., and Jensen, O. P. (2019). Impacts of historical warming on marine fisheries production. *Science* 363, 979–983. doi: 10.1126/science.aau1758

Furman, K. L., Harlan, S. L., Barbieri, L., and Scyphers, S. B. (2023). Social equity in shore-based fisheries: Identifying and understanding barriers to access. *Mar. Pol.* 148, 105355. doi: 10.1016/j.marpol.2022.105355

Gittings, S. R., Tartt, M., and Broughton, K. (2013). *National Marine Sanctuary System Condition Report 2013, NOAA Office of National Marine Sanctuaries*. Available online at: https://sanctuaries.noaa.gov/science/condition/ncr/ (Accessed January 24, 2024).

Greenly, T. (2023). Proposed Bering Sea marine sanctuary draws pushback from fishing industry, KUCB - Unalaska. Available online at: https://www.ktoo.org/2023/04/24/proposed-bering-sea-marine-sanctuary-draws-pushback-from-fishing-industry/ (Accessed February 7, 2024).

Grorud-Colvert, K., Sullivan-Stack, J., Roberts, C., Constant, V., Horta, E., Costa, B., et al. (2021). The MPA Guide: A Framework to Achieve Global Goals for the Ocean. *Science*. 373. 6550. doi: 10.1126/science.abf0861

Guiry, E. J., Kennedy, J. R., O'Connell, M. T., Gray, D. R., Grant, C., and Szpak, P. (2021). Early evidence for historical overfishing in the Gulf of Mexico. *Sci. Adv.* 7, eabh2525. doi: 10.1126/sciadv.abh2525

Hughes, R. M. (2015). Recreational fisheries in the USA: economics, management strategies, and ecological threats. *Fish Sci.* 81, 1–9. doi: 10.1007/s12562-014-0815-x

Intergovernmental Panel on Climate Change (IPCC). (2019). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. Eds. H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama and N. M Weyer. (Cambridge, UK and New York, NY, USA: Cambridge University Press).

IPBES. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. doi: 10.5281/zenodo.3553579

Jacquemont, J., Blasiak, R., Le Cam, C., Le Gouellec, M., and Claudet, J. (2022). Ocean conservation boosts climate change mitigation and adaptation. *One Ear* 5, 1126–1138. doi: 10.1016/j.oneear.2022.09.002

Jones, B. (2023).America's best idea to protect its oceans has one big problem: It's not working. Available online at: https://www.vox.com/down-to-earth/2023/5/23/23720486/marine-protected-areas-sanctuaries-fishing-conservation (Accessed January 24, 2024).

Lester, S. E., Halpern, B. S., Grorud-Colvert, K., Lubchenco, J., Ruttenberg, B. I., Gaines, S. D., et al. (2009). Biological effects within no-take marine reserves: A global synthesis. *Mar. Ecol. Prog. Ser.* 384, 33–46. doi: 10.3354/meps08029

Marcos, C., Díaz, D., Fietz, K., Forcada, A., Ford, A., García-Charton, J. A., et al. (2021). Reviewing the ecosystem services, societal goods, and benefits of marine protected areas. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.613819

Miller, R. R., Field, J. C., Santora, J. A., Schroeder, I. D., Huff, D. D., Key, M., et al. (2014). A spatially distinct history of the development of California groundfish fisheries. *PloS One* 9, e99758. doi: 10.1371/journal.pone.0099758

Mirza, Z., Carter, A., Kenney, A., and Goldstein, M. (2021). To protect 30 percent of the ocean, the United States must invest in the national marine sanctuaries program. Available online at: https://www.americanprogress.org/article/to-protect-30-percent-of-the-ocean-the-united-states-must-invest-in-the-national-marine-sanctuaries-program/ (Accessed January 24, 2024).

Monitor National Marine Sanctuary (MNMS) (2024). *Monitor National Marine Sanctuary Regulations*. Available online at: https://monitor.noaa.gov/management/regulations.html (Accessed February 6, 2024).

Morris, C. J., and Green, J. M. (2014). MPA regulations should incorporate adaptive management—The case of Gilbert Bay Labrador Atlantic cod (Gadus morhua). *Mar. Pol.* 49, 20–28. doi: 10.1016/j.marpol.2014.03.025

National Academies of Sciences, Engineering, and Medicine (NASEM). (2024). *Assessing Equity in the Distribution of Fisheries Management Benefits: Data and Information Availability* (Washington, D.C.: The National Academies Press). doi: 10.17226/27313

National Oceanic and Atmospheric Administration (NOAA). (2014). *Sanctuary Nomination Process Guide*. Available online at: https://nmsnominate.blob.core.windows.net/nominate-prod/media/documents/sanctuary-nomination-process-guide.pdf (Accessed February 6, 2024).

National Oceanic and Atmospheric Administration (NOAA). (2023). *National Marine Sanctuaries Act Fishing Regulations Frequently Asked Questions (FAQs)*. Available online at: https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/20230512-nmsa-304a5-fishing-regulation-faqs.pdf (Accessed July 15, 2024).

National Oceanic and Atmospheric Administration (NOAA). (2024). *National Marine Sanctuaries, Legislation*. Available online at: https://sanctuaries.noaa.gov/about/legislation/ (Accessed January 18, 2024).

NOAA Fisheries. (2007). *Magnuson-Stevens Fishery Conservation and Management Act*. Available online at: https://www.fisheries.noaa.gov/s3//dam-migration/msa-amended-2007.pdf (Accessed January 18, 2024).

NOAA Fisheries. (2023a). *Equity and Environmental Justice Strategy*. Available online at: https://media.fisheries.noaa.gov/2023-05/NOAA-Fisheries-EEJ-Strategy-Final.pdf (Accessed January 24, 2024).

NOAA Fisheries. (2023b). *National Standard Guidelines*. Available online at: https://www.fisheries.noaa.gov/national/laws-and-policies/national-standard-guidelines (Accessed January 24, 2024).

NOAA Fisheries. (2024a). *Understanding Fisheries Management in the United States*. Available online at: https://www.fisheries.noaa.gov/insight/understanding-fisheries-management-united-states (Accessed January 24, 2024).

NOAA Fisheries. (2024b). *Understanding Consultations with Federal Agencies*. Available online at: https://www.fisheries.noaa.gov/insight/understanding-consultations-federal-agencies (Accessed May 17, 2024).

NOAA Fisheries. (2024c). *Status of Stocks 2023: Annual Report to Congress on the Status of U.S. Fisheries*. Available online at: https://www.fisheries.noaa.gov/s3/2024-04/2023SOS-final.pdf (Accessed May 24, 2024).

NOAA Office of National Marine Sanctuaries (ONMS). (2012). Flower garden banks national marine sanctuary regulations. Available online at: https://nmsflowergarden.blob.core.windows.net/flowergarden-prod/media/archive/document_library/protdocs/fgbnmsfinalrule2012.pdf (Accessed February 6, 2024).

O'Hara, C. C., Frazier, M., and Halpern, B. S. (2021).). At-risk marine biodiversity faces extensive, expanding, and intensifying human impacts. *Science* 372, 84–87. doi: 10.1126/science.abe6731

Okey, T. A. (2003). Membership of the eight regional fishery management councils in the United States: are special interests over-represented? *Mar. Pol.* 27, 3. doi: 10.1016/S0308-597X(03)00002-2

Otts, S., Deans, O., Hamilton, S., Janasie, C., and Bowling, T. (2022). Nimbleness of federal fisheries management decision-making processes to support climate-ready fisheries: A legal analysis. *Natl. Sea Grant Law Center (U.S.)*. doi: 10.25923/e3cg-ta23

Poe, M. R., Levin, P. S., Tolimieri, N., and Norman, K. (2015). Subsistence fishing in a 21st century capitalist society: From commodity to gift. *Ecol. Econ.* 116, 241–250. doi: 10.1016/j.ecolecon.2015.05.003

Quimby, B., Crook, S., Miller, K. M., Ruiz, J., and Lopez-Carr, D. (2020). Identifying, defining and exploring angling as urban subsistence: Pier fishing in Santa Barbara, California. *Mar. Pol.* 121, 104197. doi: 10.1016/j.marpol.2020.104197

Roberts, C. M., O'Leary, B. C., McCauley, D. J., Cury, P. M., Duarte, C. M., Lubchenco, J., et al. (2017). Marine reserves can mitigate and promote adaptation to climate change. *Proc. Natl. Acad. Sci.* 114, 6167–6175. doi: 10.1073/pnas.1701262114

Rowland-Shea, J., Doshi, S., Edberg, S., and Fanger, R. (2020). The nature gap: confronting racial and economic disparities in the destruction and protection of nature in America, center for American progress. Available online at: https://www.americanprogress.org/article/the-nature-gap/ (Accessed January 24, 2024).

Sandifer, P. A., Sutton-Grier, A. E., and Ward, B. P. (2015). Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance health and biodiversity conservation. *Eco. Ser.* 12, 1–15. doi: 10.1016/j.ecoser.2014.12.007

Schlosberg, D., and Collins, L. B. (2014). From environmental to climate justice: climate change and the discourse of environmental justice. *WIREs Climate Change.* 5, 3. doi: 10.1002/wcc.275

Sullivan-Stack, J., Aburto-Oropeza, O., Brooks, C. M., Cabral, R. B., Caselle, J. E., Chan, F., et al. (2022). A scientific synthesis of marine protected areas in the United States: status and recommendations. *Front. Mar. Sci.* 9. doi: 10.3389/fmars.2022.849927

Sumaila, U. R., Lam, V. W. Y., Miller, D. D., Teh, L., Watson, R. A., Zeller, D., et al. (2015). Winners and losers in a world where the high seas is closed to fishing. *Sci. Rep.* 5, 8481. doi: 10.1038/srep08481

The White House. (2023). Ocean justice strategy. Available online at: https://www.whitehouse.gov/wp-content/uploads/2023/12/Ocean-Justice-Strategy.pdf?cb=1701982354 (Accessed March 14, 2024).

Tolowa Dee-ni' Nation. (2024). *Yurok-Tolowa Dee-ni' Indigenous Marine Stewardship Area*. Available online at: https://www.tolowa-nsn.gov/341/Yurok-Tolowa-Dee-ni-Indigenous-Marine-St (Accessed November 26, 2024).

Tony, A. B. R. (2020). Adaptive management in the context of MPAs: Challenges and opportunities for implementation. *J. Nat. Conserv.* 56, 125864. doi: 10.1016/j.jnc.2020.125864

U.S. Regional Fishery Management Councils. (2024). About the councils. Available online at: https://www.fisherycouncils.org/about-the-councils (Accessed August 6, 2024).

Wood, R. A., Vellinga, M., and Thorpe, R. (2003). Global warming and thermohaline circulation stability. *Phil. Trans. R. Soc A.* 361, 1961–1975. doi: 10.1098/rsta.2003.1245

Zupan, M., Fragkopoulou, E., Claudet, J., Erzini, K., Horta e Costa, B., and Gonçalves, E. (2018). Marine partially protected areas: drivers of ecological effectiveness. *Front. Ecol. Env.* 16. doi: 10.1002/fee.1934

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 07 February 2025
DOI 10.3389/fmars.2025.1434342

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Emilio Notti,
National Research Council (CNR), Italy
Andrew Lockley,
University College London, United Kingdom

*CORRESPONDENCE
Valentina Bortuzzo
valentina.bortuzzo2@phd.units.it

†These authors have contributed equally to this work and share first authorship

RECEIVED 17 May 2024
ACCEPTED 17 January 2025
PUBLISHED 07 February 2025

CITATION
Bortuzzo V, Bertagna S, Braidotti L and Bucci V (2025) Towards CO_2 emissions reduction of shipping: $Ca(OH)_2$ based carbon capture system for safeguarding the marine environment.
Front. Mar. Sci. 12:1434342.
doi: 10.3389/fmars.2025.1434342

COPYRIGHT
© 2025 Bortuzzo, Bertagna, Braidotti and Bucci. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Towards CO_2 emissions reduction of shipping: $Ca(OH)_2$ based carbon capture system for safeguarding the marine environment

Valentina Bortuzzo[1,2*†], Serena Bertagna[1†], Luca Braidotti[1†] and Vittorio Bucci[1]

[1]Department of Engineering and Architecture, University of Trieste, Trieste, Italy, [2]Fratelli d'Amico Armatori Spa, Rome, Italy

Climate change poses a global challenge related to the reduction of pollutant atmospheric emissions and the maritime transportation sector is directly involved, due to its significant impact on the production of Greenhouse Gases and other substances. While established technologies have effectively targeted emissions like Nitrogen Oxides (NO_X) and Sulfur Oxides (SO_X), the persistence of Carbon dioxide (CO_2) emissions represents an ongoing and significant concern. Novel technologies targeting CO_2 reduction have been lately studied and proposed for inland applications, and are now being developed for maritime applications. With this regard, the present study explores the potential of Carbon Capture Systems (CCS) to mitigate CO_2 emissions produced by cargo ships. While the implementation of CCS faces challenges, including space limitations and logistical complexities, its possible integration onboard marks a significant step in the fight against climate change. The authors propose an innovative approach using a Calcium Hydroxide $Ca(OH)_2$ based CCS, offering the dual benefit of CO_2 reduction and the potential resolution of ocean acidification through Calcium carbonate ($CaCO_3$), the final product resulting from the CO_2 capture process. Additionally, the study examines the feasibility of the generated product for reuse in industry, promoting a circular economy and addressing environmental issues. This innovative solution underscores the urgent need for transformative measures to reduce maritime emissions, in line with efforts to safeguarding the marine environment and combat climate change.

KEYWORDS

marine environment protection, atmospheric emissions reduction, ocean acidification mitigation, cargo ships, carbon capture system, calcium carbonate

1 Introduction

The effects of climate change emerge as a significant global challenge to be addressed. According to research (United Nations, 2023), over 80% of international cargo is transported by ships, which are responsible for about 3% of all global Greenhouse Gas (GHG) emissions. This is set to grow if no action is taken (IMO, 2020).

Specifically, ships are a substantial source of emissions released into the atmosphere, including Carbon Dioxide (CO_2), Nitrogen Oxides (NO_X), Carbon Monoxide (CO), Non-Methane Volatile Organic Compounds (NMVOC), Particulate Matter (PM), Sulphur Dioxide (SO_2), and methane (CH_4) (Shu et al., 2023; Aakko-Saksa et al., 2023).

While technologies such as Selective Catalytic Reduction (SCR), Scrubbers and Exhaust Gas Recirculation (EGR), are already established and proven to reduce NO_X and SO_X emissions, as reported by (Lehtoranta et al., 2015; Karatuğ et al., 2022; Andriiovych Kuropyatnyk and Victorovych Sagin, 2019), the situation differs concerning CO_2 emissions.

Moreover, among these emissions, it is noteworthy that CO_2 is the primary contributor to global warming (Yoro and Daramola, 2020). The escalating levels of CO_2 have particularly led to a rise in global average temperatures, resulting in significant climate changes, including extreme weather events, alterations in precipitation patterns, and shifts in ecosystems (Nunes, 2023).

The consequences of CO_2 emissions extend to the melting of polar ice caps and icebergs, contributing to rising sea levels that pose a direct threat to coastal communities and marine habitats (Durand et al., 2022).

Furthermore, the absorption of a substantial portion of emitted CO_2 by the oceans leads to ocean acidification resulting in a decline of calcium carbonate ($CaCO_3$) saturation state, causing a reduction in oceanic pH levels and severe repercussions for marine organisms (Kurihara, 2008; Jafari et al., 2023).

In order to address these pressing issues, regulations have been introduced to limit pollution emissions from ships. The International Maritime Organization (IMO) has implemented regulatory measures with the overarching goal of attaining net-zero GHG emissions from the shipping sector by or around 2050. Figure 1 illustrates essential regulatory measures and implementation support initiatives crucial for achieving the IMO's emission reduction objectives (IMO, 2023).

At the European level, the European Union (EU) has integrated shipping into the EU Emissions Trading System (ETS). Within this regulatory framework, shipping companies have to make financial contributions based on the emissions of CO_2 they reported in the preceding year, for voyages and port stays within the EU/European Economic Area (EEA). In 2025, shipowners' companies will be accountable for 40% of the emissions reported in 2024; this obligation will increase to 70% of their 2025 emissions in 2026. Starting from 2027, shipping companies will bear the entire cost, covering 100% of their reported emissions (DNV, 2023; European Commission, 2023).

Compliance with regulatory measures is imperative for the shipping industry, necessitating significant investments in technologies and alternative fuels (Balcombe et al., 2019). However, shipowners show less inclination to order new ships especially due to the uncertainties related to fuel technology and

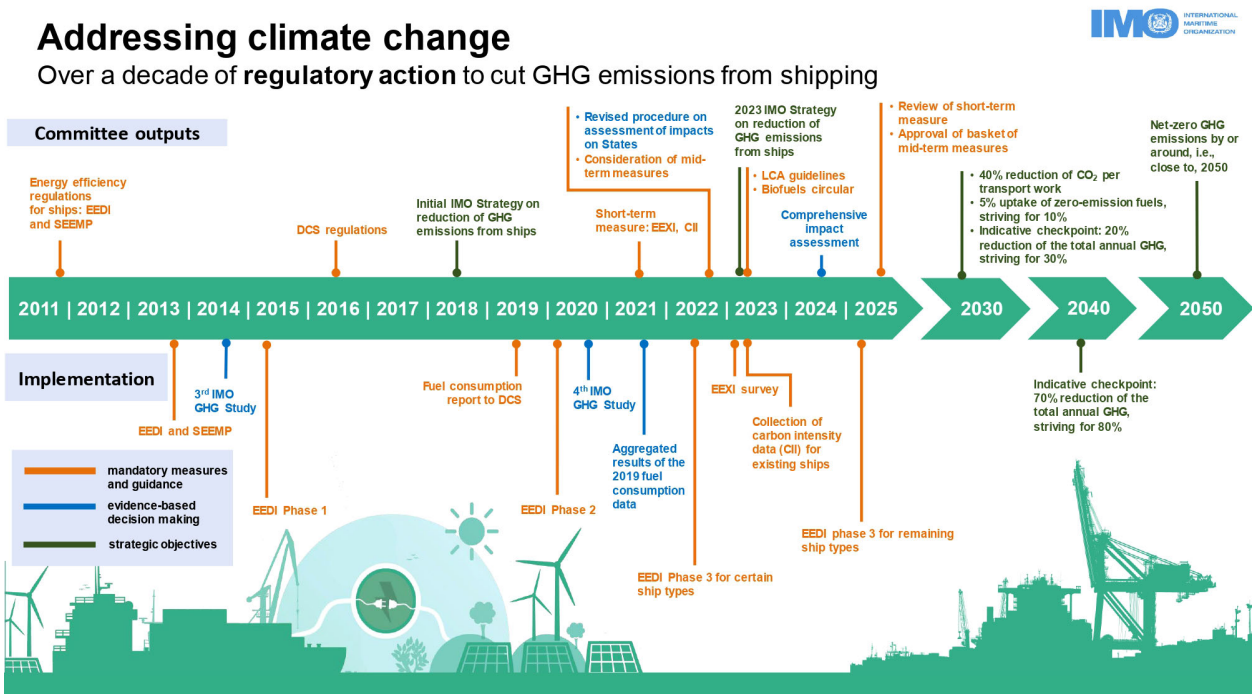


FIGURE 1
Timeline of IMO regulatory action to cut GHG emissions from shipping (IMO, 2023).

bunker costs. These factors significantly impact the decision-making process regarding solutions to reduce emissions for new ships (Zhang et al., 2021) and despite an ageing fleet, shipowners have opted to sell and purchase second-hand vessels. Because of this, while the transition to alternative fuels in the shipping industry is underway, the number of vessels operating on traditional fuels remains and is projected to be significantly high in the coming years, as evidenced by an analysis of the orderbook (Figure 2) (United Nations, 2023).

It emerges that the current fleet is predominantly composed of ships running on traditional fuels, and the prevailing order book continues to prioritize traditional fuel options. Therefore, the transition to low- and zero-impact alternative fuels is not imminent, and the maritime sector needs a technological shift to mitigate emissions. Postponing the adoption of technologies and fuels leading to climate neutrality to be fully ready is not feasible, as it would result in addressing a larger volume of emissions within a shorter timeframe (Galán-Martín et al., 2021).

Shipowners are compelled to promptly invest in onboard green technologies, given their significant influence on the emission profile of the global shipping fleet and its capacity to adhere to the GHG targets set by the IMO (Piccolo, 2023). Within this framework, it is imperative to discern the optimal solution for regulatory compliance that contributes to the immediate reduction of environmental emissions.

From the analysis of current regulations and future compliance measures in the shipping sector, aimed at addressing the challenges of climate change, CCSs emerge as a promising solution to immediately mitigate a significant amount of CO_2 emissions, while facilitating a gradual transition to more sustainable energy sources like renewables (Hua et al., 2023; Tavakoli et al., 2024).

This technology employs different types of chemical and physical processes for capturing and storing CO_2 emissions produced by the combustion of fossil fuel sources before they are released into the atmosphere and has proven effective for various inland industries (Leeson et al., 2017; Witte, 2021).

Nevertheless, implementing CCS onboard ships presents challenges due to limited space and stringent operational requirements. Additionally, the logistics of transporting captured CO_2 from ships to permanent storage sites can be complex. This

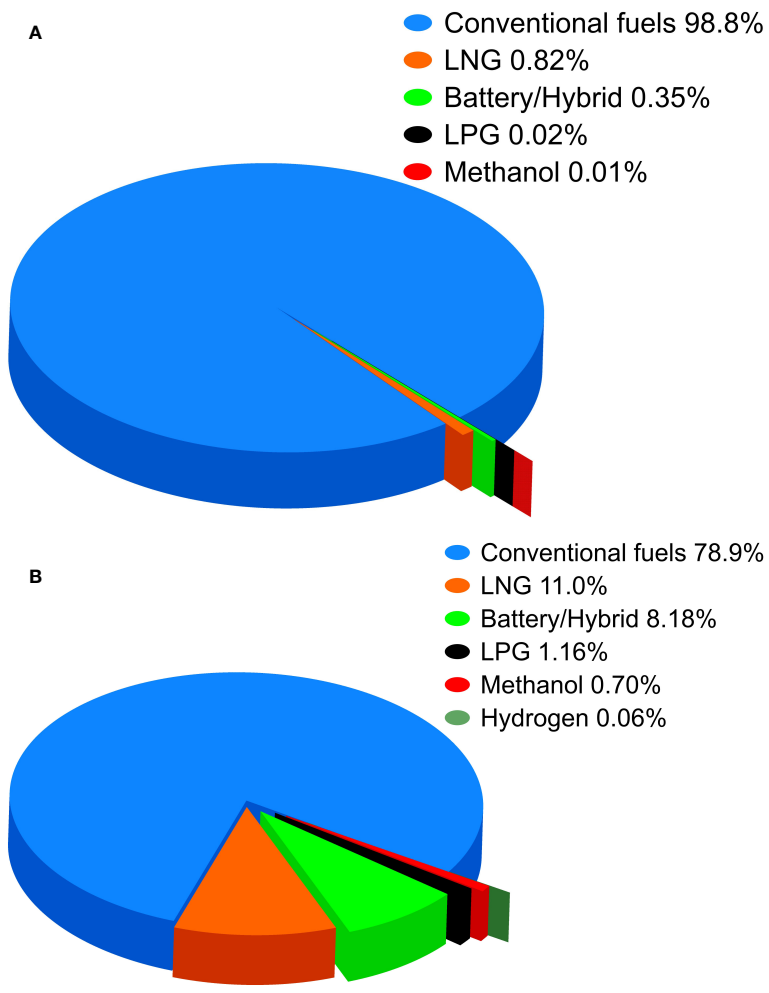


FIGURE 2
Percentage of vessels, in 2022 **(A)** and in orderbook **(B)**, running with conventional and alternative fuels.

process requires specialized equipment, infrastructure, and adherence to strict safety and environmental regulations to ensure the secure and effective storage of CO_2 (Al Baroudi et al., 2021).

Despite these challenges, the introduction of CCS technology in the maritime sector represents a significant innovation in combating climate change, aligning with international efforts towards decarbonization.

In this framework, although there are various studies on the implementation of this technology on land (Abanades et al., 2023; Han et al., 2011), the authors aim at addressing the challenges associated with its potential implementation onboard as well as the issues of CO_2 storage and transportation. To this purpose, they propose a methodology to evaluate the main features of such innovative solution never tested onboard nor yet investigated in literature. This methodology enables a preliminary sizing of the CCS, which lacks established naval applications, through stoichiometric considerations. By employing relatively quick calculations, the method facilitates a preliminary assessment of the technology's impact on the reference vessel, providing initial dimensional estimates that allow for an understanding of whether the system can be installed onboard and, subsequently, its broader impact on the vessel's operations. Building on this methodology, the feasibility assessment for retrofitting an existing vessel design with a CCS with Calcium Hydroxide is conducted, with particular attention given to system-level integration and operational challenges rather than the detailed design of the CO_2 scrubber itself. This system, as previously examined by the authors (Bortuzzo et al., 2023), provides distinct advantages over other types of CCSs. Notably, it simplifies onboard logistics by eliminating the need for CO_2 liquefaction unit and the additional energy required for its operation (Risso et al., 2023).

The objective of the system implementation is to directly reduce CO_2 emissions from ships while concurrently generating a product, $CaCO_3$. This approach aligns with ocean alkalinity enhancement strategies, such as adding lime directly to seawater, which aim at mitigating atmospheric CO_2 by enhancing the ocean's natural carbon absorption capacity (Butenschön et al., 2021; Caserini et al., 2021a, 2022; Comes et al., 2024). The proposed CCS not only reduces CO_2 emissions but also transforms the captured CO_2 into calcium carbonate, which can be released into seawater to increase alkalinity and counteract ocean acidification. Unlike direct lime addition, which faces logistical challenges such as transportation and distribution, this system could offer a more sustainable and practical alternative.

The most relevant outcomes obtained from the study and their direct correlation with CO_2 emission reduction within the maritime transportation sector and benefits for the marine environment are properly discussed.

2 Regulatory framework

To achieve zero emissions from ships promptly and protect the environment, IMO has adopted a strategy based on setting milestone GHG emissions reduction targets for the industry and aiming for a 20% - 30% reduction by 2030 to reach a remarkable reduction of 70% - 80% by 2040.

In this framework, ensuring the swift adoption of new technologies and alternative zero and near-zero GHG fuels to mitigate vessel emissions relies on two main strategies (IMO, 2023):

1. Developing standards for phased GHG emissions reduction: this involves establishing regulations to systematically decrease shipping GHG emissions over time:

   The introduction of the Carbon Intensity Indicator (CII) by the IMO is part of these new regulations. The CII is an indicator that measures the carbon intensity of a ship's operations, offering valuable insights into its environmental performance. It calculates CO_2 emissions per unit of transport work, facilitating the comparison of emission efficiency between different routes, ship types and operating methods. By implementing the CII, regulators, shipping companies and stakeholders can effectively monitor and regulate carbon emissions in the maritime industry. However, this index would require some modifications, as highlighted by the study (Braidotti et al., 2023), due to inconsistencies between emissions and CII values, leading vessels to take routes with a higher environmental footprint. Furthermore, the gradual reduction of greenhouse gas emissions from shipping involves setting carbon intensity reduction targets over time. These targets aim to progressively decrease emission intensity by encouraging the adoption of cleaner fuels, energy efficient technologies and operational practices in the maritime sector.
2. Implementing maritime GHG emissions pricing mechanisms: introducing emissions taxes can incentivize immediate adoption of emission-reducing solutions for vessels.

A similar pricing mechanism has already been introduced by the European Union, incorporating shipping companies into the EU ETS. Shipping companies are required to by allowances on ETS for the 100% of emissions generated on voyages and port stays within the EU/European Economic Area (EEA), and 50% of emissions from voyages into or out of the EU/EEA. To ensure a gradual approach in 2025, they will pay 40% of reported emissions in 2024; in 2026, they will pay 70% of 2025 emissions; and from 2027, they will pay 100% of reported emissions. Such a pricing mechanism compels shipowners to minimize this additional cost while simultaneously fostering sustainable development to maintain their competitive edge in the market.

The challenge within this context lies in finding the best solution to meet current regulations while also complying with stricter limits in the future.

Therefore, it is important to gain a deep understanding of the technological roadmap. Currently, several initiatives are aligned with the International Maritime Organization's objectives, such as the Norway-IMO Green Voyage 2050 Project, the EU-IMO GMN Project, the Republic of Korea-IMO GHG SMART Project, and

the Singapore-IMO NEXT GEN Project (IMO, 2022), which aim to transform the shipping industry towards a low GHG emission future.

Shipping will undoubtedly need new technologies, new fuels, and innovation to meet the GHG targets (Bertagna et al., 2023). A promising technology under research involves the adoption of CCS onboard ships. These innovative systems have the potential to achieve substantial reductions in CO_2 emissions produced by vessels. Key advantages include the possibility of reusing captured CO_2, addressing compliance standards effectively, and achieving significant emissions reductions that may not be feasible with other existing technologies or fuels across the entire global fleet. This technology could be applied to both new and existing vessels and in particular the retrofitting of older units could improve their long-term economic viability by substantially reducing emissions.

So, as detailed above, IMO's regulatory framework aims to reduce shipping GHG emissions by setting targets for 2030 and 2040, through strategies like phased emission reductions and emissions pricing mechanisms. These efforts are supported by initiatives and technologies such as CCS and the CII to promote cleaner fuels, energy efficiency, and sustainable shipping practices.

3 Impact of carbon capture systems on the marine environment

3.1 Technology description

Currently, existing technologies are not yet able to fully address CO_2 emissions, despite significant progress in assessing the feasibility of implementing CCS onboard ships. These systems are designed to capture a significant percentage of CO_2 emitted from fuel combustion thereby mitigating emissions into the atmosphere.

However, current research literature highlights technologies that require the CO_2 liquefaction, onboard storage, and its disposal in ports, posing various challenges as outlined below (Visonà et al., 2024; Sridhar et al., 2024; Hua et al., 2023). In this context, the authors explore an alternative CCS tailored for onboard application, distinct from commonly encountered systems. This system, which eliminates the need for liquefaction and onboard storage, not only overcomes existing challenges but also offers additional advantages.

In fact, this approach signifies a concrete commitment to reducing emissions but also underscores the increasing awareness and urgency surrounding the imperative challenge of achieving decarbonization by 2050.

The amount of reduction achievable with CCS depends on their efficiency, expressed in %, as outlined in Equation 1 (Taipabu et al., 2023).

$$CCS_{efficiency} = \frac{CO_{2,\,in} - CO_{2,out}}{CO_{2,\,in}} \quad (1)$$

where CO_2, in represents the total quantity of CO_2 entering the system in a gaseous state, and CO_2, out denotes the amount exiting the system after treatment, also in a gaseous state.

Based on the preliminary studies conducted by the authors (Bortuzzo et al., 2023), achieving a CCS efficiency of 25% appears feasible through retrofitting without compromising onboard space. While higher percentage of CO_2 reductions could be achievable, especially through retrofit approaches involving reallocating space for larger CCS at the expense of other functions like cargo storage, opting for a 25% reduction aims to sidestep the necessity of compromising onboard space and to streamline the retrofit procedure.

Various CCS proposals are currently under research, including those examined by the authors (Bortuzzo et al., 2023), defined as post-combustion systems. These systems intervene after the engine combustion process, focusing on exhaust gas treatment to reduce CO_2 emissions. The technologies explored include:

a. Carbon capture systems with molten carbonate fuel cells (MCFC);
b. Carbon capture systems with amines;
c. Carbon capture systems with calcium hydroxide.

Following the investigation conducted on the operation of the aforementioned CCS, it has been observed that the output post-CO_2 treatment in the MCFC and Amine systems poses challenges concerning onboard liquefaction of CO_2 and subsequent discharge in ports. These challenges give rise to concerns regarding environmental impact and the development of suitable disposal methods.

The imperative need for an adequate storage facility in ports, capable of maintaining CO_2 in liquid form, necessitates pressurization and freezing systems. Additionally, a robust infrastructure for the secure and reliable transportation of CO_2 is indispensable. Therefore, a well-organized network of pipelines should be instituted to facilitate the conveyance of stored CO_2 from ports to industries or for confinement within geological sites. For shorter distances and smaller quantities, alternative means such as truck or train transport can also be considered (Chen and Morosuk, 2021). It is noteworthy that the transportation of CO_2 requires special attention due to the high pressures and extremely low temperatures involved (International Energy Agency, 2020). The selection of transportation mode is influenced by economic considerations and regulatory frameworks, significantly affecting the decision-making process.

CO_2 could find different applications across various products and services, including direct utilization without chemical alteration and its conversion into valuable products. Presently, approximately 230 million tons of CO_2 are utilized globally each year (International Energy Agency, 2020), predominantly in the fertilizer and oil and gas industries. Emerging technologies present opportunities to exploit CO_2 in sectors such as fuels, chemicals, and construction materials. However, the full realization of these possibilities depends on political support and the reduction of energy costs.

An additional alternative involves the storage of CO_2 by injecting it into a deep underground geological reservoir comprising porous rocks covered by an impermeable layer, sealing the reservoir to prevent CO_2 migration upward and

dispersion into the atmosphere. Various types of reservoirs are suitable, including deep saline formations and depleted oil and gas reservoirs with greater capacity. When CO_2 is injected into a reservoir, it spreads through it, occupying porous spaces. Typically, the gas is pre-compressed to increase density and convert it into a liquid state. The reservoir must be at a depth exceeding 800 meters to maintain CO_2 in a dense liquid state (Chen and Morosuk, 2021).

The overall technical capacity for underground CO_2 storage worldwide is uncertain, especially for saline formations where further site characterization and exploration are needed but potentially vast. The total global storage capacity has been estimated between 8,000 and 55,000 gigatons (Gt) (International Energy Agency, 2020). Moreover, the existing offshore potential is substantial, particularly within 300 km from the coast and depths less than 300 meters, with an estimated capacity spanning from 2,000 to 13,000 Gt.

However, it becomes evident that transferring CO_2 to the storage site requires additional energy, leading to increased pollutant emissions associated with this operation, alongside the environmental concerns already highlighted. Moreover, the investments required to develop CO_2 confinement infrastructures demand significant resources, including those allocated for economic studies conducted by governments and stakeholders in the maritime and other relevant sectors.

Due to the problems highlighted above, the CCSs based on molten carbonate fuel cells and amine present a difficult implementation on-board ship and may not give origin to effective carbon capture in terms of reduced pollutant emissions.

On the other hand, the third CCS under consideration, involving Calcium Hydroxide, has the advantage of not encountering the challenge of CO_2 liquefaction and thus avoids the aforementioned consequences. This system presents potential environmental benefits, which will be examined by the authors in the subsequent section.

The operational principle of a CCS utilizing the Calcium Hydroxide is represented in Figure 3.

Specifically, the engine exhaust gas treatment unit is where exhaust gases are directed into an SO_X scrubber. These gases then undergo a process where 25% are diverted to the CCS unit while the remainder is released into the funnel and into the atmosphere. Once the gases reach the CCS unit, they undergo a process outlined in the following steps (Bortuzzo et al., 2023):

1. initially, a quantity of calcium oxide (CaO), also known as quicklime, which is found in a solid state as a very fine powder, is extracted from a dedicated tank and reacted with H_2O to form calcium hydroxide ($Ca(OH)_2$):

$$\boldsymbol{CaO + H_2O \rightarrow Ca(OH)_2} \quad (2)$$

This reaction occurs at specific temperatures that determine the purity of the produced $Ca(OH)_2$. Studies indicate that the optimal temperature for the carbonation of $Ca(OH)_2$ is approximately 200°C (Costagliola et al., 2022), ensuring better performance in absorbing CO_2 in the subsequent reaction. The H_2O used in this process is the same as that utilized in the SO_X scrubber system.

2. Secondly, $Ca(OH)_2$ is transferred to the designated scrubber for carbonation with CO_2. Exhaust gases, including CO_2, from the onboard engines are directed into this scrubber, and together with $Ca(OH)_2$, they enable the capture of CO_2 present in the gas stream. The product of carbonation is an inert inorganic compound, a suspension of $CaCO_3$, which is a primary constituent of mollusk shells, along with water as a byproduct.

$$\boldsymbol{Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O} \quad (3)$$

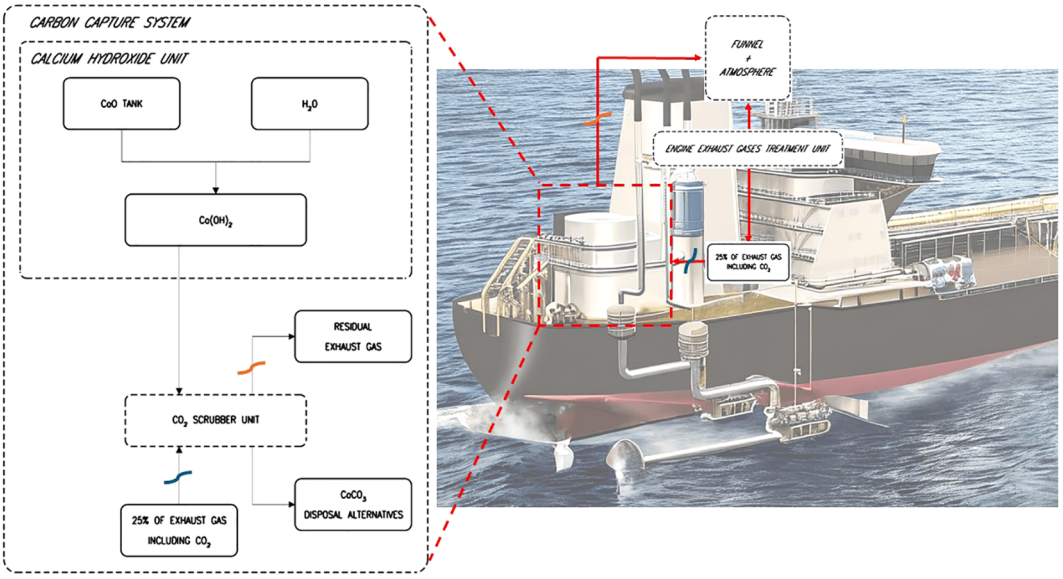


FIGURE 3
CCS utilizing calcium hydroxide integrated on board a vessel.

The choice to use slaking with $Ca(OH)_2$ in onboard carbon capture systems, rather than direct injection of stack emissions into a CaO fluidized bed, involves several technical considerations. Slaking CaO to form $Ca(OH)_2$ increases the surface area and reactivity of the sorbent, enhancing the capture efficiency of CO_2 compared to using CaO directly (Ge et al., 2022). Additionally, the slaking process occurs at lower temperatures, which can be easier to manage onboard ships. Direct injection into a CaO fluidized bed requires maintaining high temperatures (around 650°C for carbonation and 950°C for calcination), which can be challenging in the variable conditions at sea. Using $Ca(OH)_2$ also allows for more flexible operation, as the slaked lime can be stored and used as needed, whereas maintaining a fluidized bed requires continuous operation and precise control of gas flow and temperature (Valverde, 2018). However, the effectiveness of capturing CO_2 can be influenced by temperature fluctuations, kinetics of the reactions, and impurities (Morse and Mackenzie, 1990; Zeebe and Wolf-Gladrow, 2001). Impurities like SO_X and NO_X can form stable compounds with calcium-based sorbents, decreasing their availability for CO_2 capture and creating unwanted by-products (Lerman and Mackenzie, 2018). To mitigate the impact of impurities, the engine's exhaust gas treatment unit includes an SOx scrubber capable of achieving a 98% reduction in sulfur oxides, placed upstream of the CO_2 scrubber (Bortuzzo et al., 2024). As for NOx emissions, the lower combustion temperatures of a 2-stroke engine typically used onboard cargo ships minimize the risk of NOx interference with the CO_2 scrubber, which is why the supplier does not include a Selective Catalytic Reduction (SCR) unit in the design. However, for other engine types where NOx emissions could pose a challenge, incorporating an SCR unit could be considered a viable solution to reduce NOx levels. These practices ensure that the $CaCO_3$ formed is not impure and can potentially be discharged into the sea without causing pollution. In addition, reaction kinetics are affected by factors such as particle size, gas flow rates, and the partial pressure of CO_2. Smaller particle sizes increase the surface area for reactions, enhancing capture efficiency, but maintaining optimal conditions for these variables can be challenging onboard ships. Stable operation of fluidized bed reactors is essential because variations in gas flow rates and temperature can lead to channeling or particle agglomeration, which reduces process efficiency (Zeebe and Wolf-Gladrow, 2001).

The $CaCO_3$ obtained can be managed in two ways:

1. Storage in dedicated tanks onboard and subsequent disposal at ports;
2. Release overboard.

In the first scenario, a dedicated tank could be installed onboard for collecting $CaCO_3$, which could then be disposed at ports for potential resale, thus creating a circular economy.

Indeed, the system described relies on CaO, which is stored on board in a dedicated tank. The production of CaO is attained through a process known as calcination. This essential thermochemical process consists in:

a. Raw material procurement: $CaCO_3$ is extracted from quarries or limestone mines and ground into small particles;
b. Heating: subjecting $CaCO_3$ to high temperatures, typically exceeding 900°C. $CaCO_3$ thermally decomposes into CaO and CO_2, according to the following chemical reaction:

$$\boldsymbol{CaCO_3 \rightarrow CaO + CO_2} \quad (4)$$

Several studies are currently addressing how to avoid CO_2 emissions from these land-based facilities and exploring potential mitigation strategies, which could serve as a pivotal benchmark for advancing carbon neutrality within the industry (Greco-Coppi et al., 2023; Wu et al., 2023). This is essential prerequisite to assure an effective application of CSS onboard, avoiding just relocation of shipborne emissions on land.

c. Cooling and Collection: Once the decomposition is complete, the material is cooled, and the final product, CaO, is collected for use in various applications.

Therefore, in this context, the initial step regarding raw material procurement could potentially change, considering the possibility of establishing circularity of the $CaCO_3$ produced onboard the vessel through CCS with the producers of CaO, rather than sourcing it from quarries or limestone mines.

In the second scenario, releasing $CaCO_3$ directly overboard, into the sea water, could potentially mitigate the increase in water acidity. In recent years, studies conducted on marine ecosystems have highlighted the repercussions of increased CO_2 on the marine environment, leading to a phenomenon known as acidification (Hönisch et al., 2012). This process is caused by the absorption of atmospheric CO_2 into seawater, where it reacts to form carbonic acid, thereby reducing the water's pH. Marine acidification poses a serious threat to marine ecosystems, jeopardizing the survival of organisms such as corals and numerous fish species, as it can impede the formation of $CaCO_3$ shells and other skeletal structures.

In this framework, the direct discharge of $CaCO_3$ suspension, into water not only addresses pollution emission problems but also offers potential benefits, as it could help counteract the effects of ocean acidification, thus supporting marine ecosystems (Zhang et al., 2023). Some marine organisms can benefit from this process, as $CaCO_3$ is utilized by many species to form and strengthen their shells or skeletons. This shell-building process involves the conversion of calcium carbonate into a solid structure through biological reactions (Rau, 2011). According to (Dupont and Pörtner, 2013), ocean acidification has already started and has the potential to significantly impact marine ecosystems. However, it is also essential to investigate how entire ecosystems will respond to acidification over long timescales.

(Rau and Caldeira, 1999) suggested a comparable approach where dissolving $CaCO_3$ in seawater mixed with CO_2 from industrial flue gases could increase ocean alkalinity. However, a significant drawback of this approach is the large volume of seawater needed, with thousands of tons required for each ton of CO_2 captured (Renforth and Henderson, 2017). Additionally, there is a need for careful management of ocean alkalinity enhancement

processes to maximize CO_2 removal while minimizing unintended environmental impacts. For instance, as highlighted by (Moras et al., 2024), smaller grain sizes of $Mg(OH)_2$ dissolve more quickly but also promote faster $CaCO_3$ precipitation, which can reduce CO_2 capture efficiency by causing CO_2 outgassing.

Overall, implementing a CCS onboard a ship using calcium hydroxide involves the release of several tons of calcium carbonate in the form of suspension into the ocean. $CaCO_3$ as a suspension form, poses no identified hazards. According to the IBC Code for bulk transport, it is classified as OS, and as Group C under the IMSBC Code for solid bulk transport. Since it is not listed among the prohibited wastes in Annex I and II of the London Convention, the disposal of a suspension of $CaCO_3$ in the sea could be considered analogous to geological CO_2 storage, resulting in an inert, non-toxic inorganic substance either suspended or deposited on the seabed. This could potentially be allowed based on the assessment outlined in Annex III of the same convention (RINA, 2023).

Once dispersed in the sea, $CaCO_3$ suspension dissolves, helping to reduce water acidity (Harvey, 2008). The dissolution reaction is:

$$CaCO_3 \rightarrow Ca^{2+} + CO_3^{2-} \tag{5}$$

Currently, there are already practices of releasing $CaCO_3$, for example, in various locations in the deep ocean, like in the northern Atlantic and near the Southern Ocean, where deep waters are rich in anthropogenic CO_2 (Sulpis et al., 2021). Furthermore, $CaCO_3$ dissolves more efficiently in water under higher pressure and lower temperature conditions and these factors vary considerably with the season and location in the surface layers (Caserini et al., 2021b).

Therefore, excluding some special restrictions that might be enforced in port or coastal areas, it can be reasonably expected that releasing $CaCO_3$ into sea during navigation will be permitted or even incentivized by international bodies.

In summary, while innovative CCS solutions for onboard vessel applications are still under research, the use of calcium hydroxide for CO_2 capture shows promise. This system avoids challenges like CO_2 liquefaction and offers environmental benefits, including potential contributions to mitigating ocean acidification, while also addressing logistical and operational concerns for maritime emissions reduction.

3.2 Methodology for technology application onboard vessels

Given the absolute novelty of CCS with Calcium Hydroxide to be installed onboard a ship, its effective implementation is jeopardized by the lack of technical data coming from an actual case study. For such reason, the authors aim to provide a sound methodology that can allow sizing the system based on the chemical reactions, in order also to provide some reference data potentially useful for further technology developments.

The analyzed CCS is governed by the reaction Equations 2 and 3. To determine the quantities of CaO required for onboard storage on the vessel and thereby reduce CO_2 emissions, a stoichiometric approach is utilized.

Equation 3 presents the stoichiometric ratio of the reactants as 1:1, indicating that the reactants act in equivalent molar quantities. By determining the amount of CO_2 to be captured by the CCS, the number of moles of CO_2 (n_{CO2}) can be calculated using the following equation:

$$n_{CO2} = \frac{m_{CO_2}}{PM_{CO_2}} \tag{6}$$

where m_{CO_2} is the amount of CO_2 (g/s), and PM_{CO_2} is the molecular weight of CO_2 (g/mol).

Subsequently, the number of moles of calcium carbonate (n_{CaCO3}) and calcium hydroxide ($n_{Ca(OH)_2}$) are calculated based on 1:1 stoichiometric ratio. The amount of calcium hydroxide ($m_{Ca(OH)2}$) and calcium carbonate (m_{CaCO3}) are calculated:

$$m_{Ca(OH)_2} = n_{Ca(OH)_2} \times PM_{Ca(OH)_2} \tag{7}$$

$$m_{CaCO_3} = n_{CaCO_3} \times PM_{CaCO_3} \tag{8}$$

Following the same procedure, the amount of CaO (m_{CaO}) and H_2O (m_{H2O}) is determined starting from Equation 2. Since the reaction between CaO and H_2O has a 1:1 stoichiometric ratio, the same number of moles calculated for CaO can be used to determine the amount of H_2O used.

$$\frac{n_{Ca(OH)_2}}{n_{CaO}} = \frac{1}{1} \tag{9}$$

$$n_{CaO} = n_{Ca(OH)_2} \times \frac{1}{1} \tag{10}$$

$$m_{CaO} = n_{CaO} \times PM_{CaO} \tag{11}$$

$$m_{H_2O} = n_{CaO} \times PM_{H_2O} \tag{12}$$

The values of the molecular weights (PM) for each reagent type are reported in Table 1.

3.3 Procedure for the feasibility assessment for onboard installation

Based on previous considerations, the process developed by the authors to perform the sizing of a Calcium Hydroxide based CCS for an existing vessel is outlined in the following.

TABLE 1 Molecular weights (PM) of reagents.

$PMCO_2$	$PMCaCO_3$	$PMCa(OH)_2$	PMCaO	PMH_2O
g/mol	g/mol	g/mol	g/mol	g/mol
44.01	100.0869	74.096	56.0774	18.016

Firstly, it is imperative to consider the main characteristics of the vessel upon which the system is to be sized in order to identify available space and physical constraints for the installation of CCS. These characteristics include Deadweight tonnage (DWT), Length overall, Breadth, Depth, Draft, Main Engine and Auxiliary Engine specifications.

Secondly, the routes undertaken by the vessel have to be examined and the one necessitating the longest duration of navigation under loaded conditions should be selected. This ensures that the CCS is appropriately sized to effectively manage the most demanding voyage in terms of operation time of the CCS, thus assuring continuous capture of CO_2 emitted by the vessels during its operations.

Based on the chosen route and real data extrapolated from the vessel under consideration, the total voyage distance in nm, the vessel average speed in kts and the total days of navigation (days), must be collected. following parameters must be collected.

With the aim of estimating the quantities of the elements required for the CCS with Calcium Hydroxide to react with CO_2 and prevent its release into the atmosphere, the starting point is to understand the amount of CO_2 that needs to be treated.

To accurately determine the system's size, it's crucial to calculate the CO_2 emissions for the chosen voyage.

Based on total days of navigation and the vessel engine specifications at the selected average speed the daily fuel consumption (Cg), in tons/day, must be calculated as the sum of main engine fuel consumption (Cg_{ME}) and auxiliary engines fuel consumption (Cg_{AE}).

$$C_g = C_{gMP} + C_{gAE} \tag{13}$$

$$C_{gME} = SFOC_{ME} \times P_{D_{ME}} \times 24 \times 10^{-6} \tag{14}$$

$$C_{gAE} = SFOC_{AE} \times P_{D_{AE}} \times 24 \times 10^{-6} \tag{15}$$

where SFOC is the Specific Fuel Oil Consumption in g/kWh and P_D is the delivered power in kW, for both Main Engine (ME) and Auxiliary Engines (AE), respectively.

From Cg, the Total Fuel Consumption for the selected voyage (Cg_{TOT}) can be derived and the total CO_2 produced during the selected voyage ($CO_{2Voyage}$) is calculated:

$$CO_{2\,Voyage} = C_{g_{TOT}} \times C_F \tag{16}$$

where C_F is the Carbon Factor of the fuel in tonsCO_2/tonsFuel.

From the $CO_{2Voyage}$ the CO_2 flow rate production (CO_2Flow), in g/s, can be calculated, along with the CO_2 flow rate captured by CCS system, in g/s (CCS_{CO_2Flow}).

$$CO_{2Flow} = \frac{CO_{2\,Voyage}}{days \times 24 \times 3600} \times 10^6 \tag{17}$$

$$CCS_{CO_{2Flow}} = CO_{2Flow} \times \frac{CCS_{efficiency}}{100} \tag{18}$$

The methodology described in Section 3.2 is applied to calculate, as a flow rate (g/s), the quantities of products necessary to achieve the desired % reduction in CO_2 emissions compared to the capture plant's efficiency assessing the information as $Ca(OH)_{2\,Flow}$, $CaCO_{3\,Flow}$, CaO_{Flow}, H_2O_{Flow}.

These results can be correlated with the number of navigation days of the ship along the selected route to obtain the quantities of products, in tons, required for the selected voyage.

$$C_aO_{TOT} = C_aO_{Flow} \times days \times 24 \times 3600 \times 10^{-6} \tag{19}$$

$$H_2O_{TOT} = H_2O_{Flow} \times days \times 24 \times 3600 \times 10^{-6} \tag{20}$$

$$C_aCO_{3_{TOT}} = C_aCO_{3_{Flow}} \times days \times 24 \times 3600 \times 10^{-6} \tag{21}$$

Given the quantities of CaO essential for CO_2 capture during navigation, the volumes of reactants required on board the ship can be calculated. The estimation of the volume containing the necessary amounts of reactants can be accomplished using the Equation 22:

$$V = \frac{\rho}{m} \tag{22}$$

Where ρ represents the density for each reagent, defined as:

$$\rho_{CaO} = 3.34 \ \ tons/m^3 \tag{23}$$

$$\rho_{H2O} = 1.00 \ \ tons/m^3 \tag{24}$$

$$\rho_{CaCO_3} = 2.71 tons/m^3 \tag{25}$$

Total volume of CaO, H_2O and $CaCO_3$, that need to be stored onboard can be calculated.

Having established all the requisite quantities and volumes of substances essential for the operation of the CCS on board, the assessment of system installation can be conducted.

To underline the major advantages of the developed methodology, it outlines a stoichiometric approach for sizing a Calcium Hydroxide-based CCS for ships, determining the necessary quantities of reactants and assessing the feasibility of onboard installation based on vessel characteristics, voyage data, and emission calculations.

4 Test case

To thoroughly validate the presented methodology, the feasibility assessment of implementing a CCS utilizing Calcium Hydroxide on board a case study ship, consisting of an Oil Tanker Vessel depicted in Figure 4, has been conducted.

The primary characteristics of the vessel are outlined in Table 2.

The data of vessels' voyages have been meticulously recording since 2020. This comprehensive dataset includes detailed information on performance and consumption. As a result, the compiled fuel consumption data correlated with vessel speed is available as reported and Table 3.

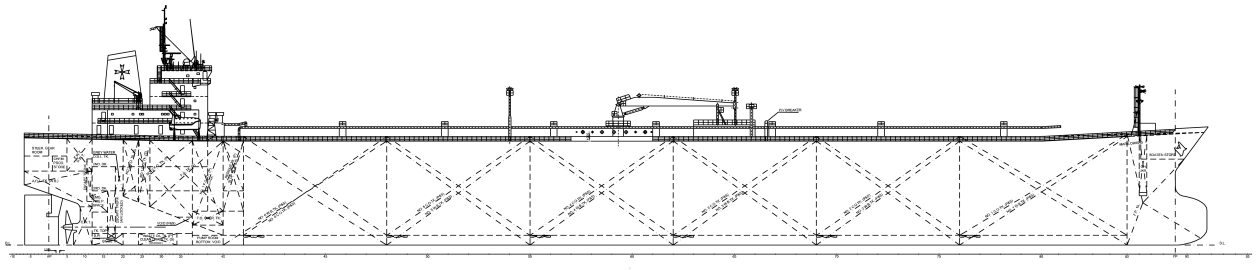


FIGURE 4
Case-study vessel.

5 Results and discussion

5.1 Results

Analyzing the available records, the most demanding voyage is the route from Ruwais (Abu Dhabi, UAE) and reaching the terminal in Rio de Janeiro (Brazil) (Figure 5). Hence, this route has been selected to size the CSS.

Based on real data extrapolated from the ship's case study, Table 4 presents the voyage characteristics.

A mentioned, initial research suggests that CCS could achieve a carbon capture efficiency (%) leading to a 25% reduction in CO_2 emissions (Bortuzzo et al., 2023). This value has been assumed to further proceed.

The calculation of the CO_2 produced in the selected voyage is conducted as reported in Table 5.

The quantities of reagents, necessary to achieve a 25% reduction in carbon dioxide emissions compared to the capture plant's efficiency are calculated and reported in Table 6.

These results are correlated with the number of navigation days of the vessel along the selected route as reported in Table 7.

The volume containing the necessary amounts of reactants are calculated considering an allowance of approximately 2% and reported in Table 8.

Having all the requisite quantities and volumes of substances to operate the CCS on board, the authors proceeded to conduct an assessment of its installation.

TABLE 2 Main characteristics of oil tanker vessel.

Characteristic	Value	Measure
DWT	110300	t
Lenght over all	245.5	m
Breadth	42	m
Depth	21.5	m
Draft	14.98	m
Main Engine Power	14	MW
$SFOC_{ME}$	171.3	g/kWh
Auxiliary Engine Power	3 x 770	kW
$SFOC_{AE}$	196	g/kWh

Two lime (CaO) tanks were positioned on the main deck in a location where they do not potentially interfere with loading and unloading operations. However, the presence of a centrally located crane restricts the placement of the lime tanks further forward due to the maneuvering space required by the crane arm. The decision to install only two tanks onboard was made to expedite lime loading operations that could occur in port. Additionally, the choice was made not to incorporate tanks inside the ship from the early design stages, as this would have necessitated numerous modifications to the ship's compartments, making the refitting complex and economically unsustainable.

Each tank's characteristics are detailed as follows and depicted in Figure 6A: length equals to 15.9 m, width equals to 6 m, height equals to 3.5 and total capacity of 520 tons.

The total volume of CaO required to operate the system in order to capture 25% of CO_2 produced during the selected voyage, which is the most demanding undertaken by the vessel, is quantified at 318 m^3. This indicates that with this quantity, the ship will be able to undertake almost all other voyages, whose voyage length is less than one considered.

The height of 3.5 meters includes the support structure of the tanks and allows for sufficient space to enable a sloped configuration at the bottom of the tank, optimizing lime flow downwards through gravitational effects. Given the considerable length of the tanks, it is advisable to install a longitudinal bulkhead to limit load oscillations during rolling. Since CaO is a hygroscopic substance, the tanks housing must be equipped with insulation and a ventilation system to ensure a dry and well-ventilated internal environment.

The transfer of lime from the tanks to the CCS is managed through a system of volumetric pumps, with lime flow pipelines that can be positioned along the main deck.

The connection between the exhaust gas collector and the CCS is made through a duct originating from the ship's funnel. To facilitate the transfer of exhaust gases from the duct inside the funnel to the one of CCS, an exhaust gas fan is installed, positioned downstream of the SO_X scrubber. This arrangement ensures that the exhaust gas that flows into the carbon capture unit is free of sulfur and nitrogen oxides.

Within the necessary refitting operation to install the CCS, it enables the accommodation of all required machinery without substantial alteration to existing spaces on board the ship. The structure of the system extends approximately three superstructure decks in height and is supported by beams positioned on the main deck (Figure 6).

TABLE 3 Vessel fuel consumption.

SPEED	LADEN				BALLAST			
	VLSFO		LSMGO		VLSFO		LSMGO	
	ME	AE	ME	AE	ME	AE	ME	AE
kts	tons/day	tons/day	tons/day	tons/day	tons/day	tons/day	tons/day	tons/day
10	NA	NA	NA	NA	17	2.5	17	2.5
10.5	NA	NA	NA	NA	18	2.5	18	2.5
11	27	2.5	27	2.5	19	2.5	19	2.5
11.5	29	2.5	29	2.5	21	2.5	21	2.5
12	32	2.5	32	2.5	24	2.5	24	2.5
12.5	34	2.5	34	2.5	26	2.5	26	2.5
13	37	2.5	37	2.5	29	2.5	29	2.5
13.5	39	2.5	39	2.5	32	2.5	32	2.5
14	43	2.5	43	2.5	36	2.5	36	2.5
14.5	47	2.5	47	2.5	39	2.5	39	2.5
15	52	2.5	52	2.5	41	2.5	41	2.5
15.5	NA	NA	NA	NA	45	2.5	45	2.5

NA, Not Available.

Additionally, the installation and operation of the CCS must consider the harsh marine environment, where factors such as humidity and salt exposure can accelerate corrosion and material degradation, affecting the system's durability. To ensure long-term performance and reliable operation, insights from marine scrubber systems emphasize the importance of using durable, corrosion-resistant materials that can withstand high operational temperatures and energy demands. Regular maintenance is essential to maintain efficiency and address impurity buildup over time.

The main results are summed up as a 25% reduction in CO_2 emissions achievable for the selected demanding voyage between Ruwais (UAE) and Rio de Janeiro (Brazil). The necessary reagents, system components, and tank design have been optimized for this reduction, ensuring system feasibility without substantial modifications to the ship. The installation plan takes into account



FIGURE 5
Route from Ruwais (Abu Dhabi, UAE) to Rio de Janeiro (Brazil).

TABLE 4 Case-study voyage characteristics.

Total voyage distance	Vessel average speed	Total days of navigation
nm	kts	days
8200	13	26

operational constraints, including space limitations and environmental conditions, while maintaining durability and efficiency in a marine setting.

5.2 Discussion

The feasibility study on the implementation of a CCS using Calcium Hydroxide onboard the real case-ship has demonstrated that its components and the subsequent impact of their installation do not require complex procedures. Therefore, it is feasible to implement such systems even on older vessels, which may emit more pollutants compared to new buildings, without necessitating extensive modifications. Particularly noteworthy is the fact that there is no need to sacrifice space intended for cargo or other purposes, making retrofitting achievable within a short timeframe without significant structural alterations.

Regarding the stability of the vessel with the implementation of CCS onboard, future assessments will be essential, especially if the realistic implementation of this system on ships is considered. However, preliminary stability studies on vessels with different CCS implementations indicate that stability remains within acceptable limits with the original design (MMMCZCS, 2022). For the specific CCS under consideration, the additional installation of CaO tanks must be evaluated not only for its impact on overall stability but also from a structural perspective. It is important to assess the integration of the hull's longitudinal strength and verify the support elements for the CaO tanks to prevent adverse effects on the vessel's stability and safety. The CaO tanks should also undergo certification to ensure compliance with safety and security guidelines, given the material's potential to cause hazardous reactions.

As evidenced by the case study, the system would be capable of reducing CO_2 emissions from a ship's voyage by approximately 25%. Given that the system has been sized for the most demanding voyage, it highlights the potential for emissions reduction across all voyages undertaken by the vessel. This undoubtedly offers significant and immediate benefits in addressing the global emissions challenge faced by the maritime sector.

In this study, no storage tank for the product discharged from the CCS, namely $CaCO_3$, was designed onboard. This decision not only saved additional space onboard but also adopted a more environmentally sustainable approach by directly discharging the $CaCO_3$ product overboard, mitigating ocean acidification.

Taking into account the potential adoption of this system throughout the global merchant fleet, which, as per the study conducted at the close of March 2022 (https://www.atlas-mag.net/en/category/tags/focus/the-world-merchant-fleet), encompasses approximately 57,000 merchant ships navigating voyages worldwide, the profound implications of this innovation cannot be overlooked. Even if only a portion of these vessels were to integrate this technology, the resultant production of $CaCO_3$ could yield a dual benefit: mitigating CO_2 emissions and promoting the health of our oceans and marine life.

However, this does not preclude the possibility of considering future onboard $CaCO_3$ storage tanks, whether it involves all the produced $CaCO_3$ or just a portion that is not discharged overboard. This substance could be disposed of in ports, to initiate a circular economy. This approach would necessitate the development of a green transport network for product distribution from the port to the utilization industry. This consideration applies even if other CCS, which require the discharge of liquefied CO_2 into ports, were to be implemented.

Being the $CaCO_3$ the substance from which CaO is produced, and the $CaCO_3$ discharged by ships could potentially be utilized instead of sourcing it from quarries or limestone mines. Moreover, since the process of producing CaO generates CO_2 emissions itself, this might be performed in an industry where CCS is already implemented. Given the widespread availability of CCS in land industries, which are already operational, highly efficient, and industrially established, this approach is promising.

Such integration could pave the way for a circular economy, as illustrated in Figure 7.

Another issue that could be addressed by implementing CCS onboard ships is certainly emissions of SO_X and CO_2 in ports. While the broader issue in ports includes more than just CO_2 emissions, reducing these emissions could effectively mitigate the problem of large quantities of pollutants released especially in urban areas. Vessels that cannot use cold ironing could rely on CCS to achieve this goal.

Once further developments of the system are made, it will also be necessary to assess the additional amount of fuel required to operate the system as well as the associated operational expenses, including maintenance and materials such as CaO. However, in the absence of a CO_2 liquefaction unit and the additional energy required for its operation, the extra energy demand typically

TABLE 5 Calculation to determine the 25% reduction of CO_2 emissions produced during the selected voyage.

Total VLSFO Consumption per day	Total VLSFO Consumption per selected voyage	Total CO_2 produced in the selected voyage	CO_2 flow rate production rate	CO_2 flow rate captured by CCS system
tons/day	tons	tons	g/s	g/s
1038	1038	3271	1441	360

TABLE 6 Flow rate of products necessary to achieve 25% of CO_2 emissions reduction.

$Ca(OH)_2$	$CaCO_3$	CaO	H_2O
g/s	g/s	g/s	g/s
606	819	459	147

needed for this unit in other types of CCSs is avoided (Bortuzzo et al., 2023; Hua et al., 2023).

However, it is worth noting that even if these costs are significant, these will be offset by savings from EU ETS or future pricing mechanisms, as well as tangible benefits for compliance with CII, EEXI, EEDI and GHG intensity regulations. In this framework, although various technologies can increase a ship's energy efficiency and reduce CO_2 emissions, such as wind-assist systems, air lubrication technology, and energy-saving devices like waste heat recovery systems, these are unlikely to achieve the same level of reduction as CCS. Consequently, CCS is expected to result in greater savings within carbon pricing mechanisms like the EU ETS.

5.3 Road map for future works

This study introduces a new framework to tackle challenges in marine environments and climate change mitigation. Future research could focus on detailed sensitivity analyses to validate assumptions about CCS efficiency and energy demands. These analyses would clarify the most influential variables and ensure the approach's robustness under different conditions.

Building upon the insights gained from sensitivity analyses, further technical investigations could focus on enhancing the operational efficiency of the calcium looping process. This would involve addressing challenges such as optimizing CO_2 capture under diverse operating conditions and minimizing associated risks. Pilot studies in real-world marine environments would also be invaluable for assessing the feasibility of the technology at scale and identifying practical barriers to implementation. Moreover, the implications related to the need to introduce new training activities for on-board personnel to operate with the novel technology must be foreseen.

TABLE 7 Quantities of products required for the selected voyage.

Cao required per voyage	H_2O required per voyage	$CaCO_3$ required per voyage
tons	tons	tons
1042	331	1859

TABLE 8 Total volume of products that need to be stored onboard.

Total volume CaO	Total volume H_2O	Total volume $CaCO_3$
m^3	m^3	m^3
318	338	700

Economic considerations represent another critical aspect for future exploration. By leveraging findings from sensitivity and technical analyses, a high-level economic evaluation could be conducted by analyzing costs related to equipment, maintenance, and energy use that are still not available due to the lack of full-scale systems installed onboard ships. This evaluation should aim to identify cost-reduction strategies and the potential financial benefits of the proposed approach. This evaluation would include projected savings from emissions credits and could inform decision-making for both policymakers and industry stakeholders.

Another essential area for future research lies in the ecological assessment of $CaCO_3$ discharge and its potential impacts on marine ecosystems. Detailed studies should examine changes to biodiversity and water chemistry across various environments, complemented by predictive ecological modelling to forecast long-term consequences. These efforts should be coupled with the development of robust regulatory and monitoring frameworks capable of tracking direct and indirect impacts over time. Incorporating feedback mechanisms into such frameworks would help mitigate any unintended adverse effects, ensuring the sustainability of the intervention. Compared to other CCSs, this system eliminates the need for CO_2 liquefaction, simplifying onboard operations and enhancing its life cycle assessment. By avoiding the complexities of discharging liquefied CO_2 offshore, developing specialized port infrastructure, and transporting CO_2 to underground storage sites, it offers a more streamlined and sustainable solution. However, for the system under study future research could explore innovative ship designs that integrate onboard $CaCO_3$ storage tanks, enabling closed-loop solutions for future deployments. This approach would allow for the partial or complete containment of generated $CaCO_3$ onboard, with subsequent disposal at ports to support a circular economy. Evaluating the feasibility of repurposing collected $CaCO_3$ for industrial applications could further promote a sustainable green transport network by facilitating its distribution from ports to industries. These initiatives would address challenges related to onboard space constraints and land-based infrastructure, creating a comprehensive and sustainable strategy for $CaCO_3$ management.

Additionally, $CaCO_3$ is not listed among the prohibited wastes in Annex I and II of the London Convention, as outlined in this study. However, future research should consider new ecological insights and assess whether this approach aligns with existing regulatory frameworks or necessitates updates to international guidelines to accommodate novel strategies for climate mitigation.

Together, these avenues for further research provide a comprehensive roadmap for advancing the current study's findings. They highlight the need for an interdisciplinary approach that integrates technical, economic, ecological and legal perspectives to maximize the potential of the proposed solution while addressing its limitations.

6 Conclusions

Drawing from prior research, it has been noted that among the investigated CCS methods, the calcium hydroxide-based approach

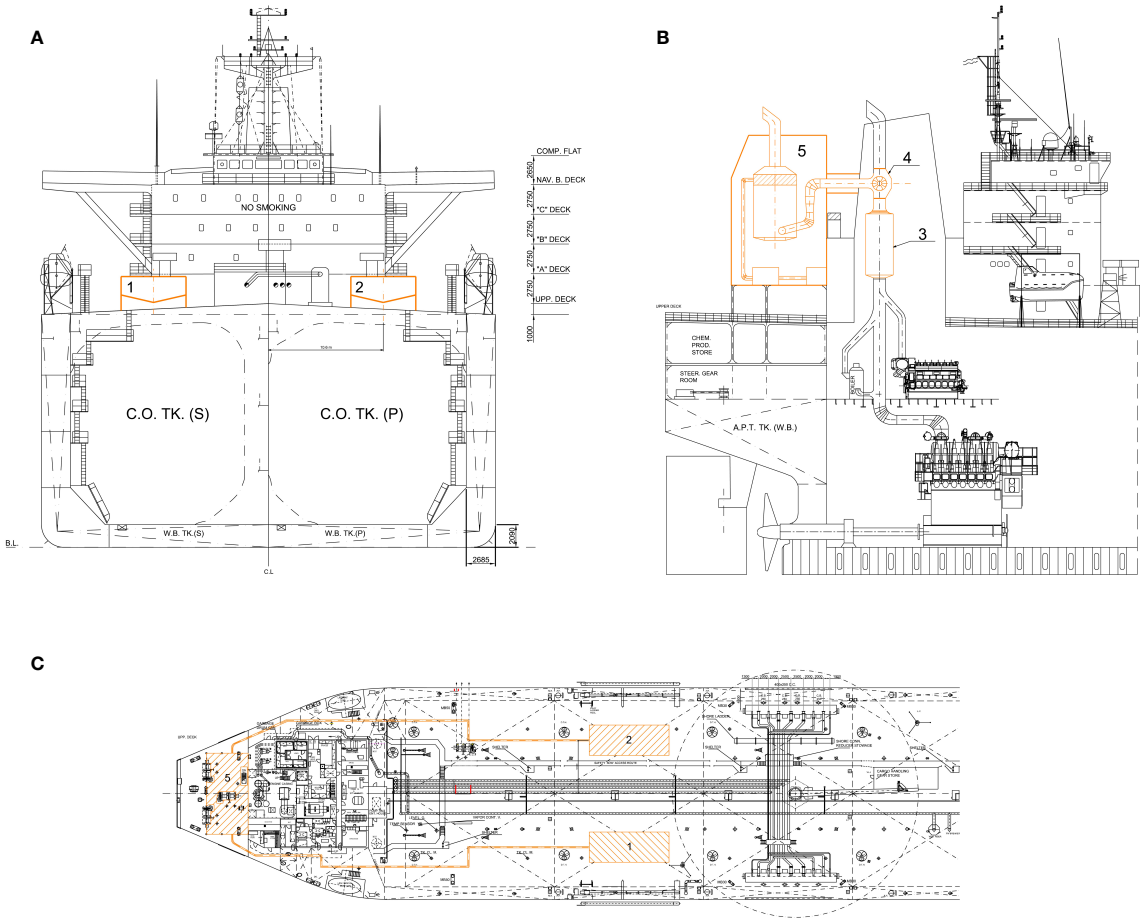


FIGURE 6
Implementation of CCS onboard case-study vessel **(A–C)**, where 1 & 2 = CaO tanks; 3 = SOx scrubber; 4 = exhaust gas vent; 5 = CCS casing.

stands out as the most effective in delivering environmental benefits. In particular, this system shows potential not only to reduce CO_2 emissions, but also to help marine ecosystems and mitigate ocean acidification. Although applications on ships have yet to be implemented, the absence of a standardized method to assess dimensional requirements highlights the significance of the methodology developed by the authors. The stoichiometric approach, which involves relatively quick calculations, facilitates a

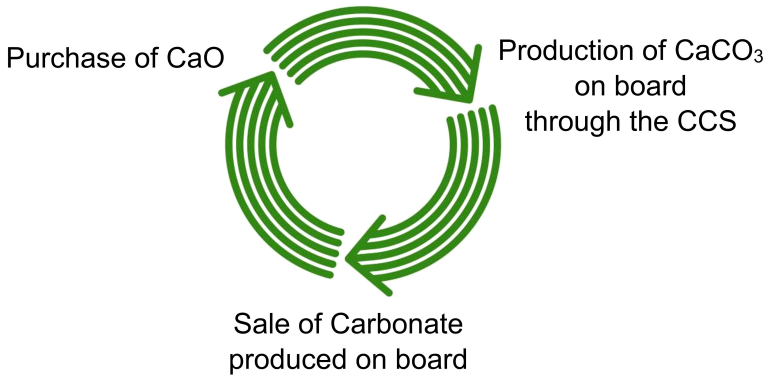


FIGURE 7
Circular economy of CaO and $CaCO_3$.

preliminary assessment of the technology's impact on the reference vessel. This methodology helps address system-level integration and operational challenges, while leaving the detailed design of the CO_2 scrubber functionality to technology suppliers.

The stoichiometric approach employed in this study has enabled the determination of the required amounts of CaO for on-board storage, allowing the estimation of potential CO_2 emission reductions. Equally significant is the calculation of the quantities of $CaCO_3$ that could be produced through this system. The authors assessed that this product is suitable for addressing a critical environmental issue related to climate change—ocean acidification—or, alternatively, for reuse in industry, thereby promoting a circular economy.

The use of such a system could also be extended to ships' port stays, addressing the port emissions issue. Currently, these emissions are managed through the cold ironing approach, but its implementation remains limited. Many ports and ships do not yet support it due to the necessary infrastructure and investments required from both ports and shipping companies. However, reducing port emissions would mark a significant stride forward for the ecosystem and human health.

Future research should focus on a more comprehensive examination of system feasibility for implementation and integration on board. This involves performing sensitivity analysis, advanced technical investigations, and economic assessments. Additionally, assessing the environmental impact of $CaCO_3$ through a life cycle assessment is necessary to provide an understanding of the system's overall benefits by considering everything from raw material extraction to final disposal, ensuring that the process meets sustainability goals. Furthermore, considering the absence of international regulations governing the discharge of $CaCO_3$ into the marine ecosystem and the need for comprehensive research and statutory approval regarding the potential efficacy of releasing varying amounts of calcium carbonate into the sea, this issue undoubtedly deserves the attention of relevant maritime regulatory bodies in the near future.

These activities can give augmented scientific soundness in the transitional period necessary to have experimental data from established applications.

The research has the potential to highlight the proposed solution and evaluate its pre-feasibility on a widely used ship type, aiming at raising attention towards CCS based on $Ca(OH)_2$ and encouraging further research in the field that could ultimately support the development of more sustainable practices within the maritime sector. In fact, despite its potential, this promising technology still faces challenges that must be addressed and it remains underexplored in terms of applications, with limited real-world implementations. By presenting these initial technical findings, the paper seeks to bridge a critical gap in the literature, stimulate broader discussion, and provide a foundation for advancing this field.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

VBo: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. SB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. LB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. VBu: Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. Research funded by the European Union through the NextGenerationEU program, National Recovery and Resilience Plan (NRRP), Missione 4, "ISTRUZIONE E RICERCA" - Componente 2, "DALLA RICERCA ALL'IMPRESA" - Linea di Investimento 1.4 - "CENTRI NAZIONALI", Sustainable Mobility Center - Centro Nazionale per la Modalità Sostenibile – MOST (CNMS PROJECT - ID Code CN_00000023 - SPOKE 3 - WATERWAYS - CUP B43C22000440001, Open Call). This manuscript reflects only the Authors' views and opinions and does not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Conflict of interest

VBo was employed by Fratelli d'Amico Armatori Spa.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Aakko-Saksa, P. T., Lehto, K., Kuittinen, N., Järvinen, A., Jalkanen, J.-P., Johnson, K., et al. (2023). Reduction in greenhouse gas and other emissions from ship engines: Current trends and future options. *Prog. Energy Combust. Sci.* 94, 101055. doi: 10.1016/j.pecs.2022.101055

Abanades, J. C., Criado, Y. A., and White, H. I. (2023). Direct capture of carbon dioxide from the atmosphere using bricks of calcium hydroxide. *Cell Rep. Phys. Sci.* 4, 101339. doi: 10.1016/j.xcrp.2023.101339

Al Baroudi, H., Awoyomi, A., Patchigolla, K., Jonnalagadda, K., and Anthony, E. J. (2021). A review of large-scale CO2 shipping and marine emissions management for carbon capture, utilization and storage. *Appl. Energy.* 287, 116510. doi: 10.1016/j.apenergy.2021.116510

Andriiovych Kuropyatnyk, O., and Victorovych Sagin, S. (2019). Exhaust gas recirculation as a major technique designed to reduce NOx Emissions from marine diesel engines. *NAŠE MORE: znanstveni časopis za more i pomorstvo* 66, 1–9. doi: 10.17818/NM/2019/1.1

Balcombe, P., Brierley, J., Lewis, C., Skatvedt, L., Speirs, J., Hawkes, A., et al. (2019). How to decarbonize international shipping: Options for fuels, technologies and policies. *Energy Convers. Manage.* 182, 72–88. doi: 10.1016/j.enconman.2018.12.080

Bertagna, S., Kouznetsov, I., Braidotti, L., Marinò, A., and Bucci, V. (2023). A rational approach to the ecological transition in the cruise market: technologies and design compromises for the fuel switch. *J. Mar. Sci. Eng.* 11, 67. doi: 10.3390/jmse11010067

Bortuzzo, V., Bertagna, S., and Bucci, V. (2023). Mitigation of CO2 emissions from commercial ships: evaluation of the technology readiness level of carbon capture systems. *Energies* 16, 3646–3646. doi: 10.3390/en16093646

Bortuzzo, V., Bertagna, S., Marino, A., and Bucci, V. (2024). Feasibility assessment for the application of carbon capture systems onboard cargo ships in response to the EU ETS regulation. *Prog. Mar. Sci. Technol.* 8, 82–93. doi: 10.3233/pmst240009

Braidotti, L., Bertagna, S., Rappoccio, R., Utzeri, S., Bucci, V., and Marinò, A. (2023). On the inconsistency and revision of Carbon Intensity Indicator for cruise ships. *Transp. Res. Part D Transp. Environ.* 118, 103662–103662. doi: 10.1016/j.trd.2023.103662

Butenschön, M., Lovato, T., Masina, S., Caserini, S., and Grosso, M. (2021). Alkalinization scenarios in the mediterranean sea for efficient removal of atmospheric CO2 and the mitigation of ocean acidification. *Front. Clim.* 3. doi: 10.3389/fclim.2021.614537

Caserini, S., Cappello, G., Righi, D., Raos, G., Campo, F., De Marco, S., et al. (2021b). Buffered accelerated weathering of limestone for storing CO2: Chemical background. *Int. J. Greenh. Gas Control.* 112, 103517. doi: 10.1016/j.ijggc.2021.103517

Caserini, S., Pagano, D., Campo, F., Abbà, A., De Marco, S., Righi, D., et al. (2021a). Potential of maritime transport for ocean liming and atmospheric CO2 removal. *Front. Clim.* 3. doi: 10.3389/fclim.2021.575900

Caserini, S., Storni, N., and Grosso, M. (2022). The availability of limestone and other raw materials for ocean alkalinity enhancement. *Glob. Biogeochem. Cycles.* 36 (5). doi: 10.1029/2021gb007246

Chen, F., and Morosuk, T. (2021). Exergetic and economic evaluation of CO2 liquefaction processes. *Energies* 14, 7174. doi: 10.3390/en14217174

Comes, J., Islamovic, E., Lizandara-Pueyo, C., and Seto, J. (2024). Improvements in the utilization of calcium carbonate in promoting sustainability and environmental health. *Front. Chem.* 12. doi: 10.3389/fchem.2024.1472284

Costagliola, M. A., Prati, M. V., and Perretta, G. (2022). Post combustion CO2 capture with calcium and lithium hydroxide. *Sci. Rep.* 12, 10518. doi: 10.1038/s41598-022-14235-5

DNV. (2023). EU ETS: Preliminary Agreement to Include Shipping In The EU's Emission Trading System from 2024. *Technical and Regulatory News No 02/2023*. Available online at: https://www.dnv.com/news/eu-ets-preliminary-agreement-to-include-shipping-in-theeu-s-emission-trading-system-from-2024-238068 (Accessed January 12, 2024).

Dupont, S., and Pörtner, H.-O. (2013). A snapshot of ocean acidification research. *Mar. Biol.* 160, 1765–1771. doi: 10.1007/s00227-013-2282-9

Durand, G., van den Broeke, M. R., Le Cozannet, G., Edwards, T. L., Holland, P. R., Jourdain, N. C., et al. (2022). Sea-level rise: from global perspectives to local services. *Front. Mar. Sci.* 8. doi: 10.3389/fmars.2021.709595

European Commission. (2023). *FAQ – Maritime transport in EU Emissions Trading System (ETS)*. Available online at: Climate.ec.europa.eu. https://climate.ec.europa.eu/euaction/transport/reducing-emissions-shipping-sector/faq-maritime-transport-euemissions-trading-system-ets_en (Accessed January 12, 2024).

Galán-Martín, Á., Vázquez, D., Cobo, S., Mac Dowell, N., Caballero, J. A., and Guillén-Gosálbez, G. (2021). Delaying carbon dioxide removal in the European Union puts climate targets at risk. *Nat. Commun.* 12, 6490. doi: 10.1038/s41467-021-26680-3

Ge, Z., Dou, B., Wang, L., Ding, Y., Chen, H., and Xuan, Y. (2022). Calcium-looping based energy conversion and storage for carbon neutrality –the way forward. *Carbon Neutral.* 1, 35. doi: 10.1007/s43979-022-00034-4

Greco-Coppi, M., Hofmann, C., Walter, D., Strohle, J., and Epple, B. (2023). Negative CO2 emissions in the lime production using an indirectly heated carbonate looping process. *Mitig. Adapt. Strateg. Glob. Change* 28, 30. doi: 10.1007/s11027-023-10064-7

Han, S.-J., Yoo, M., Kim, D.-W., and Wee, J.-H. (2011). Carbon dioxide capture using calcium hydroxide aqueous solution as the absorbent. *Energy Fuels* 25, 3825–3834. doi: 10.1021/ef200415p

Harvey, L. D. D. (2008). Mitigating the atmospheric CO2 increase and ocean acidification by adding limestone powder to upwelling regions. *J. Geophys. Res.* 113 (C4). doi: 10.1029/2007jc004373

Hönisch, B., Ridgwell, A., Schmidt, D. N., Thomas, E., Gibbs, S. J., Slujis, A., et al. (2012). The geological record of ocean acidification. *Science* 335, 1058–1063. doi: 10.1126/science.1208277

Hua, W., Sha, Y., Zhang, X., and Cao, H. (2023). Research progress of carbon capture and storage (CCS) technology based on the shipping industry. *Ocean Eng.* 281, 114929. doi: 10.1016/j.oceaneng.2023.114929

IMO (2020). Forth IMO GHG study 2020. Available online at: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf (Accessed January 22, 2024).

IMO (2022). Future fuels and technology. Available online at: https://www.imo.org/en/OurWork/Environment/Pages/Future-Fuels-And-Technology.aspx (Accessed February 14, 2024).

IMO (2023). IMO's work to cut GHG emissions from ships. Available online at: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Cutting-GHG-emissions.aspx (Accessed March 13, 2024).

International Energy Agency. (2020). Special Report on Carbon Capture Utilisation and Storage CCUS in clean energy transitions. *Energy Technology Perspectives*. Available online at: https://iea.blob.core.windows.net/assets/181b48b4-323f-454d-96fb-0bb1889d96a9/CCUS_in_clean_energy_transitions.pdf.

Jafari, F., Naeemi, A. S., Sohani, M. M., and Noorinezhad, M. (2023). Effect of elevated temperature, sea water acidification, and phenanthrene on the expression of genes involved in the shell and pearl formation of economic pearl oyster (Pinctada radiata). *Mar. pollut. Bull.* 196, 115603–115603. doi: 10.1016/j.marpolbul.2023.115603

Karatuğ, Ç., Arslanoğlu, Y., and Guedes Soares, C. (2022). Feasibility analysis of the effects of scrubber installation on ships. *J. Mar. Sci. Eng.* 10, 1838. doi: 10.3390/jmse10121838

Kurihara, H. (2008). Effects of CO2-driven ocean acidification on the early developmental stages of invertebrates. *Mar. Ecol. Prog. Ser.* 373, 275–284. doi: 10.3354/meps07802

Leeson, D., Mac Dowell, N., Shah, N., Petit, C., and Fennell, P. S. (2017). A Techno-economic analysis and systematic review of carbon capture and storage (CCS) applied to the iron and steel, cement, oil refining and pulp and paper industries, as well as other high purity sources. *Int. J. Greenh. Gas Control.* 61, 71–84. doi: 10.1016/j.ijggc.2017.03.020

Lehtoranta, K., Vesala, H., Koponen, P., and Korhonen, S. (2015). Selective catalytic reduction operation with heavy fuel oil: NOx, NH3, and particle emissions. *Environ. Sci. Technol.* 49, 4735–4741. doi: 10.1021/es506185x

Lerman, A., and Mackenzie, F. T. (2018). Carbonate minerals and the CO2-carbonic acid system. *Encycl. Earth Sci.*, 206–226. doi: 10.1007/978-3-319-39312-4_84

Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) (2022). The role of onboard carbon capture in maritime decarbonization. Available online at: https://www.zerocarbonshipping.com/publications/the-role-of-onboard-carbon-capture-in-maritime-decarbonization/ (Accessed February 22, 2024).

Moras, C. A., Joannes-Boyau, R., Bach, L. T., Cyronak, T., and Schulz, K. G. (2024). Carbon dioxide removal efficiency of iron and steel slag in seawater via ocean alkalinity enhancement. *Front. Clim.* 6. doi: 10.3389/fclim.2024.1396487

Morse, J. W., and Mackenzie, F. T. (1990). *Geochemistry of Sedimentary Carbonates* (Elsevier).

Nunes, L. J. R. (2023). The rising threat of atmospheric CO2: A review on the causes, impacts, and mitigation Strategies. *Environments* 10, 66. doi: 10.3390/environments10040066

Piccolo, V. (2023). *GHG Emissions From Shipping: How to Overcome Persistent Challenges* (Social Science Research Network). doi: 10.2139/ssrn.4506467

Rau, G. H. (2011). CO2 mitigation via capture and chemical conversion in seawater. *Environ. Sci. Technol.* 45, 1088–1092. doi: 10.1021/es102671x

Rau, G., and Caldeira, K. (1999). Enhanced carbonate dissolution: a means of sequestering waste CO2 as ocean bicarbonate. *Energy Convers. Manage* 40 (17), 1803–1813. doi: 10.1016/S0196-8904(99)00071-0

Renforth, P., and Henderson, G. (2017). Assessing ocean alkalinity for carbon sequestration. *Rev. Geophys.* 55 (3), 636–674. doi: 10.1002/2016RG000533

RINA (2023). From today to 2050 challenges and opportunities for the maritime industry. Available online at: https://scresources.rina.org/media/From-Today-to-2050-Challenges-and-Opportunities-for-the-Maritime-Industry.pdf (Accessed January 29, 2024).

Risso, R., Cardona, L., Archetti, M., Lossani, F., Bosio, B., and Bove, D. (2023). A review of on-board carbon capture and storage techniques: solutions to the 2030 IMO regulations. *Energies* 16, 6748. doi: 10.3390/en16186748

Shu, Y., Hu, A., Zheng, Y., Gan, L., Xiao, G., Zhou, C., et al. (2023). Evaluation of ship emission intensity and the inaccuracy of exhaust emission estimation model. *Ocean Eng.* 287, 115723–115723. doi: 10.1016/j.oceaneng.2023.115723

Sridhar, P., Kumar, A., Manivannan, S., Farooq, S., and Karimi, I. A. (2024). Technoeconomic evaluation of post-combustion carbon capture technologies on-board a medium range tanker. *Comput. Chem. Eng.* 181, 108545–108545. doi: 10.1016/j.compchemeng.2023.108545

Sulpis, O., Jeansson, E., Dinauer, A., Lauvset, S. K., and Middelburg, J. J. (2021). Calcium carbonate dissolution patterns in the ocean. *Nat. Geosci.* 14, 423–428. doi: 10.1038/s41561-021-00743-y

Taipabu, M. I., Viswanathan, K., Wu, W., Handogo, R., Mualim, A., and Huda, H. (2023). New improvement of amine-based CO2 capture processes using heat integration and optimization. *Chem. Eng. Process.* 193, 109532–109532. doi: 10.1016/j.cep.2023.109532

Tavakoli, S., Gamlem, G. M., Kim, D., Roussanaly, S., Anantharaman, R., Yum, K. K., et al. (2024). Exploring the technical feasibility of carbon capture onboard ships. *J. Clean. Prod.* 452, 142032–142032. doi: 10.1016/j.jclepro.2024.142032

United Nations (2023). *Review of Maritime Transport 2023* Vol. 2023 (Geneva: United Nations Conference on Trad and Development).

Valverde, J. M. (2018). The Ca-looping process for CO2 capture and energy storage: role of nanoparticle technology. *J. Nanopart. Res.* 20, 39. doi: 10.1007/s11051-017-4092-3

Visonà, M., Bezzo, F., and d'Amore, F. (2024). Techno-economic analysis of onboard CO2 capture for ultra-large container ships. *Chem. Eng. J.* 485, 149982. doi: 10.1016/j.cej.2024.149982

Witte, K. (2021). Social acceptance of carbon capture and storage (CCS) from industrial applications. *Sustainability* 13, 12278. doi: 10.3390/su132112278

Wu, E., Wang, Q., Ke, L., and Zhang, G. (2023). Study on carbon emission characteristics and emission reduction measures of lime production—A case of enterprise in the Yangtze River Basin. *Sustainability* 15, 10185. doi: 10.3390/su151310185

Yoro, K. O., and Daramola, M. O. (2020). Chpater 1 - CO2 emission sources, greenhouse gases, and the global warming effect. *Adv. Carbon Capture*, 3–28. doi: 10.1016/b978-0-12-819657-1.00001-3

Zeebe, R. E., and Wolf-Gladrow, D. (2001). *CO_2 in seawater: equilibrium, kinetics, isotopes* (Vol. 65). (Gulf Professional Publishing).

Zhang, X., Bao, Z., and Ge, Y.-E. (2021). Investigating the determinants of shipowners' emission abatement solutions for newbuilding vessels. *Transp. Res. Part D Transp. Environ.* 99, 102989. doi: 10.1016/j.trd.2021.102989

Zhang, H., Wang, K., Fan, G., Li, Z., Yu, Z., Jiang, J., et al. (2023). Feedbacks of CaCO3 dissolution effect on ocean carbon sink and seawater acidification: a model study. *Environ. Res. Commun.* 5, 021004. doi: 10.1088/2515-7620/aca9ac

frontiers | Frontiers in Marine Science

TYPE Policy and Practice Reviews
PUBLISHED 21 February 2025
DOI 10.3389/fmars.2025.1489091

Check for updates

OPEN ACCESS

EDITED BY
Mehran Idris Khan,
University of International Business and Economics, China

REVIEWED BY
Abhishek Joshi,
Mohanlal Sukhadia University, India
Henry P. Huntington,
Independent Researcher, Eagle River, AK, United States

*CORRESPONDENCE
Yitong Chen
chenyitong@ouc.edu.cn

RECEIVED 31 August 2024
ACCEPTED 03 February 2025
PUBLISHED 21 February 2025

CITATION
Chen Y and Cheng K (2025) Decarbonizing Arctic shipping: governance pathways and future directions.
Front. Mar. Sci. 12:1489091.
doi: 10.3389/fmars.2025.1489091

COPYRIGHT
© 2025 Chen and Cheng. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Decarbonizing Arctic shipping: governance pathways and future directions

Yitong Chen* and Kaiyue Cheng

School of Law, Ocean University of China, Qingdao, China

Arctic shipping is a significant source of greenhouse gas (GHG) emissions, including carbon dioxide and black carbon, which intensify climate risks in the region. While the International Maritime Organization (IMO) has established the International Code for Ships Operating in Polar Waters (Polar Code) to address environmental and safety concerns of polar navigation, it falls short in promoting the decarbonization of Arctic shipping. The collaboration between the IMO and the Arctic Council, along with the contributions of the Arctic Council's task forces, is essential but requires further strengthening. In response to the climate crisis, the IMO has raised environmental standards, leading efforts to promote low-carbon growth in Arctic shipping through measures such as sulfur limits, heavy fuel oil bans, and reductions in black carbon emissions. Despite these initiatives, the governance of Arctic shipping decarbonization remains fragmented. To achieve meaningful decarbonization, the Polar Code must be strengthened and expanded into a unified regulatory framework. Additionally, enhanced collaboration between the IMO and the Arctic Council is crucial to maximize their collective impact. As a key player in Arctic shipping, China must strengthen compliance with international regulations through updated domestic legislation and Arctic policies. By actively engaging in multilateral mechanisms and developing a port state control inspection network, China can play a pivotal role in advancing Arctic shipping governance and IMO energy efficiency standards, contributing to a more coordinated and sustainable approach to the region's environmental challenges and global maritime governance.

KEYWORDS

climate change, arctic shipping, decarbonization, the polar code, governance pathways, China

1 Introduction

Over the past few decades, the Arctic has undergone significant environmental changes due to global warming, including a sharp decline in sea ice, melting permafrost, and an expansion of open water areas. These changes have driven the growth of energy projects, marine tourism, and trade, contributing to a sustained increase in Arctic shipping activities. In 2020, the Arctic Council's Working Group on the Protection of the Arctic Marine Environment (PAME) published the first Arctic Shipping Status Report (ASSR), which documented a notable rise in ship traffic between 2013 and 2019 (PAME, 2020). By 2024,

PAME released a comprehensive 10-year report on Arctic shipping trends, showing a continued increase in both the number of vessels and the distances they travel in the region. The number of ships entering the Arctic rose from 1,298 in 2013 to 1,628 in 2019, and further to 1,782 by 2023 (PAME, 2024a). This upward trend is closely linked to the reduction in Arctic sea ice and the expansion of energy exploration and development projects.

The melting of sea ice has heightened the conflict between the growth of Arctic shipping and the preservation of vulnerable Arctic marine ecosystems, which are highly sensitive to environmental disturbances. Pollution from Arctic shipping primarily takes two forms: primary pollution, which includes degradation of atmospheric and water quality from ship emissions, wastewater, noise, light pollution, and the introduction of invasive species; and man-made or accidental pollution, such as illegal waste discharges, hazardous substances, and accidental oil or chemical spills (Qi et al., 2024). The 2009 Arctic Shipping Assessment Report identifies accidental oil spills and illegal discharges as the most serious threats to the Arctic marine environment (PAME, 2009). These pollutants not only disrupt fragile ecosystems but also pose significant risks to the global climate (Winther et al., 2014), underscoring the urgent need for stricter environmental regulations and more effective management practices in Arctic shipping.

Historically, emission reduction efforts have focused on carbon dioxide, the primary driver of climate change. However, scientific studies have revealed that black carbon—produced by the incomplete combustion of fossil fuels and other carbon-based materials—also has a significant warming effect, approximately 1.1 watts per square meter. This impact is roughly two-thirds that of carbon dioxide and more than double previous estimates. As a result, black carbon has become the second most significant climate forcing agent after carbon dioxide, surpassing methane in its contribution to global warming (Bond et al., 2013).

The growth of Arctic shipping has significantly increased emissions of greenhouse gases, including carbon dioxide and black carbon. Due to the region's amplification effect, the Arctic is warming at a rate 3-4 times faster than the global average (AC, 2023a). Research by Rantanen and colleagues suggests that current climate models may underestimate this effect, with actual warming potentially reaching nearly four times the global average (Rantanen et al., 2022). In 2020, the Arctic recorded its highest temperature of 38°C, and projections indicate that the Arctic Ocean could be ice-free by the mid-21st century (IPCC, 2013; AMAP, 2011). As a critical global climate regulator, the Arctic's rapid warming and ice melt could trigger severe global consequences, including accelerated global warming, rising sea levels, more frequent extreme weather events, and significant biodiversity loss (Liu and Chen, 2010).

The decarbonization of Arctic shipping depends on a collaborative relationship between regional and global governance frameworks. The International Maritime Organization (IMO), a specialized UN agency responsible for the safety and environmental protection of international shipping, reached a key milestone with the development of the International Code for Ships Operating in Polar Waters (Polar Code) over seven years. This code established the first enforceable mandatory standards and recommended measures for Arctic shipping governance. At the same time, the Arctic Council, the leading regulatory body for the Arctic, has worked closely with the IMO to promote greener shipping through various policy initiatives and to strengthen its own governance mechanisms. The Arctic Council's task forces have made significant contributions to this process. Nevertheless, the decarbonization of Arctic shipping remains a major challenge. To address it effectively, greater engagement and cooperation between the IMO, the Arctic Council, and other relevant bodies is crucial.

Effective governance of Arctic shipping depends not only on cooperation among the eight Arctic States but also on the collaboration of port states and flag states. Although China is not an Arctic State, it has become a significant player in shipping, port operations, and shipbuilding. China has consistently shown its commitment to the sustainable development of the Arctic region, actively engaging in scientific research, economic activities, and governance (Chen, 2023). In 2018, China released a white paper on its Arctic Policy, marking the culmination of five years of increasing involvement in Arctic governance as an observer to the Arctic Council. This white paper outlined China's position as a near-Arctic State and Arctic stakeholder, emphasizing its role in the development, utilization, and governance of the Arctic.

This study focuses on the decarbonization and emission reduction of Arctic shipping within the broader context of environmental protection, to analyze governance pathways for decarbonizing Arctic shipping and provide recommendations that could stimulate further measures for sustainable development in the region. The paper is organized as follows: Section 2 reviews past decarbonization policies by the IMO and the Arctic Council, with a particular focus on the Arctic Council's task forces as key initiatives. Section 3 examines recent developments in the IMO's governance of Arctic shipping decarbonization. Section 4 offers recommendations for achieving decarbonization in Arctic shipping and China's contribution in this effort, in line with its dual-carbon target policy. Section 5 concludes the study. By understanding international regulatory mechanisms and policy dynamics, this research aims to promote green and sustainable development in the Arctic while providing a scientific basis for China to enhance its global contribution.

2 Multilevel governance pathways for decarbonizing Arctic shipping

The escalating crisis of Arctic warming, combined with increasing stakeholder collaboration, has led to the development of a multifaceted governance framework for decarbonizing Arctic shipping (see Table 1). The IMO, operating under the mandate of the United Nations Convention on the Law of the Sea (UNCLOS), addresses the unique challenges of polar shipping through the Polar Code. Regionally, the Arctic Council, alongside international organizations like the IMO and non-governmental organizations (NGOs) like the International Arctic Science Committee (IASC), plays a crucial role in driving initiatives, facilitating negotiations, and supporting policy implementation (Chen and Liu, 2023). This collaborative approach has fostered a dynamic regime complex, characterized by overlapping, non-hierarchical institutional arrangements (Keohane and Victor, 2011).

TABLE 1 Multilevel governance pathways for decarbonizing Arctic shipping.

Governance levels	Actor
International level	United Nations, International Maritime Organization
Regional level	Arctic Council, Non-governmental organizations et al
National level	Arctic states, Non-Arctic States

2.1 IMO's policy on decarbonizing Arctic shipping

2.1.1 Polar Code

The Polar Code, which came into force on January 1, 2017, marks a new era in shipping regulation for polar waters. Structurally, the Polar Code is divided into four main parts: the preamble, the introduction, Part I on safety, and Part II on environmental protection. Part II-A (mandatory measures) consists of five chapters that reflect the standards set by the International Convention on the Prevention of Pollution from Ships (MARPOL), but with more stringent requirements. Notably, the Polar Code does not currently include a specific chapter on the prevention of air pollution from polar ships. The Code's blend of mandatory and non-mandatory measures enhances its acceptance and broadens its applicability (Chen, 2018). By fully embodying the precautionary principle, the Polar Code provides comprehensive norms and standards for Arctic shipping governance, which contribute to reducing environmental and safety risks and significantly contribute to the effective governance of polar shipping (Huntington et al., 2023).

2.1.2 Gaps in Polar Code shipping standards

While the Polar Code represents a significant advancement in the development of safety and environmental standards for polar navigation, it still requires adjustments. Its pollution prevention and environmental protection measures are not comprehensive enough to address all environmental concerns. Since its implementation, criticisms of the Polar Code have primarily centered on its lack of comprehensiveness and the perceived inadequacy of its environmental safeguards (Chen, 2018). One of the most notable shortcomings is the absence of climate governance provisions, particularly in two key areas.

2.1.2.1 Absence of ban on heavy fuel oil usage or carriage

Heavy fuel oil (HFO), a byproduct of the refining process, is commonly used in large vessels such as bulk carriers, cargo ships, and cruise ships. Due to its high toxicity and viscosity, HFO poses significant environmental risks. It is a major source of air pollutants, including sulfur oxides (SOx), nitrogen oxides (NOx), and black carbon, all of which are emitted during its combustion. An accidental spill of HFO in the Arctic would have catastrophic effects on the marine environment and wildlife. Unlike conventional oil, HFO forms a thick, mousse-like substance in seawater that is highly toxic and decomposes very slowly in cold waters, complicating cleanup efforts. The Arctic's remote location, harsh weather conditions, and limited resources for emergency response further hinder effective spill recovery. Additionally, HFO spills threaten the livelihoods and cultures of indigenous communities who depend on marine resources, jeopardizing both their economic stability and traditional ways of life (CAA, 2021).

Although heavy fuel oil (HFO) was banned in Antarctic waters in 2011, ships operating in the Arctic used over 83,000 metric tons of HFO in 2015—double the amount used in 2012. HFO accounts for 57% of the total fuel used in Arctic marine shipping (ICCT, 2017). Given its widespread use, the International Maritime Organization (IMO) acknowledged that enforcing a complete ban on HFO in the Arctic would be difficult. As a result, the final version of the Polar Code only encourages, rather than mandates, the prohibition of HFO use and carriage in Arctic operations.

2.1.2.2 Insufficient measures against black carbon pollution

Black carbon, an aerosol produced by the incomplete combustion of fossil fuels and biomass, exerts a significant warming effect, particularly in the Arctic. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report highlights that the deposition of black carbon on snow and ice contributes to increased Arctic warming (IPCC, 2021). When black carbon settles on Arctic ice, it reduces the ice's albedo (reflectivity), leading to greater heat absorption and accelerated ice melt. This exposes more open water, further decreasing reflectivity and creating a self-reinforcing feedback loop that intensifies warming (IPCC, 2019). Fortunately, black carbon has a short atmospheric lifetime—ranging from a few days to weeks—making its emission control a powerful short-term strategy for mitigating climate warming and achieving immediate decarbonization benefits (EGBCM, 2019).

The primary global sources of black carbon are the combustion of fossil fuels and biomass (Bond et al., 2007). In the Arctic, major contributors to black carbon emissions include fishing vessels (25%), general cargo vessels (19%), and service vessels (12%). In 2015, approximately two-thirds of black carbon emissions from Arctic shipping were linked to heavy fuel oil consumption (ICCT, 2017). The IMO began addressing black carbon emissions in 2008, following advocacy from Friends of the Earth International (FOEI). Initially, the IMO regulated black carbon alongside greenhouse gases (GHGs), but in October 2010, during the 61st session of the Marine Environment Protection Committee (MEPC), black carbon was separated from the broader GHG emissions issue (MEPC, 2010). By 2011, driven by the United States, Norway, and Sweden, MEPC62 focused specifically on the impacts of Arctic black carbon emissions, approving a work plan that initiated research on definitions, measurement methods, and control measures (MEPC, 2011). After several years of discussions, MEPC68 adopted a

definition of black carbon in 2015, and efforts then shifted towards developing control measures (CCS, 2015). Despite these efforts, black carbon remains unaddressed in the final version of the Polar Code or in amendments to the MARPOL Convention.

2.2 Arctic Council's decarbonization initiatives for Arctic shipping

2.2.1 Arctic Council and its task forces

2.2.1.1 Strengths and limitations of Arctic Council

At the regional governance level, the Arctic Council is the most influential body in the region. Oran Young describes it as a "decision incubator" with a "generative" function, meaning it plays a key role in shaping decisions rather than making binding decisions itself (Young, 2016). The Arctic Council's operational framework enables greater flexibility than the IMO, allowing it to use informal mechanisms for institutional interaction and policy complementarity with global organizations like the IMO. The Council has actively contributed to Arctic lawmaking, developing a range of soft law regulations (Abbott and Snidal, 2000) and, more recently, three legally binding regional international agreements (Koivurova, 2020). By focusing on areas such as marine environmental protection (AC, 2013), emergency response (AC, 2011) and scientific cooperation (AC, 2017), the Arctic Council has fostered synergies between global and regional mechanisms. Through its scientific assessments and recommendations, the Council has effectively leveraged both hard and soft law to achieve complementary benefits.

However, the Arctic Council faces significant limitations in governing the decarbonization of Arctic shipping. Its membership is confined to the eight Arctic States, which restricts its geographic and political influence. As a high-level intergovernmental forum, the Council's internal instruments are not legally binding. Moreover, the Council lacks independent financial resources and depends heavily on contributions from member states.

2.2.1.2 The task forces and their effectiveness

To effectively leverage its decision-shaping role, the Arctic Council has established six working groups, eleven task forces, and three expert groups to carry out specific tasks, such as scientific assessments. For example, the Working Group on the Protection of the Arctic Marine Environment (PAME) and the Black Carbon and Methane Expert Group (EGBCM) have played pivotal roles in addressing the decarbonization of Arctic shipping.

It is important to recognize that goal-oriented task forces have been crucial, albeit often overlooked, in the Arctic Council's governance framework. Since 2009, the Council has created eleven task forces, each designed to tackle specific issues in Arctic governance. These task forces, composed of experts from the Working Groups and representatives from Arctic States, are appointed for fixed periods to achieve targeted outcomes. Due to their focused mandates and temporary nature, task forces serve as auxiliary bodies to the Arctic Council. Their objectives typically center on addressing environmental and climate challenges, enhancing international cooperation, improving local infrastructure, and promoting sustainable development in the Arctic. All eleven task forces have now completed their original mandates and are currently inactive.

The function and influence of task forces should not be underestimated. These groups are often established to conduct scientific assessments on specific issues and offer feasibility recommendations. They may also develop framework documents or facilitate the negotiation of agreements. For instance, the Task Force on Short-Lived Climate Forcers (SLCF) completed a comprehensive technical assessment of black carbon emissions and abatement options. This task force analyzed black carbon emission trends, reviewed existing policies and programs, and evaluated potential abatement strategies. The feasibility analyses and recommendations provided by the SLCF have served as critical scientific references for the Arctic Council, the IMO, and other decision-makers.

Task forces also play a vital role as platforms that consolidate state interests and support the negotiation of legally binding agreements under the Arctic Council. For example, the Task Force on Search and Rescue facilitated the signing of the Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic in 2011. Similarly, the Task Force on Arctic Marine Oil Pollution Prevention and Response (TFOPP) contributed to the negotiation of the 2013 Agreement on Cooperation on Marine Oil pollution Preparedness and Response, which established a cooperative framework for oil spill response and provided essential legal safeguards. Additionally, the Task Force for Enhancing Scientific Cooperation in the Arctic (SCTF) played a key role in the signing of the Agreement on Enhancing International Arctic Scientific Cooperation in 2017.

The creation and implementation of these three agreements have elevated the Arctic Council's legislative function, marking a significant shift in its role. Unlike science-driven working groups, which typically operate without a political agenda, task forces function as intergovernmental negotiating bodies, where the stakes are higher, and participants are focused on crafting politically sensitive agreements. The task forces' goal-oriented approach—centered on securing legal agreements or establishing clear timelines for program implementation—has strengthened the political will of states to address pressing issues effectively.

The task forces have been pivotal in establishing key mechanisms within the Arctic Council and the broader Arctic governance framework. For example, the Task Force on Black Carbon and Methane (TFBCM) directly contributed to the creation of the Expert Group on Black Carbon and Methane (EGBCM). The effectiveness of these task forces, as evidenced by their achievements, highlights their critical role within the Arctic Council. Not only have they helped transform the Council's function and broaden its influence, but they have also strengthened the scientific foundation of the Council's decision-

making and law-making processes. Their ongoing impact underscores their essential contribution to Arctic governance.

2.2.2 Arctic Council's Initiative for decarbonizing Arctic shipping

Even before the Polar Code came into force, the Arctic Council had been actively advancing climate governance policies. In 2004, the Council published the Arctic Climate Impact Assessment (ACIA), which highlighted the environmental and socio-economic consequences of Arctic climate change. The findings were subsequently incorporated into the IPCC's Fourth Assessment Report. In 2009, the Council established the Task Force on Short-Lived Climate Forcers (SLCF), focusing on black carbon reduction. Its report, Black Carbon Impacts on the Arctic Climate, suggested that reducing black carbon emissions could be an effective short-term strategy for mitigating climate change. That same year, the Council released the Arctic Maritime Shipping Assessment (AMSA), which identified opportunities for black carbon emission reductions in Arctic shipping (PAME, 2009).

In 2015, the Council adopted the Enhanced Framework for Action on Black Carbon and Methane Emissions Reduction, calling for regional and collective action among Member States. This framework emphasized the importance of scientific research, the implementation of a black carbon emissions reporting system, and strengthened collaboration between Member and observer States to accelerate emissions reductions. The following year, in celebration of its 20th anniversary, the Council adopted the 20th Anniversary Joint Declaration—The Arctic Council: A Forum for Peace and Cooperation. This declaration urged member states to protect the Arctic environment in line with the Paris Agreement and commit to reducing GHG emissions to combat climate change and promote sustainable development. Empirical studies have found that the Declaration's policy initiatives have positively impacted GHG emission reductions in the Arctic, particularly in raising awareness about black carbon (Wang et al., 2023). Despite its limited authority and capacity, the Arctic Council has significantly elevated the profile of Arctic climate change within the global governance framework.

Following the entry into force of the Polar Code, Arctic States, observers, industry stakeholders, NGOs, and other parties, through the Arctic Council, have developed various measures to mitigate the climate impacts of Arctic shipping. These initiatives include establishing a database on Arctic shipping traffic, exchanging best practices in Arctic shipping, publishing reports on the state of Arctic shipping and the use of heavy fuel oil, participating in the governance of black carbon, and creating low-impact shipping corridors. Throughout this process, the Arctic Council has closely collaborated with the IMO, supporting the implementation of the Polar Code while also addressing its shortcomings. By leveraging its unique position to coordinate the interests of Arctic States, the Arctic Council has systematically worked to fill the gaps left by the Polar Code.

2.2.2.1 Artic shipping status report

PAME's Arctic Shipping Status Reports (ASSR), based on the Arctic Ship Traffic Data (ASTD) system, analyze key trends in Arctic shipping. The first report (2020) covered trends from 2013 to 2019, while the second report (2021) noted an 82% increase in fuel consumption since 2016, with 10% of ships using hazardous heavy fuel oil (HFO). The third report (2021) highlighted a rise in both ship numbers and distances traveled in the Northwest Passage (PAME, 2021). In 2023, the fourth report analyzed 1,661 vessels, 1,349 flagged by Arctic States and 96 by observer states, with Russia leading at 885 ships (PAME, 2023). The fifth report (2024) showed that fishing vessels (44%) were the most common, followed by general cargo ships (11%) and bulk carriers (7%), with natural resource exploration driving much of the growth (PAME, 2024b).

In January 2024, PAME updated its 2013-2019 report to include data for 2020-2023, revealing a continuous increase in Arctic shipping. In 2023, 1,782 ships entered Arctic waters, a 37% increase from 2013. Shipping distance grew by 111%, reaching 12.9 million nautical miles. Bulk carriers rose sharply from 71 in 2013 to 119 in 2023, linked to energy projects like Mary River Mine and Yamal Gas (PAME, 2024a). This rise in shipping coincides with a decline in Arctic Sea ice, shrinking from 6.1 million square kilometers in September 1999 to 4.3 million in 2019. While the report does not directly address shipping impacts, it has drawn attention to the growth of Arctic shipping among policymakers.

2.2.2.2 Arctic heavy oil research report

Since 2011, PAME has published four reports on the use and transport of heavy fuel oil (HFO) in Arctic shipping, focusing on black carbon emissions and technologies for their reduction. In October 2020, PAME's report on HFO use in 2019 noted that 61% of Arctic ships used distillate marine fuel. Although the number of ships in the Arctic increased by only 2% from 2016 to 2019, the use of HFO rose significantly, from 117 to 165 ships—an increase of over 40%, with bulk carriers leading the rise (PAME, 2019). The report also highlighted environmental risks such as HFO spills and black carbon emissions, bridging the knowledge gap at the IMO and serving as an early warning, urging action toward a potential HFO ban.

2.2.2.3 Black Carbon Governance

In April 2015, the Arctic Council adopted the Framework for Action to Enhance Black Carbon and Methane Emission Reductions, overseen by the EGBCM. This framework aimed to evaluate progress based on national reports, Working Group outputs, and other relevant data. The EGBCM's first progress report led to the 2017 Fairbanks Declaration, calling for a 25-33%

reduction in black carbon emissions by 2025. Recognizing the global impact of black carbon and methane, the Arctic Council invited observer states to join these efforts.

This initiative marked the first coordinated effort by Arctic States to set climate reduction targets and propose national measures for mitigating short-term climate forcers. However, the targets are non-mandatory and modest—EGBCM projects a 24% reduction with minimal action. While groundbreaking, the Arctic Council's work on black carbon governance requires further strengthening.

The Council's contributions to Arctic shipping decarbonization include conducting scientific assessments, raising awareness, issuing recommendations, formulating new rules, generating flexible soft law, and fostering collaboration. Task forces have played a key role in bridging knowledge gaps, offering assessments, and providing negotiation platforms, representing a potential new model for decarbonization governance.

3 IMO's latest efforts to decarbonize Arctic shipping

In response to global shipping emissions reduction goals, the IMO has issued work plans and measures to strengthen environmental standards and enhance the mandatory nature of its regulations. These efforts include provisions specifically targeting the Arctic, aimed at addressing gaps in the Polar Code to maximize its effectiveness. The IMO's proactive approach is paving the way for a low-carbon Arctic shipping industry and offers hope for a more environmentally sustainable future in Arctic shipping.

3.1 Timely revision of the GHG mitigation strategy for global shipping

To combat global warming, the IMO has developed and continuously refined its GHG emission reduction strategy for international shipping, marking a new era in green shipping governance. These initiatives also impact Arctic shipping.

The IMO has long recognized the air pollution caused by international shipping, amending the MARPOL Convention in 1997 to include air pollution prevention in Annex VI. This annex has been updated several times, including in 2011 when the mandatory Ship Energy Efficiency Code was adopted, introducing the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Program (SEEMP). These measures formed the first global mandatory GHG reduction mechanism for international transport. However, while Annex VI encourages innovative energy technologies and mandates their application, its technical requirements have raised concerns about limiting the rights of developing countries, conflicting with the "common but differentiated responsibilities" principle (Liu et al., 2023).

In 2018, the IMO introduced its Initial Strategy for GHG Emission Reduction from Ships, setting carbon reduction targets: a 40% reduction in carbon intensity by 2030 and a 50% reduction in total GHG emissions by 2050 (IMO, 2018). The strategy supports developing countries through technology transfer and research cooperation, balancing the needs of both developed and developing nations (Doelle and Chircop, 2019), but it notably excludes black carbon from its targets.

In June 2021, the IMO's Marine Environment Protection Committee (MEPC76) adopted amendments to Annex VI of the MARPOL Convention. These amendments introduced the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII), effective from January 1, 2023. Ships over 5,000 gross tons must calculate and verify their CII, with those receiving a D or E rating for three consecutive years required to develop an energy efficiency improvement plan. This marked the first formal ship rating mechanism to improve energy efficiency and reduce GHG emissions.

The IMO's updated GHG Emission Reduction Strategy, adopted at MEPC80 in 2023, sets a long-term net-zero target for international shipping by 2050, aligning with the Paris Agreement's goals (IMO, 2023). As shown in Figure 1, the strategy includes targets for alternative fuel adoption, aiming for 5-10% of international shipping to use zero or near-zero GHG technologies by 2030. It also sets GHG reduction milestones: 20-30% by 2030 and 70-80% by 2040, compared to 2008 levels.

Medium-term measures are being developed, including GHG intensity standards for bunker fuels and a carbon pricing mechanism. In March 2024, MEPC81 adopted revised Guidelines on the life cycle GHG intensity of marine fuels and discussed a draft net-zero framework, which includes GHG fuel intensity (GFI) targets and flexible implementation mechanisms. Future interim measures will be based on this framework (IMO, 2024).

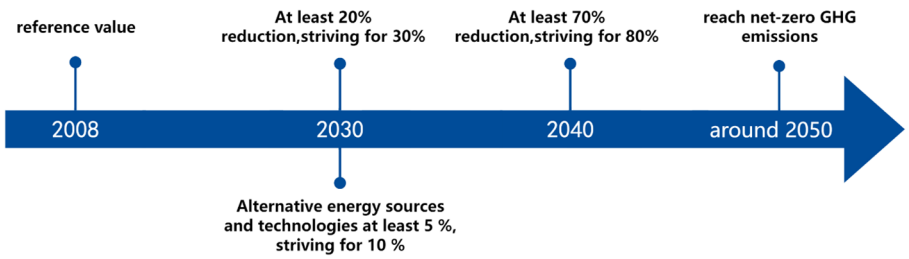


FIGURE 1
Timeline for the IMO ship greenhouse gas emission reduction strategy (2023).

3.2 New sulfur limit regulations

The IMO's sulfur and carbon restriction measures work in tandem to promote cleaner shipping practices. Effective from January 1, 2020, the IMO 2020 sulfur regulations mandate that ships transition from high-sulfur fuel oil (HSFO) with 3.5% sulfur content to very low sulfur fuel oil (VLSFO) with a 0.5% sulfur content. Only ships equipped with desulfurization systems (scrubbers) are allowed to continue using HSFO. This regulation has significantly impacted the global shipping industry, including in the Arctic, marking a shift to cleaner marine fuels. However, the transition has resulted in higher fuel costs, required modifications to ships (e.g., installing scrubbers), and operational challenges due to the less stable quality of VLSFO. Despite these challenges, most of the world's trading ships have already switched to VLSFO.

The IMO has also examined the impact of VLSFO on carbon emissions to ensure sulfur restrictions align with carbon reduction goals. However, the sulfur restrictions have sparked concerns due to their potential unintended climate effects. Although the reduction in sulfate aerosols from low-sulfur fuels benefits human health, it also alters atmospheric light-scattering properties, indirectly influencing climate change (Sofiev et al., 2018). VLSFO, which often contains high levels of aromatic compounds like benzene and toluene, can significantly increase black carbon emissions (ICCT, 2017). Refiners have developed various fuel blends to reduce compliance costs, but these could lead to a sharp rise in black carbon emissions (IMO, 2019a). Research funded by Germany and Finland indicates that the switch from HFO to VLSFO could increase black carbon emissions by up to 85% (IMO, 2019b), potentially undermining the IMO's efforts to reduce GHG emissions and worsening global climate change (High North News, 2020).

3.3 Initial actions on Arctic Black Carbon Governance

To address the warming effects of Arctic shipping, the IMO has introduced measures targeting black carbon, the second most significant contributor to climate warming. In November 2021, during MEPC77, the IMO adopted a decision encouraging the voluntary use of cleaner fuels in the Arctic to reduce black carbon emissions. The resolution urges member states and ship operators to voluntarily adopt distillate fuels, alternative cleaner fuels, or other propulsion methods that minimize black carbon emissions in or near the Arctic (MEPC, 2021). However, the resolution is not mandatory and relies on voluntary compliance, leading to limited enthusiasm from ship operators due to the increased operating costs. In response, the Clean Arctic Alliance (CAA) has called for mandatory rules to enforce this approach.

The IMO has identified several methods for reducing black carbon emissions, including transitioning from HFO to distillates or LNG, using diesel particulate filters or electrostatic precipitators to remove black carbon from exhaust gases, and adopting zero-emission technologies such as batteries and hydrogen fuel cells (ICCT, 2019a). However, the practical implementation of these technologies into substantive policy remains contentious, primarily due to high conversion costs. The absence of mandatory black carbon regulations has drawn criticism from environmental organizations, who argue that reducing black carbon emissions is feasible and urge the IMO to expedite the transition to distillate fuels in all Arctic shipping. They also call for global regulations to ban high black carbon emissions, with Arctic countries taking the lead in supporting and enforcing these initiatives (High North News, 2022; ICCT, 2019b).

3.4 Formal ban on Arctic heavy oil

The combustion of heavy fuel oil (HFO) contributes significantly to black carbon, carbon dioxide, and sulfur dioxide emissions, all of which accelerate Arctic and global warming. Additionally, the risk of HFO spills during transport poses a severe threat to the Arctic environment (PAME, 2009). At MEPC72, a proposal to ban the use and transport of HFO in Arctic waters gained widespread support, and after years of consultation, the ban was formalized.

In June 2021, MEPC76 adopted an amendment to MARPOL Annex I, introducing the Arctic HFO ban. The ban will be implemented in three phases: an initial period, a transition period, and full implementation. Starting July 1, 2024, the ban will prohibit the use and carriage of HFO in Arctic waters, with exceptions for ships involved in safety, search and rescue, or maritime oil spill response. Some vessels can continue using and carrying HFO until July 1, 2029, after which the ban will be fully enforced.

The phased implementation has sparked controversy, particularly over exemptions for certain ships during the transition period. The Clean Arctic Alliance (CAA) has called for a more stringent ban, arguing that the gradual phase-out allows ships to continue burning significant quantities of HFO, prolonging black carbon emissions and spill risks (CAA, 2021). In 2022, the CAA proposed that Nordic countries enforce a 12-nautical-mile HFO ban within their territorial waters to strengthen Arctic protection and ensure equal enforcement of the ban.

Given that HFO accounted for 60% of fuel consumption in Arctic shipping (High North News, 2019), the IMO's HFO ban represents a significant shift. The phased implementation, tailored to specific countries and timelines, makes compliance and enforcement more feasible (Chen and Wang, 2019). Many shipping operators are already moving away from HFO, with companies like Maersk pledging carbon-neutral shipping by 2050 and Ponant discontinuing HFO use in its cruise fleet (High North News, 2019).

At MEPC81, the IMO approved a proposal by Norway and Canada to establish Emission Control Areas (ECAs) in the Arctic, further accelerating HFO controls. ECAs aim to reduce pollutants like sulfur oxides (SOx), particulate matter, and nitrogen oxides (NOx), with new rules reducing fuel sulfur content from 0.5% to 0.1%. Environmental groups welcomed this move, as the Norwegian Sea ECA is expected to cut particulate matter, including black carbon, by 58% by 2030 compared to 2020 levels (High North News, 2024).

The combination of the Polar Code, sulfur restrictions, and the HFO ban signals a transformative shift toward cleaner Arctic shipping. These measures, alongside industry-led initiatives, align with the broader goal of achieving net-zero GHG emissions by 2050, marking a new era in Arctic green shipping.

4 Governance pathways for decarbonization of Arctic shipping and China's contribution

Given the growing complexity of the Arctic environment and the increasing volume of shipping, it is critical to implement effective strategies to address the emerging risks and challenges. First, the Polar Code should be revised and strengthened to serve as the central framework for Arctic shipping governance. Second, greater collaboration between the IMO and the Arctic Council is needed to create a synergistic governance structure that facilitates the green transformation of Arctic shipping. This collaboration should also highlight the strategic role of the Arctic Council's task forces. Finally, China, as a major shipping nation with a dual role in both Arctic and global shipping, is pivotal in shaping policies for the decarbonization of Arctic shipping.

4.1 Revise and strengthen the Polar Code as a unified core guideline for Arctic shipping governance

The fragmented governance of Arctic shipping reflects broader global governance challenges, such as the competing priorities of developed and developing countries and the differing approaches to ocean governance (Chen and Liu, 2023). Given the Arctic's fragile ecosystem and the urgent climate crisis, it is critical to overcome diverse political divides and reach a consensus on a unified and more stricter international agreement.

The Polar Code, as the first international legal framework governing Arctic shipping, offers a foundation for such an agreement. With broad participation from member states and the authority of the IMO as the global regulator of maritime affairs, the Polar Code can expedite the process of decarbonizing Arctic shipping. By refining and strengthening the existing framework, the Code can facilitate quicker and more cost-effective implementation.

To address critical regulatory gaps, particularly concerning black carbon emissions, it is essential to incorporate insights from the Arctic Council, and other relevant bodies into the Polar Code. Establishing stringent emission standards, alongside appropriate incentives, will be essential for progress. Black carbon, like other air pollutants and greenhouse gases (GHGs), should be regulated in tandem with GHGs and other emissions from ships. Given the unique sensitivity of the Arctic environment, a new section on "Prevention of Air Pollution" could be added to the Polar Code, addressing pollutants such as carbon dioxide, sulfur oxides (SOx), nitrogen oxides (NOx), volatile organic compounds (VOCs), carbon monoxide (CO), and black carbon.

The revision process should involve not only Arctic states but also non-Arctic countries, non-governmental organizations, and Indigenous peoples, ensuring that the updated Polar Code is comprehensive, inclusive, and relevant for all stakeholders. The ultimate goal should be to establish the Polar Code as the central, binding framework for Arctic shipping governance.

4.2 Enhance collaboration between the Arctic Council and IMO, emphasizing the role of Arctic Council task forces

Global issues such as climate governance, marine environment protection, and biodiversity often involve diverse national interests, making coordination challenging and leading to fragmented legal frameworks. This complex landscape of overlapping and non-hierarchical regimes is referred to as a "regime complex" (Raustiala and Victor, 2004). Oran Young further refines this concept, defining regime interaction as the dynamic relationships within a regime complex, where rules, institutions, and operations from different legal regimes influence one another (Orsini et al., 2013; Trevisanut et al., 2020). These interactions can result in either conflict and regulatory chaos or synergies with neutral outcomes (Young, 1996).

In the case of Arctic shipping decarbonization, the interaction between the IMO and the Arctic Council closely mirrors a "nested regime" interaction, where specific arrangements are embedded within a broader institutional framework. This dynamic is particularly marked by the coexistence of hard law (IMO regulations) and soft law (Arctic Council initiatives). The IMO, as the global regulator of international shipping, has led the charge in shipping decarbonization, including initiatives specific to Arctic shipping. However, the Polar Code, while an important step, has yet to fully address the urgent and comprehensive decarbonization needs of Arctic shipping.

The Arctic Council, while a high-level intergovernmental forum rather than a formal treaty-based organization, offers considerable flexibility in governance. It plays a critical role in Arctic shipping decarbonization by producing knowledge, fostering consensus among Arctic States, promoting political will, and engaging with other relevant international bodies (Chen and Gao, 2020). The IMO's observer status in the Arctic Council, granted in 2019, further strengthens the collaboration between these two bodies, facilitating more integrated and effective governance efforts (Bai, 2021).

As shown in Figure 2, the synergistic interaction between hard and soft law within the regime complex governing Arctic shipping

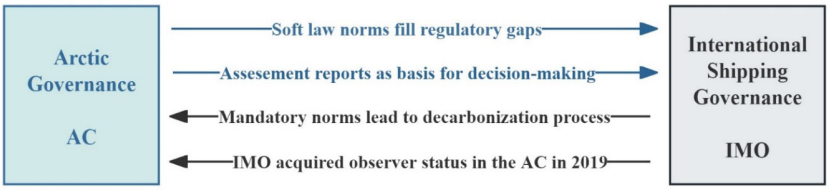


FIGURE 2
Regime interaction between IMO and the Arctic Council.

decarbonization can yield positive outcomes by mitigating regulatory conflicts. Specifically, the Arctic Council's soft law norms help address gaps in the IMO's polar shipping standards, contributing to a more comprehensive approach to low-carbon development in Arctic shipping. For example, the Arctic Shipping Assessment Report by PAME in 2009 provided crucial data and practical solutions that informed the development of the IMO's Polar Code. These interactions also foster enhanced collaboration among states, facilitating the sharing of resources such as funds, technology, and expertise, thereby supporting sustainable Arctic shipping governance (Huntington et al., 2023).

Effective decarbonization management requires strengthened cooperation between the IMO and Arctic Council to enhance these synergies. Both organizations should share knowledge, information, and development plans at each other's meetings, reducing research costs, resolving conflicts, and filling regulatory gaps. Additionally, aligning principles such as the precautionary principle and harmonizing the scope of agreements can further streamline efforts. Simplifying monitoring and reporting obligations to avoid duplication would ease the burden on countries and improve the efficiency of data collection and reporting. Further, linking measures like capacity-building, scientific cooperation, and technology transfer across mechanisms will increase effectiveness and transparency (Van Asselt, 2014). Establishing a common green shipping fund and facilitating the sharing of best practices through the Arctic Shipping Best Practices Forum will also promote collective learning and progress.

As Arctic governance evolves, the increasing complexity of institutional arrangements will necessitate careful management of these interactions to ensure the regime complex remains effective. Interplay management refers to coordinated efforts to improve institutional interactions, whether through legal frameworks, institutional coordination, or autonomous management (Oberthür, 2009; Van Asselt, 2014). Proper management of these interactions will help prevent fragmentation and conflict, enhance synergies, and address existing gaps within the governance network.

Oran Young argues that it is unrealistic to expect a comprehensive Arctic Ocean Convention to address the coordination needs of the Arctic Ocean regime complex. Even if the SMM (SAO-based marine mechanism) under the Arctic Council's framework evolves into a permanent body, it will still fall short of addressing the broad challenges posed by the increasingly dense and complex governance structures in the Arctic Ocean (Young and Kim, 2021). To address these challenges, it is essential to engage in joint discussions on coordinating regime interactions for Arctic shipping decarbonization, involving Arctic and non-Arctic states as well as non-state actors.

Although the Arctic Council lacks the legal capacity to act as the primary coordinator, it can leverage its convening power and meeting venues to organize informal international workshops. These workshops could bring together key stakeholders, including representatives from the IMO, the Arctic Council, and other relevant bodies, to exchange information on recent developments, resolve conflicts, enhance synergies, and fill regulatory gaps. Such a collaborative approach would foster a unified, comprehensive regulatory framework for Arctic shipping decarbonization, integrating efforts across global, regional, and national levels.

While task forces under the Arctic Council have been pivotal in Arctic shipping governance, their current work plans often underutilize their potential contributions. Although all 11 task forces have completed their mandates and ceased operations, the urgency of the Arctic climate crisis calls for renewed focus. The Arctic Council should consider reactivating the Task Force on Black Carbon and Methane (TFBCM) or establishing a new task force dedicated to Arctic decarbonization. This task force could serve as a platform for convening meetings, sharing information, technology, and capacity, and providing scientific evaluations on key pollutants such as black carbon, methane, carbon dioxide, and other greenhouse gases.

Furthermore, this task force could play a pivotal role in aligning national efforts and supporting the negotiation of a new Arctic decarbonization agreement. It is crucial for all countries to continue supporting and actively participating in the Arctic Council's work, revitalizing its task forces. This involvement would not only enhance their influence within the Arctic Council but also inject new momentum into the green transformation of Arctic shipping, contributing to innovative solutions for climate governance in the region.

4.3 Pathways for China's contribution to decarbonization of Arctic shipping

China plays a pivotal role in the decarbonization of Arctic shipping, holding dual positions as a Category A member of the IMO and an official observer state of the Arctic Council. As a global leader in both shipping and shipbuilding, China significantly influences Arctic shipping routes. Maritime transport accounts for approximately 95% of China's international trade, and in 2023, China's shipping import and export trade represented over 30% of global shipping volumes. Furthermore, China surpassed Greece in August 2023 to become the world's largest ship-owning nation by gross tonnage (Clarkson Research, 2023).

While pursuing the Maritime Silk Road, China is also concerned with carbon emissions from international shipping, including Arctic shipping. China has actively supported the IMO's strategy to reduce greenhouse gas emissions from ships. In 2020, China set dual carbon goals: carbon peaking by 2030 and carbon neutrality by 2060. "Carbon peaking" refers to the point at which CO2 emissions stop growing and begin to decline, while "carbon neutrality" aims to offset emissions through measures such as afforestation, energy conservation, and emission reduction (People's Daily, 2021). Under these dual-carbon goals, China can make significant strides in reducing emissions in the shipping industry through policies, legislation, technological innovation, and international cooperation, contributing to global efforts, including in the Arctic shipping sector. China's actions could thus positively impact Arctic shipping governance and the development of international law in this area. Furthermore, in November 2024, China and Russia convened the first meeting of the Sub-Committee on Arctic Shipping Route Cooperation to discuss the development

of Arctic shipping routes. This new mechanism aims to advance polar ship construction, ensure the safety of Arctic navigation, and protect the Arctic ecosystem, demonstrating China's commitment to Arctic shipping governance (Ministry of Transport of the People's Republic of China, 2024).

China has made significant strides in applying green technologies within the shipping industry. Notably, the "Three Gorges 1," a new-energy electric cruise ship powered by clean hydropower, is the world's largest and most advanced electric cruise ship in terms of capacity and intelligence. It can replace 530 tons of fuel oil annually and reduce harmful gas emissions by over 1,600 tons (People's Daily Online, 2022). Additionally, China Yangtze River Shipping Group (CSCG) is constructing river-sea vessels with LNG-for-tanks technology, and the "Chuanjiang 130-meter standard ship" under development will feature methanol dual-fuel power. CSCG plans to launch these vessels soon, with a target of building 80 new energy ships over the next three years to create a clean energy fleet and support large-scale green operations (Chongqing Municipal People's Government, 2024).

China is committed to responsible maritime practices and has set ambitious "carbon peak" and "carbon neutrality" targets, supported by a range of policy measures to achieve these goals. China's involvement in the green development of Arctic shipping is expected to positively influence the IMO, Arctic shipping governance, and the evolution of international law in this domain (Bai and Li, 2021; Bai and Zhu, 2023). China's contributions to this process can unfold in several key ways.

4.3.1 Enhance compliance through domestic legislation and policy updates

The Arctic shipping route offers significant economic and environmental advantages by shortening the distance between Europe and Asia, reducing both transport costs and carbon emissions. As a key user of these routes and an active participant in relevant governance mechanisms, China must closely monitor and adapt to evolving Arctic shipping policies, strengthening domestic compliance through legislation and policy updates. As climate change accelerates, Arctic shipping policies will likely tighten, and China should prepare for the impact of the IMO's evolving regulations on Arctic operations.

In the short term, China's Green Ship Rules, developed by the China Classification Society (CCS), already integrate the Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP). As the IMO tightens energy efficiency standards and promotes the adoption of green technologies and alternative fuels, China should continue to invest in research and development in these areas. This includes innovations in green ship technologies, promoting nuclear-powered icebreakers, and introducing financial policies such as subsidies, tax incentives, and low-interest loans to facilitate their practical application.

In the medium to long term, China has begun establishing a shipping carbon emissions trading market (China Financial News, 2024). This initiative requires the timely implementation of supporting policies and regulations to ensure its effectiveness and sustainability. To align with international efforts, China should also regularly update its Arctic policy. Since the release of its 2018 Arctic Policy white paper, the region's climate, environment, and geopolitical landscape have evolved significantly. In comparison, countries like the UK, a "near-Arctic" nation, have been more agile in adapting their policies to these changes. By regularly revising its Arctic policy, China can ensure its approach remains relevant, strategic, and responsive to shifting dynamics in the region. Moreover, continuous review and follow-up on policy implementation will help China navigate and influence Arctic governance more effectively.

4.3.2 Promote port state control inspection network for Arctic shipping

To strengthen governance in Arctic shipping, it is essential to expedite domestic policy updates and leverage the critical role of port state control. Port state control extends beyond territorial sovereignty, incorporating rights and obligations under international conventions and national regulations. Through vessel inspections and detentions, port states uphold maritime safety and support flag states in their jurisdictional responsibilities.

As both a destination port for Arctic shipping and a key port state at the Asian end of the Arctic route, China plays a pivotal role in port state control inspection. As one of the world's leading port nations, China has actively participated in international efforts to oversee port state inspection and eliminate substandard ships, contributing to global maritime safety.

Given the absence of a unified port state control organization, regional cooperation through memorandums of understanding (MoUs) is crucial. China can continue its participation in regional port state control agreements across the Asia-Pacific, Indian Ocean, and South Pacific. By collaborating with Arctic coastal states and other port nations, China can exchange policies, share information, promote technological cooperation, and jointly enforce regulations. These actions would explore a port state control inspection network specifically for Arctic shipping. Establishing unified inspection standards with other nations would enhance safety and environmental protection in Arctic waters, compensating for the limitations of flag state oversight.

4.3.3 Proactive engagement in improving Arctic shipping governance and IMO energy efficiency standards

As the Arctic shipping governance system, centered around the Polar Code, undergoes revision, China has an opportunity to play a constructive role. As an Arctic stakeholder, China should leverage its observer status to actively engage with task forces, working groups, and expert groups. By doing so, China can ensure that the perspectives of developing countries are represented, seek opportunities for international cooperation, and propose initiatives that align with its national interests while reflecting the broader goals of countries using Arctic shipping routes.

In recent years, the IMO has placed increasing emphasis on higher energy efficiency standards for ships. A significant milestone in this effort was the release of the ISO 23453:2022 standard in December 2022, which provides "Guidelines on the Design and Manufacture of Vortex Reducing Fins for Fixed-Pitch Propellers for

Ships and Marine Technology Vessels" (ISO, 2022). Led by China's No. 702 Institute of the China Shipbuilding Group Corporation (CSSC) and supported by other domestic institutions, this standard exemplifies China's contribution to meeting IMO's stringent energy efficiency requirements.

China has previously made significant contributions to the IMO, including proposals to improve the Energy Efficiency Design Index (EEDI) formula, the establishment of an International Maritime Sustainable Fund, and the development of incentive mechanisms (IMO, 2016, IMO, 2022). Moving forward, China should deepen its engagement with multilateral mechanisms such as the IMO and the Arctic Council, continue submitting proposals on shipping emission reductions, and contribute to global public goods. Additionally, China should strengthen bilateral and multilateral cooperation to reduce misunderstandings, bridge differences, and achieve mutual benefits (Pan and Huntington, 2024). This proactive involvement will not only safeguard China's shipping interests but also contribute positively to Arctic and global maritime governance (Chen, 2017).

5 Conclusions and prospects

Global warming and the accelerated melting of Arctic sea ice are intensifying climate risks, with greenhouse gases like carbon dioxide and particulate matter such as black carbon posing severe threats. The IMO and the Arctic Council, as central bodies in maritime and Arctic governance, have taken effective actions through coordinated regime interactions. The integration of both soft and hard law is essential for establishing robust governance. In this framework, the Arctic Council's task forces play a critical but often underappreciated role. These task forces conduct scientific assessments, provide feasibility recommendations, draft framework documents, and facilitate agreements, enhancing the scientific rigor and influence of the Council's decisions. Given their vital role in Arctic governance and sustainable development, there is a compelling case for reactivating or establishing new task forces to address the climate risks posed by Arctic shipping more effectively.

Since the Ukraine crisis, the Arctic Council has effectively suspended its operations, halting official meetings and multilateral cooperation on Arctic governance (Chen and Wang, 2022). Russia, as the largest Arctic nation and a key player in the Northern Sea Route, has long been central to global shipping activities in the region. Arctic shipping, which significantly impacts the environment through emissions such as black carbon, exhaust gases, and waste, has been further complicated by Russia's absence from the Council. This highlights the geopolitical tensions that have spilled over into Arctic governance, impeding progress on crucial environmental issues. Meanwhile, the impacts of global warming on Arctic ecosystems and biodiversity are accelerating at an alarming rate (Kim et al., 2023). This underscores the urgent need to restore and strengthen Arctic governance, particularly through the resumption of the Arctic Council's activities and enhanced international cooperation.

On May 11, 2023, Norway assumed the rotating chairmanship of the Arctic Council from Russia, a role it will hold until 2025. Norway's chairmanship prioritizes Arctic stability and constructive cooperation, focusing on four key areas: oceans, climate and environment, sustainable economic development, and the well-being of Arctic peoples. In the climate and environment domain, Norway will highlight the impacts of climate change on the Arctic, advocate for adapting management systems, and address environmental challenges arising from increased human activity. Special attention will be given to short-term climate factors such as methane and black carbon, with the aim of reducing their emissions by 2030 to slow Arctic warming. Norway also plans to support efforts to mitigate the environmental impact of Arctic shipping, including the exploration of green shipping corridors as pilot projects.

Since taking on the chairmanship, Norway has adopted an active governance approach, focusing on the gradual resumption of the Council's operations, particularly its working groups (AC, 2023b). A key priority has been placing the issue of worsening Arctic wildfires on the Arctic Council's agenda, reflecting a commitment to addressing climate change and enhancing governance. Norway's leadership in shaping Arctic shipping policies aligns with its broader climate goals.

Given the severity of the Arctic climate crisis, it is essential for Arctic nations, international organizations, non-governmental organizations, and other stakeholders to collaborate effectively to push for a revised Polar Code for decarbonization of Arctic shipping. This revised code should aim to become the most authoritative, comprehensive, and mandatory legal framework for polar waters. As a major Arctic stakeholder, China has a responsibility to take proactive measures, including strengthening its domestic compliance through legislative updates and enhancing its role in port state control. China should actively work with other nations, Arctic Council, and the IMO, to build a robust regulatory network for decarbonizing Arctic shipping and sustainable future.

Author contributions

YC: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. KC: Data curation, Formal analysis, Investigation, Validation, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was funded by the National Social Science Fund of China, Grant No. 20CFX082.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Abbott, K. W., and Snidal, D. (2000). Hard and soft law in international governance. *Int. Organ.* 54, 422–423. doi: 10.1162/002081800551280

AC (2011). *Agreement on cooperation on aeronautical and maritime search and rescue in the arctic*. Available online at: https://oaarchive.arctic-council.org/items/9c343a3f-cc4b-4e75-bfd3-4b318137f8a2 (Accessed December 20, 2024).

AC (2013). *Agreement on Cooperation on Marine Oil pollution Preparedness and Response in the Arctic*. Available online at: https://oaarchive.arctic-council.org/items/ee4c9907-7270-41f6-b681-f797fc81659f (Accessed December 20, 2024).

AC (2017). *Agreement on enhancing international arctic scientific cooperation*. Available online at: https://oaarchive.arctic-council.org/items/9d1ecc0c-e82a-43b5-9a2f-28225bf183b9 (Accessed December 20, 2024).

AC (2023a). *Norway's chairship of the arctic council 2023–2025*. Available online at: https://arctic-council.org/about/Norway-chair-2/ (Accessed March 23, 2023).

AC (2023b). *Three months into the Norwegian chairship: a status update with SAO chair Morten Høglund*. Available online at: https://arctic-council.org/news/three-months-into-the-norwegian-chairship-a-status-update-with-sao-chair-morten-hoglund/ (Accessed July 23, 2023).

AMAP (2011). *Arctic climate issues 2011: changes in arctic snow, water, ice and permafrost*. Available online at: https://www.amap.no/documents/download/2267/inline (Accessed October 23, 2023).

Bai, J. (2021). The trend of heavy oil control in Arctic shipping and China's response. *Dong Yue Tribune.* 42, 171–182. doi: 10.15981/j.cnki.dongyueluncong.2021.10.020

Bai, J., and Li, X. (2021). IMO's marine environmental regulatory governance and China's role: an empirical study of China's submissions. *Sustainability.* 13, 10243. doi: 10.3390/su131810243

Bai, J., and Zhu, K. (2023). China's engagement in arctic governance for its sustainable development based on international law perspective. *Sustainability.* 15, 5429. doi: 10.3390/su15065429

Bond, T. C., Bhardwaj, E., Dong, R., Jogani, R., Jung, S., and Roden, C. (2007). Historical emissions of black and organic carbon aerosol from energy-related combustion 1850–2000. *Global biogeochemical cycles* 21. doi: 10.1029/2006GB002840

Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., and DeAngelo, B. J. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *J. geophysical research: Atmospheres.* 118, 5380–5552. doi: 10.1002/jgrd.50171

CAA (2021). *The risks from heavy fuel oil in the arctic*. Available online at: https://cleanarctic.org/campaigns/arctic-biodiversity/heavy-fuel-oil-free-arctic/ (Accessed July 23, 2023).

CCS (2015). *MEPC68 highlights quick facts*. Available online at: https://www.ccs.org.cn/ccswz/file/download?fileid=201900004000004327 (Accessed December 20, 2024).

Chen, Y. (2017). "Time to ask: what can China contribute to the Arctic," in *The law of the sea and emerging issues*. Eds. G. Xue and J. Zheng (Chinese democratic legal system press, Beijing), 106–117.

Chen, Y. (2018). "Can the Polar Code effectively mitigate the environmental and safety risks of Arctic shipping," in *Marine legal studies II*. Ed. G. Xue (Shanghai JiaoTong University Press, Shanghai), 108.

Chen, Y. (2023). China's arctic policy and engagement: review and prospects. *Asia Policy.* 18, 29–38. doi: 10.1353/asp.2023.0005

Chen, Y., and Gao, X. (2020). International regime for the use of Arctic marine resources and China's response. *Resource Science.* 42, 2062–2074. doi: 10.18402/resci.2020.11.02

Chen, Y., and Liu, Y. (2023). The contributions and constraints of NGOs in the arctic council: from a club theory perspective. *China Oceans Law Review.* 19, 192–221.

Chen, Y., and Liu, H. (2023). Critical perspectives on the new situation of global ocean governance. *Sustainability.* 15, 10921. doi: 10.3390/su151410921

Chen, Y., and Wang, Y. (2019). "The new trend after the Polar Code taking effect and its implications to the Arctic shipping governance," in *Report on arctic development*. Ed. H. Liu (Social sciences academic press, Beijing), 216–233.

Chen, Y., and Wang, Y. (2022). The north sea and svalbard fisheries management regimes in the context of brexit: divergence and implications. *Fishes.* 7, 351. doi: 10.3390/fishes7060351

China Financial News (2024). *Shanghai carbon market includes 31 shipping companies, 770,000 tonnes of carbon allowances traded annually*. Available online at: https://www.financialnews.com.cn/2024-04/22/content_291360.html (Accessed December 13, 2024).

Chongqing Municipal People's Government (2024). *Yangtze river green bulk carrier capacity pool established, 26 green bulk carriers in upper yangtze river to pilot carbon footprint accounting*. Available online at: https://www.cq.gov.cn/zwgk/zfxxgkml/zdlyxxgk/stbh/hjbh/202412/t20241213_13890038.html (Accessed December 16, 2024).

Clarkson Research (2023). *Clarkson Research: Chinese shipowners top the list*. Available online at: https://sin.clarksons.net/ (Accessed October 23, 2023).

Doelle, M., and Chircop, A. (2019). Decarbonizing international shipping: An appraisal of the IMO's initial strategy. *Rev. European Comp. Int. Environ. Law.* 3, 268–277.

EGBCM (2019). *Expert group on black carbon and methane summary of progress and recommendations 2019*. Available online at: https://oaarchive.arctic-council.org/handle/11374/714 (Accessed October 11, 2023).

High North News (2019). *IMO inches forward with ban on heavy fuel oil in arctic*. Available online at: https://www.highnorthnews.com/en/imo-inches-forward-ban-heavy-fuel-oil-arctic (Accessed July 23, 2023).

High North News (2020). *IMO mandate for low sulphur fuel results in high black carbon emissions endangering arctic*. Available online at: https://www.highnorthnews.com/en/imo-mandate-low-sulphur-fuel-results-high-black-carbon-emissions-endangering-arctic (Accessed August 23, 2023).

High North News (2022). *IMO again fails to act on black carbon emissions in arctic*. Available online at: https://www.highnorthnews.com/en/imo-again-fails-act-black-carbon-emissions-arctic (Accessed July 23, 2023).

High North News (2024). *IMO approves proposal for new emission control areas in norwegian and canadian arctic waters*. Available online at: https://www.highnorthnews.com/en/imo-approves-proposal-new-emission-control-areas-norwegian-and-canadian-arctic-waters (Accessed July 20, 2024)).

Huntington, H. P., Olsen, J., Zdor, E., Zagorskiy, A., Shin, H. C., and Romanenko, O. (2023). Effects of Arctic commercial shipping on environments and communities: context, governance, priorities. *Transportation Res. Part D: Transport Environment.* 118, 103731. doi: 10.1016/j.trd.2023.103731

ICCT (2017). *Prevalence of heavy fuel oil and black carbon in Arctic shipping 2015 to 2025*. Available online at: https://theicct.org/sites/default/files/publications/HFO-Arctic_ICCT_Report_01052017_vF.pdf (Accessed August 22, 2023).

ICCT (2019a). *Transitioning away from heavy fuel oil in Arctic shipping*. Available online at: https://theicct.org/publication/transitioning-away-from-heavy-fuel-oil-in-arctic-shipping/ (Accessed November 15, 2023).

ICCT (2019b). *IMO agrees that we can control black carbon emissions from ships. But will we.* Available online at: http://theicct.org/imo-agrees-that-we-can-control-black-carbon-emissions-from-ships-but-will-we/ (Accessed November 15, 2023).

IMO (2016). *ISWG-GHG 12: reducing GHG emissions from ships*. Available online at: https://www.imo.org/en/MediaCentre/PressBriefings/pages/ISWGHGMay2022.aspx (Accessed December 13, 2024).

IMO (2018). *Initial IMO GHG strategy*. Available online at: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx (Accessed August 22, 2023).

IMO (2019a). *PPR 7/8/3*. Available online at: https://www.euractiv.com/wp-content/uploads/sites/2/2020/01/PPR-7-8-3-The-need-for-urgent-action-to-stop-the-use-of-blended-low-sulphur-residual-fuels-leading-t-FOEI-WWF-Pacific-Enviro.pdf (Accessed August 22, 2023).

IMO (2019b). *PPR 7/8*. Available online at: https://www.euractiv.com/wp-content/uploads/sites/2/2020/01/PPR-7-8-Initial-results-of-a-Black-Carbon-measurement-campaign-with-emphasis-on-the-impact-of-the-Finland-and-Germany.pdf (Accessed August 22, 2023).

IMO (2022). *Marine environment protection committee (MEPC 70)*. Available online at: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-70th-session.aspx (Accessed December 13, 2024).

IMO (2023). *2023 IMO strategy on reduction of GHG emissions from ships*. Available online at: https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx (Accessed November 17, 2023).

IMO (2024). *Marine Environment Protection Committee 81st session (MEPC 81), 18-22 March 2024*. Available online at: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-81.aspx (Accessed July 22, 2024).

IPCC (2013). *Climate change 2013: the physical science basis*. Available online at: https://www.ipcc.ch/report/ar5/wg1/ (Accessed August 18, 2023).

IPCC (2019). *Special report on the ocean and cryosphere in a changing climate*. Available online at: https://www.ipcc.ch/srocc/ (Accessed December 20, 2024).

ISO (2022). *ISO 23453:2022*. Available online at: https://www.iso.org/standard/75620.html (Accessed December 13, 2024).

Keohane, R. O., and Victor, D. G. (2011). The regime complex for climate change. *Perspect. politics.* 9, 7–23.

Kim, Y. H., Min, S. K., Gillett, P., et al. (2023).Observationally-constrained projections of an ice-free Arctic even under a low emission scenario (Accessed December 22, 2023).

Koivurova, T. (2020). "The legal landscape in the Arctic – implications for the governance and security of the region," in *The future of Arctic security: The geopolitical pressure cooker and the consequences for the Netherlands. Clingendael Netherlands Institute of International Relations, Clingendael Report, Annex 2*. Eds. D. Julkaisussa, Z. K. Kruijver and A. Stoetman, (The Netherlands: lingendael Netherlands Institute of International Relations) 64–68.

Liu, H., and Chen, Y. (2010). A study on legal problems of the arctic from the perspective of climate change. *J. Ocean Univ. China: Soc. Sci. Edition*. 3, 1–5. doi: 10.3969/j.issn.1672-335X.2010.03.001

Liu, H., Mao, Z., and Li, X. (2023). Analysis of international shipping emissions reduction policy and China's participation. *Front. Mar. Sci.* 10, 1093533. doi: 10.16390/j.cnki.issn1672-0393.2012.06.021

MEPC (2010). *Marine Environment Protection Committee (MEPC) 61st session: 27 September to 1 October 2010*. Available online at: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-61st-Session.aspx (Accessed December 20, 2024).

MEPC (2011). *Marine Environment Protection Committee (MEPC) – 62nd session*. Available online at: https://www.imo.org/en/MediaCentre/SecretaryGeneral/Pages/MEPC-62.aspx (Accessed December 20, 2024).

MEPC (2021). *Resolution MEPC*. Available online at: https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.342(77).pdf (Accessed December 22, 2023).

Ministry of Transport of the People's Republic of China (2024). *Liu Wei attended the China-Russia Prime Ministers' Regular Meeting Committee First meeting of the Sub-Committee on Arctic Route Cooperation*. Available online at: https://www.mot.gov.cn/jiaotongyaowen/202411/t20241127_4160163.html (Accessed December 11, 2024).

Oberthür, S. (2009). Interplay management: enhancing environmental policy integration among international institutions. *Int. Environ. Agreements: Politics Law Economics.* 9, 371–391. doi: 10.1007/s10784-009-9109-7

Orsini, A., Morin, J. F., and Young, O. R. (2013). Regime complexes: A buzz, a boom, or a boost for global governance. *Global Governance: A Rev. Multilateralism Int. Organizations.* 19, 27–39. doi: 10.1163/19426720-01901003

PAME (2009). *The arctic shipping assessment report 2009*. Available online at: https://www.pame.is/index.php/projects/arctic-marine-shipping/amsa (Accessed July 17, 2023).

PAME (2019). *Heavy Fuel Oil use by Ships in the Arctic 2019*. Available online at: https://oaarchive.arctic-council.org/handle/11374/2735 (Accessed July 22, 2023).

PAME (2020). *The increase in arctic shipping 2013-2019*. Available online at: https://www.pame.is/document-library/shipping-documents/arctic-ship-traffic-data-documents/reports/arctic-shipping-status-reports-jpg-version/arctic-shipping-report-1-the-increase-in-arctic-shipping-2013-2019-jpgs (Accessed December 22, 2023).

PAME (2021). *Report on shipping in the northwest passage launched*. Available online at: https://arctic-council.org/news/report-on-shipping-in-the-northwest-passage-launched/ (Accessed October 12, 2023).

PAME (2023). *Flag states of ships in the arctic*. Available online at: https://oaarchive.arctic-council.org/items/e229d1aa-a620-4484-b989-9eefdccb4f25/full (Accessed December 15, 2023).

PAME (2024a). *The increase in Arctic Shipping: 2013-2023*. Available online at: https://oaarchive.arctic-council.org/items/01ddf449-9048-4d6a-a056-65303831bb63 (Accessed July 15,2024).

PAME (2024b). *Arctic shipping status report 5: types of ships in the arctic*. Available online at: https://pame.is/projects-new/arctic-shipping/pame-shipping-highlights/411-arctic-shipping-status-reports (Accessed July 22, 2024).

Pan, M., and Huntington, H. P. (2024). China-US cooperation in the Arctic Ocean: Prospects for a new Arctic exceptionalism. *Mar. Policy.* 168, 106294. doi: 10.1016/j.marpol.2024.106294

PCC (2021). *Climate change 2021: the physical science basis*. Available online at: https://www.ipcc.ch/report/ar6/wg1/ (Accessed December 20, 2024).

People's Daily (2021). *Peak carbon and carbon neutrality - the way to green development*. Available online at: http://env.people.com.cn/n1/2021/0813/c1010-32192059.html (Accessed December 15, 2024).

People's Daily Online (2022). *The world's largest pure electric cruise ship "Three Gorges of the Yangtze River 1" has a range of 100 kilometers on a single charge*. Available online at: http://finance.people.com.cn/n1/2022/0330/c1004-32387856.html (Accessed December 16, 2024).

Qi, X., Li, Z., Zhao, C., Zhang, Q., and Zhou, Y. (2024). Environmental impacts of Arctic shipping activities: A review. *Ocean Coast. Management.* 247, 106936. doi: 10.1016/j.ocecoaman.2023.106936

Rantanen, M., Karpechko, A. Y., Lipponen, A., Nordling, K., Hyvärinen, O., and Ruosteenoja, K. (2022). The Arctic has warmed nearly four times faster than the globe since 1979. *Commun. Earth environment.* 3, 168. doi: 10.1038/s43247-022-00498-3

Raustiala, K., and Victor, D. G. (2004). The regime complex for plant genetic resources. *Int. Organization.* 55, 277–309. doi: 10.2139/ssrn.441463

Sofiev, M., Winebrake, J. J., Johansson, L., Carr, E. W., Prank, M., and Soares, J. (2018). Cleaner fuels for ships provide public health benefits with climate tradeoffs. *Nat. Commun.* 9, 406. doi: 10.1038/s41467-017-02774-9

Trevisanut, S., Giannopoulos, N., and Holst, R. R. (2020). *Regime interaction in ocean governance: problems, theories and methods (Vol. 91)* (Leiden, Netherlands: Brill).

Van Asselt, H. (2014). *The fragmentation of global climate governance: Consequences and management of regime interactions* (Cheltenham, UK: Edward Elgar Publishing).

Wang, C., Liu, D., Tao, R., Wang, X., and Shan, H. (2023). Analysis of carbon emission reduction effect and policy effect in Arctic region based on double difference model. *J. Cent. China Normal Univ. (Natural Sciences).* 57, 140–142. doi: 10.19603/j.cnki.1000-1190.2023.01.013

Winther, M., Christensen, J. H., Plejdrup, M. S., Ravn, E. S., Eriksson, Ó. F., and Kristensen, H. O. (2014). Emission inventories for ships in the arctic based on satellite sampled AIS data. *Atmospheric Environment.* 91, 1–14. doi: 10.1016/j.atmosenv.2014.03.006

Young, O. R. (1996). Institutional linkages in international society: polar perspectives. *Global Governance.* 2, 1–24. doi: 10.1163/19426720-002-01-90000002

Young, O. R. (2016). The arctic council at twenty: how to remain effective in a rapidly changing environment. *Univ. California Irvine Law Review.* 6, 99–119.

Young, O. R., and Kim, J. D. (2021). Next steps in Arctic Ocean Governance Meeting the challenge of coordinating a dynamic regime complex. *Mar. Policy.* 133, 104726. doi: 10.1016/j.marpol.2021.104726

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 21 February 2025
DOI 10.3389/fmars.2025.1503748

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Moe Sin,
University of Malaysia Terengganu, Malaysia
Arie Afriansyah,
University of Indonesia, Indonesia

*CORRESPONDENCE
Muhammad Murad Zaib Butt
muradzaib98@gmail.com
Liu Lina
liulina@xjtu.edu.cn

†These authors share first authorship

RECEIVED 29 September 2024
ACCEPTED 22 January 2025
PUBLISHED 21 February 2025

CITATION
Lina L and Murad Zaib Butt M (2025) Analysing Pakistan's fisheries legislation and institutional framework: integrating Sustainable Development Goal 14 within the scope of International Fisheries Law.
Front. Mar. Sci. 12:1503748.
doi: 10.3389/fmars.2025.1503748

COPYRIGHT
© 2025 Lina and Murad Zaib Butt. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Analysing Pakistan's fisheries legislation and institutional framework: integrating Sustainable Development Goal 14 within the scope of International Fisheries Law

Liu Lina*† and Muhammad Murad Zaib Butt*†

School of Law, Xi'an Jiao Tong University, Xi'an, Shaanxi, China

International Fisheries Law (IFL) provides innovative approaches to fisheries governance at national levels. The emergence of Sustainable Development Goal 14 (SDG 14) is phenomenal for fisheries because it creates new means for implementing IFL. Under SDG 14, fisheries governance for sustainable fisheries has become a complex and challenging task for any state. Developing States like Pakistan are struggling to achieve SDG 14 with new approaches to fisheries governance. The current situation of fisheries governance in Pakistan motivated the content of this research paper. This research paper adopted the comprehensive literature review (CLR) methodology to analyse existing fisheries governance mechanisms in Pakistan. Besides CLR, the paper also analysed a 'case study' on fisheries governance of Pakistan entitled 'National Policy and Strategy for Marine Fisheries. Furthermore, one hundred sixty-seven research articles and national and international legislation on fisheries governance from 2010 - 2023 are analysed. The results of the CLR methodology suggested that an extensive integrated mechanism under a comprehensive framework should be developed for fisheries governance. The framework forwarded a policy mechanism incorporating sustainable development goals with SDG 14 that should be implemented coherently for sustainable fisheries. The discussion followed the analysis and suggested that regional to local and bottom-up and top-down approaches in fisheries governance are required to address the challenges to sustainable fisheries in Pakistan. The conclusion of the discussion portrayed that future research related to fisheries governance in Pakistan shall be based on the practical implementation of SDG 14.

KEYWORDS

fisheries governance, SDG 14, Pakistan, International Fisheries Law, South Asia

1 Introduction

Marine fisheries as an industry in the Islamic Republic of Pakistan (Pakistan) was initiated after independence in 1947. In 1958, a fish harbour was constructed in Karachi to expand marine fisheries resources (Siddiqi, 1992). Pakistan became aware of its potential in marine fisheries and developed a mechanised ocean exploitation system. While recognising the importance of international fisheries trade and other multilateral economic ties, Pakistan formally became a member of the United Nations (UN) in 1947 (Kaczan and Patil, 2020). It initiated a process of adopting international law instruments (including ocean and fisheries) into its national legal system. Pakistan has signed and ratified crucial international law instruments related to public health, human development, and environmental protection, directly or indirectly related to the global, regional, and national fisheries governance mechanisms (Shahzad and Gillani, 2022).

While vigorously participating in the UN General Assembly (as a permanent member) and Security Council (as a non-permanent member), Pakistan has joined important international fisheries organisations, including but not limited to the UN Division for Ocean Affairs and the Law of the Sea (UN-DOALAS), Food and Agriculture Organization (FAO), United Nations Development Programme (UNDP), World Food Programme (WFP), International Union for Conversation of Nature (IUCN), United Nations Environment Programme (UNEP) and International Maritime Organization (IMO) (Hussain and Bhatti, 2023). International organisations endorse fisheries as a pertinent part of ocean governance besides marine environment and coastal conservation (Panneerselvam, 2017). The international organisations also ratified the Sustainable Development Goal 14 (SDG 14) to protect and preserve 'life below water'. SDG 14 is divided into three parts: i) marine environmental protection, ii) conservation of coastal and marine areas and iii) preservation of fisheries (Zhang et al., 2024).

Various developed States have already adopted the approaches provided by SDG 14 for fisheries and ocean governance. Albeit in ways, developing States like Pakistan are far behind in the effective implementation of SDG 14. In this scenario, Regional Fisheries Management Organisations (RFMOs) and aforementioned international organisations assist the developing States (like Pakistan) in forming and enabling institutions for national and local implementation of SDG 14 (Andrew and Lugten, 2008). The (fisheries-related) organisations provide different guidelines under international and regional conventions, treaties and declarations to develop appropriate legal and policy frameworks with institutional mechanisms to effectively implement SDG 14 (Butt et al., 2022).

SDG 14 advocates for local implementation of international instruments related to fisheries or international fisheries law (IFL). SDG 14 states that local implementation mechanisms are developed systematically with national, regional and international law instruments. This approach is also known as a bottom-up approach of implementation through top-down policy and governance (Cormier and Elliott, 2017). Therefore, a critical step in implementing SDG 14 in (States like) Pakistan shall be effective local governance, operative national policy, robust regional cooperation and better participation in international organisations. Integration of national policies with local, regional and global systems is becoming imperative for (developing States like) Pakistan because of its involvement in regional projects through bilateral arrangements (for example, China's Belt and Road Initiative) (Zhang et al., 2023a). The fisheries resources exhibit great potential for emerging economic opportunities (under regional initiatives) in (States like) Pakistan. At the same time, fisheries are threatened due to marine pollution, climate change, depletion, and unregulated fishing practices (Khawaja et al., 2018).

Considering such significance, Pakistan's marine fisheries are now strategically important and integral to the economy. However, the threat to fisheries resources is increasing, and Pakistan has no specific umbrella legislation governing marine fisheries. Although Pakistan has signed and ratified several IFL instruments, there is a lack of coordinated policy mechanisms and effective fisheries governance. In the context of SDG 14, it is argued that Pakistan shall rearrange its segmented and fragmented rules and regulations of fisheries governance (Awais et al., 2019). For such purposes, Pakistan shall establish constructive policies and legislation for the long-term conservation and protection of marine fisheries.

Given the above, Pakistan needs to address the knowledge, institutional capacity building and science-policy gaps in fisheries governance. This research paper is motivated by the existing situation of fisheries governance in Pakistan, and it has analysed existing legislative and policy frameworks, institutional capacity, and mechanisms of fisheries governance in Pakistan. This paper adopted the 'Comprehensive (international, regional and national) Law and Literature Review (on the subject matter) (CLR)' methodology and data (based on reports) for analysis (Zulfiqar and Butt, 2021). The methodology is applied in two sections according to standards. The first section analyses the existing IFL to establish a research framework, and the second section analyses Pakistan's existing legislation, policies, and data.

In the next section, this paper explains the CLR methodology process, a step-by-step application and analysis procedure. After initiating and reviewing IFL and relevant literature (from 2010 – 2023), a research framework with policy principles is established under the objectives of SDG 14. The developed research framework analyses Pakistan's fisheries policy, legislation and governance mechanisms. In Section 4.1, the CLR methodology is applied in the context of Pakistan, analysing the existing reports and a case study of fragmentation among central and provincial governments (National Policy and Strategy for Fisheries and Aquaculture Development in Pakistan - Part - I, 2007). After applying the research framework, this paper observed the gaps and lacunas in existing fisheries governance mechanisms in Pakistan. The suggestions are made based on CLR that legislative reform and improvement in institutional mechanisms can help Pakistan achieve fisheries goals as provided under SDG 14.

2 Section I of methodology – comprehensive literature review of international law

This paper adopts a comprehensive approach to investigate the policy, legislation and governance mechanisms for effective implementation. In this section, a comprehensive approach has been applied to establish a 'Research Framework' (for national governance) that will assist in reviewing the (existing) 'Legislation', 'Literature' and 'Policy' of the particular national governance mechanism (Hussain and Bhatti, 2023). The CLR methodology was adopted after reviewing various research articles on 'law and governance'. The CLR methodology adopted by the research articles on law and governance provided significant results and innovatively discussed policy implications. Therefore, it is stated that CLR is a methodology that helps to demonstrate the existing best practices of law enforcement (Hunt and Watkiss, 2011).

The CLR methodology takes one of two forms: analysis of the existing literature on international law and global governance and the analysis of the existing policies, legislation and literature on national implementation (Zulfiqar and Butt, 2021). From this perspective, the CLR methodology also assists in analysing the reports and case studies conducted by non-governmental and governmental organisations. The two forms of CLR methodology (analysis of the existing literature on the IFL and the analysis of the existing policies, legislation and literature on Pakistan fisheries governance) align seamlessly with the research objectives as stated above (Butt et al., 2021a). The methodology allowed for a holistic exploration of the interplay between legislation and institutional practices in achieving SDG 14 targets in Pakistan.

CLR integrates qualitative and quantitative methodologies as a research design, enabling a thorough examination of the literature, policy and legal instruments governing fisheries, and the practical implications of institutional arrangements (Hunt and Watkiss, 2011). The qualitative aspect involved an in-depth analysis of relevant legal documents, encompassing policies, regulations, and agreements pertinent to fisheries governance at international and regional levels. The quantitative aspect assists in developing legal principles and governance rules to achieve sustainable fisheries.

2.1 Data selection mechanism – articles selected for the CLR

The data extraction and selection method is provided below in steps that establish a reasonable basis for developing the research framework for fisheries governance utilised in this paper (Table 1). One hundred and sixty-seven articles were selected through the stepwise method (as provided below and shown in Figure 1) that matches the keywords of governance principles under international law. The governance principles are selected based on repetition and reiteration in the literature on IFL and Sustainable Development Goals (SDGs) that establish mechanisms to achieve sustainability.

2.1.1 Step 1

The data for this paper was extracted from three sources: i) Web of Science, ii) Google Scholar, and iii) Research Gate. The sources are the primary databases for updated research articles on any subject and are globally recognised. Therefore, many researchers and scholars widely utilise these sources (databases) to review the literature and available data on any topic (Papaioannou et al., 2010).

2.1.2 Step 2

The search criteria for extracting the articles were: i) 'fisheries governance', ii) 'international fisheries law', iii) 'fisheries management', iv) 'regional fisheries management organisations', and v) 'global fisheries law' under the timeline of years 2010 – 2023.

2.1.3 Step 3

After reviewing international law on global fisheries governance, the selection criteria of the articles were established. That criterion is the governance principles of international law as provided below:

i. ecosystem-based approach,
ii. cooperation,
iii. science-policy integration,
iv. precautionary measures, and
v. institutional capacity.

TABLE 1 Stepwise application of CLR methodology.

Step – 1 The databases	Step – 2 Search Criteria and Terms/Keywords	Step – 3 Establishing Principles	Step – 4 Selection of Articles	Step – 5 Review, Writing and Developing Research Framework
→	→	→	→	→
• **Web of Science** • **Google Scholar** • **Research Gate**	• fisheries governance • international fisheries law fisheries management• • regional fisheries management organisations • global fisheries law	• ecosystem-based approach • cooperation • science-policy integration precautionary measures• • Institutional capacity (for implementation)	• Selection of 85 articles each on International Fisheries Law and Governance and National and Regional Fisheries Law and Governance	• Review from SDG 14 Perspectives

Refer to Supplementary Material and as Explanation Below.
The arrows portray stepwise approach and bold letters indicate from where the data has been taken as shown in the header of the table.

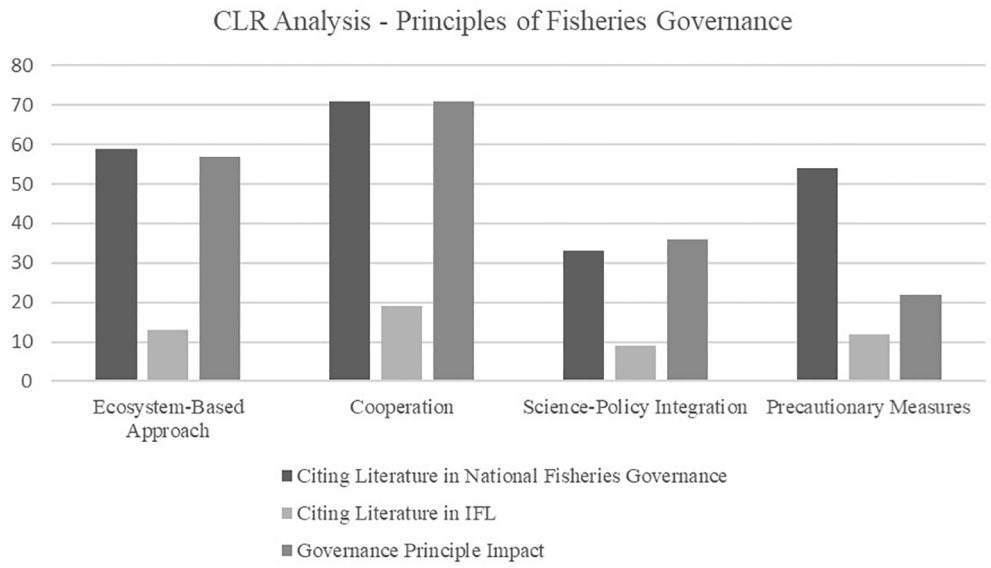


FIGURE 1
Principles extracted by utilizing CLR and their references in International Law. Source: CLR Analysis – Supplementary Tables 1 and 2.

The given principles are repetitively utilised in the literature related to IFL and governance and related to RFMOs (further details of the given principles are provided in the sections below).

2.1.4 Step 4

After utilising the search criteria of the given principles, one hundred and sixty-seven (167) articles on international, national, and regional fisheries' governance were selected for further review.

2.1.5 Step 5

Due to the importance of SDG 14 in fisheries governance, the articles from 2010 – 2015 were selected based on discussion on the 'importance of sustainability in fisheries'. Further articles from 2015 – 2023 were selected based on discussion on 'integration of SDG 14 in fisheries'.

2.2 Next steps for CLR

The timeline for selected articles is made based on 'updates in data and recent developments' (Rotenberg and Jacobs, 2013). These bases are adopted with the given developments of timeline in international law for sustainable development. The update in data and developments is used in CLR to provide the latest structures of governance as provided in IFL. Therefore, the bases and CLR provided a clear structure for analysing fisheries governance in Pakistan under SDG 14 and IFL perspectives (Fabbri, 1998).[1]

The selected articles were further divided into two categories: first, they provided the top-down approach of IFL in national governance mechanisms, and second, they provided a bottom-up approach to fisheries governance through national governance and RFMOs (Matz-Lück and Al-Hajjaji, 2024). The principles of IFL (as reiterated in the articles) are discussed in a manner that establishes the legitimacy of the research framework, as provided in Figure 1, Table 2. The selected articles with the IFL and SDG 14 perspectives clarified how coordinated mechanisms can be developed to achieve 'sustainable fisheries'.

2.3 Review of selected articles from SDG 14 and IFL perspectives

The primary instrument governing global fisheries is the United Nations Convention on Law of the Sea (UNCLOS) (United Nations Convention on Law of the Sea, 1982). Under UNCLOS, coastal states are granted jurisdiction over fisheries within their Exclusive Economic Zones (EEZs) and are tasked with implementing measures to ensure the sustainable use of fisheries (Alencar Mayer Feitosa Ventura, 2020b). Such a position of the UNCLOS develops a nexus between national fisheries institutions and RFMOs and also urges institutional capacity building (Table 2). Fifty-six articles selected through this CLR established that the principles of fisheries governance for 'coordination' between national and regional institutions are requisite to achieve sustainable fisheries (Rahman, 2023). Furthermore, thirty-two articles discussed the role of the United Nations Declaration on Environment and Development (Rio Declaration) in the preservation and sustainable exploitation of fisheries with institutional capacity building and coordination.

During the Earth Summit, three international agreements emphasised sustainable fisheries, including the Rio Declaration and the Convention on Biological Diversity (CBD) (Table 1; Figure 2) (Convention on Biological Diversity, 1992; United Nations

1 The formula used for quantitative analysis for governance establishes the rules and principles of international law which are utilised for administration of an institution.

TABLE 2 Purpose of the IFL in national fisheries governance.

Year	IFL	Citing Literature	Relevant Principle	Sustainable Fisheries Objectives
1982	UN Law of the Sea Convention	56	Reiterated all the principles for fisheries governance	Promote and Enhance the Preservation of Fisheries
1992 (Earth Summit)	Rio Declaration	32	Ditto	Preservation of Genetic Resources and Biodiversity (including fisheries)
	Convention on Biological Diversity	16	Science-policy integration	
	United Nations Framework Convention on Climate Change	19	Cooperation in all forms of governance, including ocean and fisheries	Preservation of Oceans as an ecosystem – including Fisheries as its part
1995	FAO Code of Conduct for Responsible Fisheries (CCRF)	61	Precautionary Measures in Fisheries Governance – Institutional Capacity at National Levels	Promote research on fisheries and relevant ecosystems to sustain fisheries as a stock
1995	CBD Jakarta Mandate on Marine and Coastal Biological Diversity	35	Cooperation in all forms of governance, including ocean and fisheries	Facilitate research and other activities which assist in achieving sustainable fisheries
2001	UN Fish Stocks Agreement	63	Under the UNCLOS, all principles are reiterated	Preservation of fish stocks
2002	Johannesburg Declaration on Sustainable Development and Plan of Implementation	10	Reinforcement of Sustainability and Improvement of Institutional Capacity	Preservation of ecosystems (including fisheries)
2015	The 2030 Agenda for Sustainable Development or Sustainable Development Goals	22	Reiterated all the principles for fisheries governance and Enhancing Institutional Capacity	Preservation of ecosystems, marine scientific research and other associated programmes for sustainable fisheries

Source: Developed through the conduct of CLR – International Legal Framework for Fisheries Governance.

Conference on Environment and Development/Rio Declaration on Environment and Development, 1992). Effective implementation of CBD envisions the interconnectivity of SDG 14 with other SDGs because the impact of marine pollution (mainly from land-based sources), climate change, and biodiversity protection on fisheries was realised by the parties at the Earth Summit. As the impacts of climate change were visible on the ocean and fisheries, the United Nations Framework Convention on Climate Change (UNFCCC) also became a relevant instrument in fisheries governance (Table 1; Figure 2) (United Nations Framework Convention on Climate Change, 1992).

Sixteen articles thoroughly discussed fisheries as part of biodiversity protection, and nineteen articles discussed the impacts of climate change on fisheries. In this manner, these articles connected SDG 14 (for fisheries governance), SDG 6 for clean water and sanitation (as part of land-based pollution, sanitation impacts the marine environment and fisheries), SDG 12 on responsible consumption (because overconsumption impacts biodiversity) and SDG 13 on Climate Change (because climate change is affecting oceans and fisheries) (Arlinghaus et al., 2019).

Responsible consumption is part of responsible fisheries under the IFL, as discussed in sixty-one articles related to the FAO Code of Conduct for Responsible Fisheries (CCRF). Furthermore, sixty-three articles urge the States to enhance 'institutional capacity' for responsible fisheries because fisheries are part of nutrition as provided under SDG 2 (for improved nutrition) (Carlisle and Gruby, 2018). The Agreement relating to the Implementation of Part XI of the UNCLOS (Implementing Agreement about the Area and its resources) and the Agreement Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UN Fish Stocks Agreement) precisely regulate fisheries in a particular manner (as discussed in sixty-three articles and mentioned in Table 2, Figure 2) (Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, 1995).

The aforementioned international instruments, as part of IFL, urge States to develop mechanisms of 'total-allowable catch (TAC)' under the principle of 'maximum sustainable yield (MSY)' (Andrew and Lugten, 2008). Such provision of MSY provides that institutions governing marine fisheries shall adopt an 'ecosystem-based approach'. As part of the UNCLOS and CBD, the Jakarta Mandate on Marine and Coastal Biological Diversity further provides that enhancing 'institutional capacity' under the principles of 'precautionary measures' and 'science-policy integration' is part of fisheries governance under IFL (Dereynier, 1998). Accurate information about the fisheries, trained personnel, relevant research capabilities, and equipment for analysis are part of the institutional capacity provided in Jakarta Mandate (also discussed in thirty-five articles).

The principles of governance establishing mechanisms for implementation are mainly part of SDG 14 and SDG 17 (Strengthen the means of implementation and revitalise the Global Partnership for Sustainable Development) (Mamun et al.,

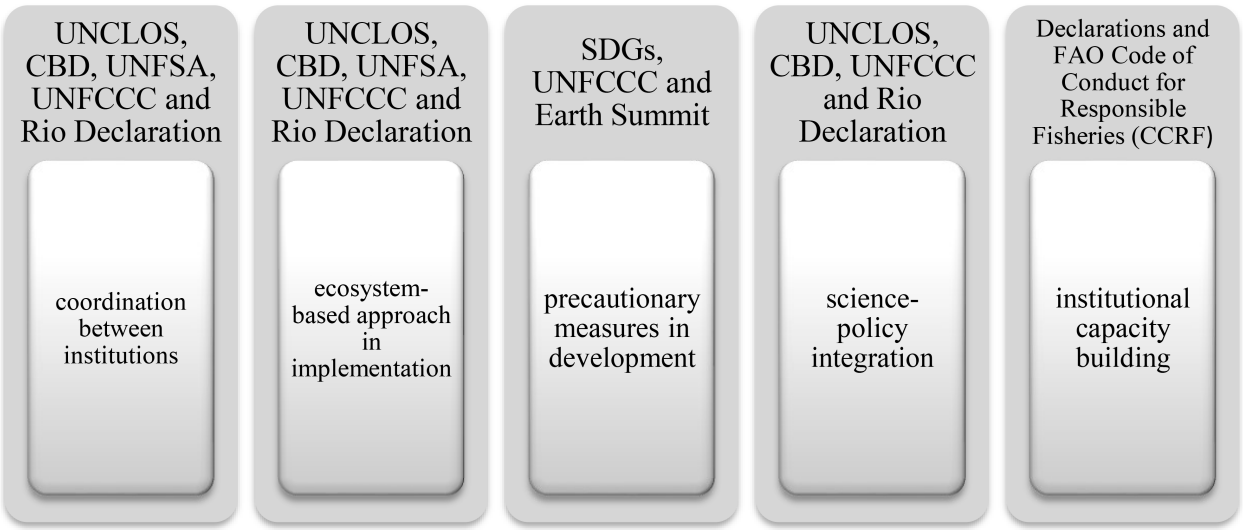


FIGURE 2
Citation of each principle in International Law. Source: CLR Analysis – Supplementary Data Available.

2016). 'Science-policy integration' in SDG 14 and SDG 17 is based on scientific information in governance objectives. Similarly, 'precautionary measures' are part of IFL that provide means for preventing marine pollution. Furthermore, 'coordination' and 'ecosystem-based approach' are envisioned in policy coherence and multistakeholder partnerships. 'Institutional capacity' is developed with the appropriate knowledge and research, technical training and equipment, effective monitoring and robust financial structure as per SDG 17 (Spijkers et al., 2023).

3 Towards research framework – principles for fisheries governance under IFL

The selected articles on IFL further explained how a legal framework for national fisheries governance should be developed. The rules and principles reiterated in the research articles have a unique capacity to develop a mechanism for coordination between institutions, institutional capacity building, science-policy integration, ecosystem-based approach in implementation and precautionary measures in development (Zhang et al., 2023b). The rules and principles are used to establish multiple modes of fisheries governance and their evolving patterns in interpretative debates (Butt and Chang, 2021). The rules and principles also demonstrate that a top-down approach is required for legislation under IFL and a bottom-up approach for implementation mechanisms.

With an apparent resolution of the conflict, the rules formed are determined by interpreting research articles. The success of the rules is measured through an effective implementation mechanism. The impact of principles is determined by the ratio of their repetition in articles (Figure 1). The reviewed articles provided that the principles are cooperative with common interests, are interpreted through the literature and are applicable to the national legislation of various States. The principles are interconnected because they intersect with each other and guide the States to develop a legislative system, which shall be from the national to the local level. As reflected in these principles, the reforms required are rigorous, iterative and transparent through consensus-building. Therefore, through quantitative analysis, CLR methodology provides qualitative discussion to develop the impact of the principles on a scale of governance. The impact of a principle is measured through its repetition in research articles, as shown in Figure 1.

While understanding how the legal provisions should be manoeuvred at national levels, CLR methodology further involves extracting information from legal documents regarding the roles of institutions involved at local and sub-national levels (Table 2; Figure 2). The principles are further explained below in a manner that connects with SDGs as a whole and SDG 14 in principle. The principles are reiterated in SDGs for global sustainable development and can be applied to fisheries governance under SDG-14, as shown in Figures 2, 3. In the following sections, the institutional arrangements encompassing the organisational structures, roles, and responsibilities assigned to various entities involved in fisheries governance are analysed under the given principles.

3.1 Ecosystem-based approach

An ecosystem-based approach is a fundamental principle for governing complex marine ecosystems, including fisheries, as emphasised by IFL instruments, including UNCLOS and the Earth Summit (Atkins et al., 2011). The UNCLOS advocates the integrated nature of fisheries and supports the ecosystem-based approach, which involves recognising the interdependence of environmental components (Cicin-Sain and Knecht, 1993). This approach necessitates cooperation across governing institutions and consistent legislation from international to local levels to align with

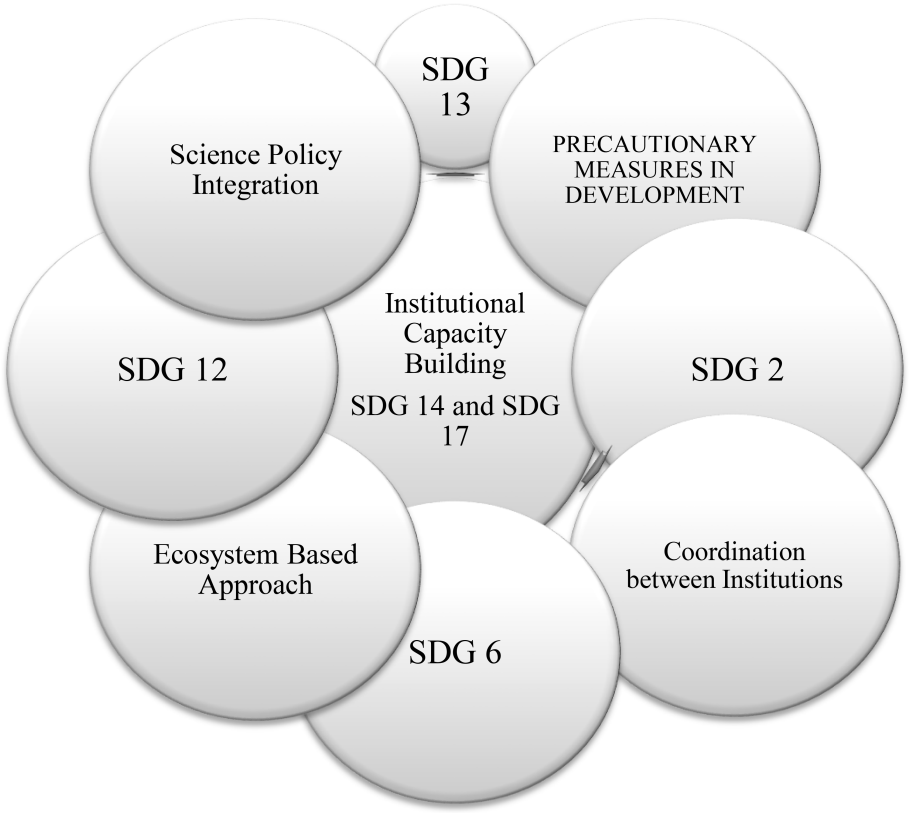


FIGURE 3
Interconnected SDGs with SDG-14. Source: CLR Analysis – Supplementary Data Available.

SDG 14 (Alencar Mayer Feitosa Ventura, 2020a). The ecosystem-based approach links SDG 14 with SDG 13 (Climate Action), SDG 6 (Clean Water and Sanitation), and SDG 17 (Policy Coherence) (Figures 2, 3) (Friess et al., 2019). SDG 13 highlights the need to integrate climate change into national strategies, making it crucial for fisheries governance. SDG 6 calls for reducing waste, recycling wastewater, and minimizing agricultural runoff to protect marine ecosystems (Final list of proposed Sustainable Development Goal indicators, 2016). SDG 17 emphasises policy coherence, advocating for integrated, intersectoral governance. Collectively, these SDGs underscore the need for an interconnected, ecosystem-based policymaking process to ensure effective fisheries management and sustainability.

3.2 Coordination

Effective coordination, supported by robust monitoring and information-sharing systems, is crucial for building institutional capacity and driving technical development in fisheries governance (Kim, 2023). Legal reforms, expert capabilities, and adequate resources are essential to strengthen these processes (as shown in Figures 2, 3) (Schubert and Gupta, 2013). Coordination is best achieved through a bottom-up approach, where local institutions monitor and share data with higher-level institutions, ensuring alignment across governance scales. Institutional coordination is vital for sustainable fisheries management, encompassing cooperation across all relevant ocean and environmental ecosystem institutions (Figures 2, 3) (Al Arif, 2017). SDG 14 highlights the need for scientific collaboration at all levels, linking fisheries governance with SDG 2 (food security and nutrition), SDG 6 (clean water), and SDG 13 (climate action). SDG 2 calls for addressing malnutrition and reducing overproduction and overconsumption of fisheries. Interconnections between SDGs 6, 13, and 14 further underscore the importance of national-level coordination to address fisheries-related challenges effectively (Zhang et al., 2024).

3.3 Science-policy integration

Science-policy integration in fisheries governance means policy decisions informed by scientific knowledge for sustainable fisheries governance. The Earth Summit established that effective governance mechanisms require scientific data to inform policy frameworks (Butt et al., 2021b). SDG 14 reinforces this by urging states to enhance scientific knowledge and research capacity to protect marine biodiversity, linking fisheries governance to SDG 13 (climate

action) and SDG 17 (policy coherence). Scientific data is critical for fisheries management concepts like Total Allowable Catch (TAC), Maximum Sustainable Yield (MSY), and precautionary measures under the Biosafety Protocol (Achbari, 2015). This principle requires cooperation between institutions, with scientists supporting policymakers in addressing overfishing, environmental threats, and illegal, unreported, and unregulated (IUU) fishing (Figures 2, 3) (Convention on international trade in endangered species of wild fauna and flora 1973 (Enforced 1975), n.d.). The integration of scientific information is also vital for monitoring climate change and pollution under SDG 13 and for ecosystem-based governance approaches implemented through top-down methods. The interconnected principles of science-policy integration, cooperation, and an ecosystem-based approach were foundational elements of the Earth Summit and international agreements like CITES (Chircop, 2010).

3.4 Precautionary approach or measures

Precautionary measures in fisheries governance are to mitigate the impacts of development and production on ecosystems. SDG 14 emphasises the need for regulating fisheries harvesting, ending overfishing, combating IUU fishing, and implementing science-based management plans to restore fish stocks to sustainable levels (MSY) (Kaebnick et al., 2016). These precautionary approaches are critical for addressing issues like climate change, pollution, and ecosystem degradation, which are interconnected with SDG 14 and other related SDGs. The Rio Declaration establishes precautionary measures as a fundamental principle, urging their adoption before any development or use of genetic resources to prevent significant environmental harm (Figures 2, 3) (Fousteris et al., 2018). This approach is integrated into fisheries governance frameworks to combat overfishing, IUU fishing, and fish stock depletion, which negatively impact marine ecosystems (Convention for Cooperation in the Protection and Sustainable Development of the Marine and Coastal Environment of the Northeast Pacific, 2002). As a legal and policy principle, the precautionary approach is linked with other governance principles and forms a core part of sustainable fisheries management.

3.5 Institutional capacity building

Institutional capacity building in fisheries governance involves enhancing the ability of institutions to implement laws, policies, and regulations effectively (Ibrahimi, 2017). Institutions play a critical role in managing fisheries across all stages, from hatching to export, by enabling effective policies and ensuring robust monitoring and reporting mechanisms supported by data and research. They also facilitate communication, policy development, and collaboration with stakeholders (Kim, 2023). SDG 14 underscores the importance of institutional capacity building, linking it to the integration of scientific knowledge and the transfer of marine technology to ensure the effective implementation of the IFL (Figures 2, 3).

4 Assessment of existing legislation and institutional framework of Pakistan based on rules and principles of research framework

The results of the CLR indicate that a legal framework based on five principles is required to govern fisheries. The principles consistently develop cooperation among institutions, integrate scientific information into policy, and consider interconnected issues like climate change and pollution (Allison, 2001). The ecosystem-based approach is a fundamental principle for governing complex marine systems and fisheries, as emphasised in IFL and SDG 14. SDG 14 aligns closely with the ecosystem approach and can serve as a comprehensive framework for implementing IFL. Improved coherence across governing instruments and increased cooperation among institutions are necessary to govern fisheries effectively.

In this section, the fisheries governance framework of Pakistan is analysed based on the principles of fisheries governance as established above through the CLR of IFL. This section describes the applied methodology for a comprehensive analysis of law, policy and governance framework for fisheries in Pakistan. The analysis in this section is based on CLR (comprehensive review of law and literature) related to Pakistan's fisheries governance mechanism. This analysis is divided into three parts because Pakistan is a pertinent player in global and regional governance. Therefore, the fisheries governance framework of Pakistan has been analysed through three parts: i) Pakistan in International Fisheries, ii) Pakistan in Regional Fisheries and iii) the National Fisheries Governance Framework of Pakistan (Khan and Khan, 2011).

4.1 Section II of methodology – CLR (review of law and literature) of fisheries governance in Pakistan (case study and analysis)

This part has argued that international and regional developments are pertinent to Pakistan's national fisheries governance. It has been observed that Pakistan, as a state, recognises marine fisheries as a global, regional, and national subject. The practical governance mechanisms of Pakistan are analysed by determining its relationships with regional fisheries governance organisations. In this manner, the CLR methodology captures how responsibilities are distributed and coordinated among different entities. Similar stepwise methods have been used for this part of CLR to observe how IFL and RFMOs have impacted fisheries governance in Pakistan.

Therefore, CLR assists in identifying government agencies, departments, and other institutions responsible for implementing and overseeing the fisheries policies and regulations.

4.1.1 Step 1

The articles on the Web of Science, Google Scholar, and Research Gate related to Pakistan's fisheries' governance were selected.

4.1.2 Step 2

Due to the scarcity of literature on the subject, the search terms were 'fisheries + management + governance + law + Pakistan'. These terms produced relatively low output, with no more than fifty research articles.

4.1.3 Step 3

The principles searched in these articles are also in meagre numbers as compared to governance principles' impact (Figure 4).

4.1.4 Step 4

Review of Law – federal and provincial laws, rules, regulations and policies are analysed and presented below. An analysis is conducted to determine whether Pakistan has followed international law principles, and the results can be observed below.

The literature review on fisheries governance in Pakistan observed that institutional capacity is the major problem. Nine articles discussed institutional capacity issues in national and local fisheries governance, and eleven articles raised concerns about institutions not having an appropriate international engagement policy (Figure 4). Seven articles suggested engaging with RFMOs for institutional capacity building, marine technology development, transfer, and information exchange. Ten articles recommended that Pakistan adopt technological means for information and assessment through international organisations, including the World Trade Organization (WTO) and FAO (Figure 4).

Eleven articles raised concerns about the lack of an ecosystem-based approach to fisheries governance in Pakistan (Panneerselvam, 2017). These articles suggested that such approaches are necessary to preserve fisheries sustainably. Fifteen articles discussed a similar approach differently, entitled 'lack of cooperation' between local, national and regional institutions in fisheries governance (Noman et al., 2022). The articles suggested that Pakistan should cooperate with the South Asian Region and neighbouring States (mainly China) in fisheries governance (Figure 4). Bilateralism in fisheries governance with China shall assist Pakistan in transferring marine technology and sustainable practices to preserve fish stocks and to develop mechanisms for long-term sustainability in fisheries production (Ahmed et al., 2019).

4.2 National policy and strategy for fisheries and aquaculture development in Pakistan – case study

Initially, there was no specific mechanism in Pakistan for fisheries governance. In 1987, the Agricultural Commission,

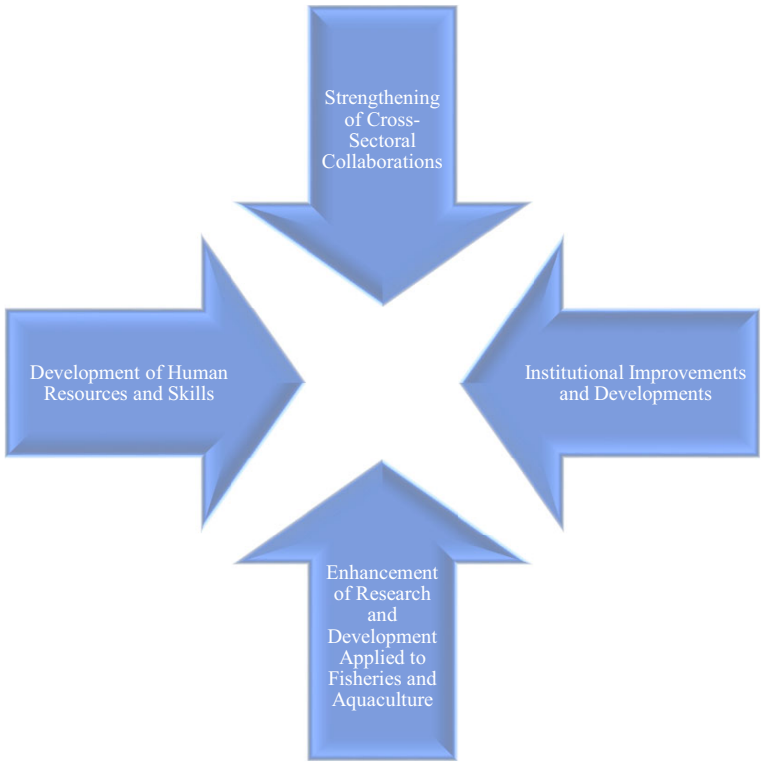


FIGURE 4
Recommendations of National Policy Strategy for Fisheries and Aquaculture Development in Pakistan. Source: Report of National Policy Strategy for Fisheries and Aquaculture Development in Pakistan.

under the auspices of the Ministry of Agriculture, provided some recommendations for developing a mechanism for marine fisheries governance (Siddiqi, 1992). In 1988, the first-ever fisheries policy was established by providing a mechanism of institutional coordination and capacity building (Nazir et al., 2015). The policy also suggested that there should be strong coordination among and between federal, provincial and local governments for appropriate fisheries governance mechanisms. In 2007, a national case study was conducted to analyse the existing fisheries governance mechanisms in Pakistan (National Policy and Strategy for Fisheries and Aquaculture Development in Pakistan - Part - I, 2007). The study clearly indicated fragmentation issues and a lack of cooperation among the institutions. The study also highlighted that due to such challenges, the fish stocks are depleting and IUU fishing is increasing. Moreover, the report suggested implementing specific measures regarding precaution and scientific integration into policy frameworks. Accordingly, the report suggested that territorial policy fragmentation is another root cause of challenges because provincial governments govern fisheries in territorial seas, and EEZs are governed by the federal government.

The study recommended increasing the national fisheries supply management through better and sustainable governance mechanisms (as shown in Figure 4). First and foremost is institutional coordination to develop a conducive environment that will create suitable and sustainable conditions in the market (as shown in Figure 4). Such a conducive environment will be created through the realisation of four fundamental 'common elements' including cross-sectoral coordination, institutional development, enhancement of research and human skills. Given that, it is necessary to create an enabling environment with legal and policy specifications, which is further discussed in the light of this study in the following sections.

4.3 Pakistan in international fisheries

According to the given study, the CLR establishes that active participation in UNCLOS negotiations paved the way for Pakistan to work with pertinent international fisheries organisations. Pakistan regularly receives assistance from the FAO in producing and preserving fisheries because FAO was a pertinent stakeholder in the study. Pakistan also engages with UNDP and UNEP for ocean governance and fisheries development as per regional and international agendas. Pakistan is an active member of WFP (due to its food and health issues), IUCN (for the protection of the marine environment) and IMO (for the shipping and fisheries vessel development) (Mohsin et al., 2017).

As Pakistan recognises the importance of its marine resources (including fisheries) and underdeveloped mechanisms of exploiting oceans, it aligned itself with other developing coastal States in the Group of Seventy-seven (G-77) (Shafique and Mahmood, 2008). Pakistan adopted a soft-law approach in marine fisheries under the UNCLOS. Pakistan acknowledged the rights and obligations in the maritime zones related to fisheries (and other marine resources) and urged other States in G-77 to cooperate (Butt et al., 2021a). Pakistan also cooperates with land-locked (disadvantaged) states in the fields of trade, transit, and marine fisheries. Pakistan refers to the doctrine of 'unity' and considers that it is unfair to keep disadvantaged States away from the oceans.

Although this position of Pakistan was disregarded during the negotiations for UNCLOS, Pakistan still cooperates with many land-locked States and provides them with various advantages of oceans (Kumar, 2021). In 2022, during the UN Ocean Conference, the G-77 plenary, supported by Pakistan, endorsed the commitments made under international environmental agreements related to oceans (Wyns, 2022). Pakistan adhered to the principle of 'international cooperation' or 'cooperation' while participating in international environmental negotiations. Pakistan advocated for 'cooperation' in ocean governance and maritime security in the Indian Ocean Region. It cooperated with the United Arab Emirates, the Sultanate of Oman and the Islamic Republic of Iran in this region.

4.4 Pakistan in the Indian Ocean Region fisheries

In 1982, the South Asian Cooperative Environment Programme (SACEP) laid its foundation. As Pakistan is in the South Asian Region, it followed the initiatives of SACEP, including i) Plastic Free Rivers, ii) Biodiversity Conservation, iii) Sustainable Consumption and Production, iv) Climate Change, v) Waste Management and vi) South Asian Seas Programme (Noman et al., 2022). All these initiatives are linked to the governance of marine fisheries in the Indian Ocean (Table 3) (Programme and Programme, 1997; Ali, 2008). The neighbouring States to Pakistan, except India, have a good relationship with it, and there are several opportunities to develop a fisheries governance framework at the regional level by utilising the abovementioned principles.

TABLE 3 Pakistan in the Regional fisheries arrangements.

Year	Title of the Regional Agreement	Citing Literature	Objective in the field of Marine Fisheries	Progress
1982	South Asian Cooperative Environment Programme	6	Preservation and Protection of the Environment, including habitat (fisheries)	Ineffective implementation due to lack of resources
1995	South Asian Seas Programme	3	Protection and Preservation of Ocean Ecosystems, including fisheries	No follow-up to develop a regional framework
1996	IOTC – Agreement for Establishment of the Indian Ocean Tuna Commission	2	Preservation of Indian Ocean Tunas	Effective implementation due to the interests of many States in the Indian Ocean region

Source: CLR Analysis and Governance of Ocean and Fisheries in Pakistan.

After the South Asian Seas Programme, Pakistan joined the Indian Ocean Tuna Commission (IOTC) to conserve and optimise tuna and other tuna-like fish stocks (Agreement for the establishment of the Indian Ocean Tuna Commission, 1993. (Enforced - 1996) (1927 UNTS) - Available Online: https://treaties.un.org/pages/showDetails.aspx?objid=08000002800a7f47, n.d.). Two articles observed that effective implementation of the IOTC agreement is lacking at various levels (Table 3). IOTC itself is not subject to scrutiny through neighbouring States in the Indian Ocean. With continued overfishing in the Indian Ocean, specifically in the Arabian Sea, marine fisheries' lives are impacted disastrously (Sinan and Bailey, 2020). Therefore, appropriate measures are required in the Indian Ocean region to preserve marine fisheries. In these regards, Pakistan can play an influential role in the region for the conservation of its own interests and for the overall goal of achieving sustainable fisheries.

Regarding regional development, South Asia lacks a coordinated and multifaceted approach to any environmental or ecological issue, as discussed in six articles (Table 3) (Riskas et al., 2018). Fisheries governance faces the same threats because there is no existing RFMO in the region. South Asian Seas Programme under the SACEP is ineffective without developing a mutual agreement like other agreements governing RFMOs (Anwar, 2020). Therefore, it is argued that ocean governance in South Asia requires a coordinated approach and cooperative mechanisms. On the other hand, it is also argued that Pakistan should cooperate with the Gulf and African States located in the west of the Indian Ocean for fisheries and other ocean-related issues.

4.5 Analysis of national, provincial and local fisheries legislation of Pakistan

After reviewing Pakistan's fisheries legislation and institutional frameworks, this CLR observed a lack of coordination and cooperation among the institutions at all levels. The study also indicated that there is a sheer disregard for 'precautionary measures' and 'scientific' information to be taken into fisheries policy. This is mainly because of territorial policy disintegration, as provincial governments govern fisheries in territorial seas, and EEZs are governed by the federal government. Therefore, the institutions of both governments lack coordination and capacity to address the concerns of sustainable fisheries as advocated by SDG 14.

According to the Constitution of Pakistan, the fisheries in the territorial seas are governed by the provincial governments of (Sindh and Baluchistan) Pakistan. However, fisheries in the seas beyond 12 nautical miles up to 200 nautical miles (also known as EEZ) are governed directly by the federal government of Pakistan (Territorial Waters and Maritime Zones Act, 1976, 1976). The two types of governments governing fisheries have enacted a multitude of legislation and regulations that provide the policy and regulatory framework (Table 4) (Constitution of the Islamic Republic of Pakistan, 1973: as Amended up-to-Date. Lahore: All Pakistan Legal Decision, 2015, n.d). The Rules of Business is essential legislation designating fisheries business specifically for institutions (Pakistan and Cabinet Division, 1973.). Pakistan Fisheries Act operates as an umbrella law and adopts a generalised approach towards fisheries (Siddiqi, 1992). The West Pakistan Fisheries Rules are developed under the Pakistan Fisheries Act for fishing boats, trawlers and other fishing vessels (Table 4).

The provincial governments have their own rules and legislation for fisheries, as mentioned in Table 4. In principle, provincial Rules of Business and Fisheries Rules are the primary framework governing fisheries within territorial seas. The government of the province of Sindh govern fisheries under the Sindh Government Rules of Business (which is the primary document of governance), the Sindh Fisheries Ordinance, the Sindh Fisheries Rules and Korangi Fisheries Harbour Ordinance (Table 4) (Kaczan and Patil, 2020). The Directorate General Fisheries Department works under the direction of the Livestock

TABLE 4 Laws, policies & agreements impacting fisheries.

Government	Legislation	Objectives
Federal	The Constitution of the Islamic Republic of Pakistan 1973	Establishing Authority for Fisheries
	Rules of Business 1973	Designating Authority to Institutions
	Pakistan Fisheries Act 1897	General Rules and Principles for Fishing
	West Pakistan Fisheries Rules 1965	Regulation of Fishing Equipment
Baluchistan Province	The Baluchistan Government Rules of Business 2012	Designating Authority to Baluchistan Provincial Institutions
	The Baluchistan Sea Fisheries Ordinance 1971	General Rules and Principles for Fishing
	Baluchistan Sea Fisheries Rules 1971	Regulation of Fishing Equipment
Sindh Province	The Sindh Government Rules of Business 1986	Designating Authority to Sindh Provincial Institutions
	The Sindh Fisheries Ordinance 1980	General Rules and Principles for Fishing
	Sindh Fisheries Rules 1983	Regulation of Fishing Equipment
	Korangi Fisheries Harbour Ordinance 1982	Regulation of Fisheries in Harbour

Source: CLR Analysis and Official Website of Government of Pakistan – (Further sources are provided in the references section).

and Fisheries Department (Table 5). Similarly, the government of the Province of Baluchistan govern fisheries under the Baluchistan Government Rules of Business, the Baluchistan Sea Fisheries Ordinance, and the Baluchistan Sea Fisheries Rules (Table 4) (Deep Sea Fishing Policy of Pakistan, 1995). The Directorate General Fisheries Department works under the direction of the Coastal Development and Fisheries Department (Table 5) (Siddiqi, 1992).

In Sindh province, the legislative system is comprehensive for fisheries governance. However, the government departments governing fisheries are not coherent (Noman et al., 2022). Similarly, in Baluchistan province, the cooperation of government departments at upper and lower levels is flawed, and stakeholder consultation is not part of any policymaking mechanism. The specific implementation of fisheries laws, regulations, and rules depends on local government departments. There is no policy for seasonal bans, fishing trawlers, impact assessments, or climate change (Nazir et al., 2015).

Effective implementation of the given rules and legislation is questionable because the government adopts an isolated approach

TABLE 5 Institutions governing fisheries.

Government/ Ministry	Governing Division	Department	Objectives
Ministry ofNational Food Security and Research	National Food Security and Research Division	Fisheries Development Board (FDB)	Promotion of fisheries as nutrition according to national nutrition and food policy
		The Marine Fisheries Department (MFD)	
Ministry of Maritime Affairs	Maritime Affairs Division	Office for promotion of Deep-Sea Fisheries Resources in Exclusive Economic Zone.	Protection of fisheries in CITES Convention, exploitation of fisheries and promotion of fisheries production
		Directorate of Marine Fisheries, Karachi.	
		Fisheries Training Centre/Deep Sea Fishing Vessel.	
		Korangi Fisheries Harbour Authority, Karachi	
		Marine Fisheries Research Laboratory Karachi.	Research on fisheries for preservation and protection
Baluchistan	Coastal Development and FisheriesDepartment	Provincial Directorate General of Fisheries	Regulation of Fisheries in the Coastal Areas of the province and Seasonal bans help in the development and production of fisheries.
Sindh	Livestock and Fisheries Department	Directorate General Fisheries Department	

Source: CLR Analysis.

in policymaking and legislation (Pakistan and Cabinet Division, 1973). The institutions under the federal government known as the Office for Promotion of Deep-Sea Fisheries Resources in Exclusive Economic Zone, Fisheries Training Centre/Deep Sea Fishing Vessel and Directorate of Marine Fisheries promote the exploitation of fisheries. Conversely, the institutions of provincial governments known as Directorates of Fisheries are developing mechanisms to preserve fisheries.

The Marine Fisheries Department under the Ministry of National Food Security and Research and National Food Security and Research Division (formerly Ministry of Food, Agriculture and Livestock) responsible for ensuring the growth and production of fishery resources at sustainable levels works under the federal government (Noman et al., 2022). However, the Marine Fisheries Department works for policy development and approaches the provincial governments with limited authority and resources. Similarly, the Fisheries Development Board of the federal government promotes sustainable fisheries in EEZ without any mechanism that the provincial governments should implement in territorial seas (Table 4). Although the institutions in the provinces coordinate with each other at some scale (such as seasonal bans and protection of fisheries under the CITES Convention), further coordination for the preservation of fish stocks is required to strengthen the governance mechanism (Table 4).

Based on the analysis above, it can be argued that the governments of Pakistan (both provincial and federal) are already involved in multiple and multilevel governances of fisheries at global and regional levels (Khan and Khan, 2021). Several coordination and policy issues hamper the development of any preservation policy. At provincial levels, Pakistan's approach is top-bottom, which means that the national level for local implementation influences the policy (Pakistan Environmental Protection Agency, Archives, 2012). The principal issue is the lack of centralised policies, which contributes to the degradation of fisheries' resources (through destructive fishing practices) and impacts overall ocean ecosystems.

4.6 2004 fisheries policy and institutional framework

In 2004, the Fisheries Development Board initiated a 'National Fisheries Policy' and established a task force to deal with inland and marine fisheries and aquaculture. Under a collaborative process (at the provincial and federal levels), the two sub-groups prepared policy documents related to their areas (Mohsin and Mu, 2019, pp. 1950–2014). A five-year plan was proposed for medium-term planning, with the recommendation of approaching FAO to fund a technical cooperation project (TCP) to assist in formulating a policy and a strategy to enhance fisheries and aquaculture (Mehmood et al., 2020).

The project goal was to create an environment conducive to the sustainable development and management of a growing fisheries and aquaculture sector. The emphasis was on the contribution of fisheries to economic growth, poverty alleviation, food security and environmental conservation (Allison et al., 2009). After that, the project was initiated to support the ongoing fisheries and aquaculture policy and strategy development process in Pakistan and to facilitate its implementation. A separate committee for fisheries was constituted to prepare these plans, and its recommendations were accommodated. However, none of the five-year plans have addressed many of the broad issues faced by those in the fisheries and aquaculture sectors.

As output of the project, an agreement on the appropriate course of actions for the project to follow and required contribution to Pakistan's ongoing policy processes; i) A well-defined fisheries and aquaculture policy and strategy based on good consultation; ii) An effective implementation plan for the policy and strategy at national and Provincial/Areas levels (Mohsin et al., 2017). It was also agreed that all Provinces of Pakistan should implement TAC and MSY measures as provided in the UNCLOS. Furthermore, effective implementation of regional and international instruments related to IFL was suggested to be reasonably implemented in coastal areas.

The review of the 2004 policy through CLR also depicted that Pakistan's major marine fisheries are over-exploited (Ali, 2018). Due to untrained personnel and the capabilities of the officials, the reporting mechanism of fish stocks is inadequate. Furthermore, the weak infrastructure for policy implementation lacks an appropriate reporting mechanism. The institutions lack the capability and technology to assess the fish stocks, impacting the reporting mechanisms (Ali, 2018). This argument is based on the statement that only 30-35% of fish captured is reported, and more than 60% of stocks are depleted. The non-compliance of the industrial fisheries is due to weak compliance mechanisms in legislation and the ineffective capacity of the institutions.

4.7 Deep Sea Fishing (Licence) Policy 1995 – 2001 and 2018

In 1988, Pakistan adopted the national fisheries and aquaculture-specific policy. Marine fisheries issues were covered in the 1988 policy to some extent as livestock. Further policies were developed for deep-sea fishing in 1995 and 2001, specifically aiming to promote fisheries under licensing arrangements in the EEZ. Albeit in ways, the policies only marginally covered aspects of local/small-scale coastal fisheries and focused on large-scale industrial fishing (Mustafa and Ahmad, 2003). The reports of the Agriculture Enquiry Committee and National Agriculture Commission of Pakistan observed that the marine fisheries policies have not addressed the industrial issues and lack significant measures for sustainable fisheries.

A specific deep-sea fishing policy was established in 1995 and followed a six-year implementation process. The provincial regulations and departments were enhanced to implement deep-sea fishing policy effectively and allowed further exploration and exploitation of fisheries (Deep Sea Fishing Policy of Pakistan, 1995). It also grants curing yard licenses and issues certificates of quality for processed and unprocessed fish for domestic consumption, inter-provincial trade, and export. Accordingly, the advanced fishing trawlers based in Karachi were prohibited from fishing within the 3-mile inshore waters of Baluchistan.

The Deep Sea Fishing Licensing Policy was introduced in 2018 under the Exclusive Fishery Zone (Regulation of Fishing) Act. This policy recognises the extension of the EEZ of Pakistan to the continental shelf (from 200 to 350 nautical miles) (Deep Sea Fishing Licensing Policy, 2018). This policy observed IUU fishing and overexploitation of fisheries resources under the existing policies and practices in the EEZ of Pakistan. The stock-assessment surveys of 2009-2015 indicated a decline in fish stocks and even a decrease in engendered species (as per CITES). Therefore, through this policy, significant measures have been taken to curb IUU fishing and overfishing.

The policy divided the maritime zones into three parts with significant caps and control in fishing practices. For example, fishing of Tuna was limited to 90 days per year as per the TAC and MSY of UNCLOS and mesopelagic fishing up to 60 days per year (Deep Sea Fishing Policy of Pakistan, 1995). The MSY for tuna fish was decided as per UNCLOS implementation mechanisms (CCRF and UNFSA) that limit the licences for fishing. The policy stated that for a 'sustainable fishing method', the Pakistan Maritime Security Agency (PMSA) will monitor all the fishing fleets, and Marine Fisheries Department (in the provinces) shall develop regular reporting and monitoring mechanisms.

According to the government of Pakistan, the 2018 policy is equated with a sustainable fisheries mechanism. The CLR observed that the success of the 2018 policy depends on the results that have to be assessed, such as how far the relevant departments have adopted institutional coordination and pertinent other principles of governance. The policy is based on a two-pronged approach, as it initially stated that 'Pakistan has exclusive rights over fisheries in EEZ and continental shelf' and noted in the second portion that 'sustainable fisheries' are also important. Furthermore, the policy was established in 2018 (three years after SDGs) and has not included the relevant issues of SDG 14. Therefore, it is questionable to what extent this policy can effectively implement SDG 14 as per the given measures of IFL.

4.8 The approach used in the TCP: bottom-up and consensus-based policy formulation for fisheries

In 2005, the FAO-TCP Inception Workshop was conducted, and a wide range of stakeholders (institutions, fishing communities, and fishing companies) prepared a detailed project implementation plan. The outcomes from the two government task forces were amalgamated into a single 'National Fisheries Policy' draft (Birnie, 1999). The contents of this draft were synthesised into a policy brief by the international consultants hired by the government with the assistance of the Network of Aquaculture Centres in Asia-Pacific (NACA-STREAM) (Hosch et al., 2011). The policy brief was also sent to numerous stakeholders from provincial and local governments, harbour authorities and non-governmental (fisheries and environmental) organisations for comments.

The participants gave their input to prioritise the various recommendations in the draft policy and its implementation. The first phase of community consultations and the feedback received from consulted stakeholders also recommended the various industrial usage of fisheries, preservation, and effective utilisation of fish stocks (Mohsin and Mu, 2019). FAO redrafted the draft policy after a round of provincial/area stakeholder consultations based on the scientific information. Task force members and other project stakeholders from the government made observations on its contents, which were then further revised by FAO (Mohsin and Mu, 2019).

According to FAO (after consultations), the 2005 policy recommendations devised that a comprehensive legislative system for fisheries governance at national and provincial government levels is the essential requirement (Mehmood et al., 2020). Further, integrating government departments at federal and provincial levels and institutional capacity enhancement is suggested (Beunen et al., 2017). After reviewing the policy, this CLR indicates that the 2005 policy recommendations for integrating marine fisheries were practical in institutional coordination at various levels. Under the 2005 policy, coastal provinces were required to be integrated into a governance mechanism with a bottom-up approach (Zhang et al., 2023a). Policymaking and implementation with a top-down approach requires cooperation between government departments at upper and lower levels. Effective implementation of seasonal bans and regulation of fishing trawlers are among other suggestions based on scientific information and precautionary measures approaches.

4.9 Results of CLR – top-down and bottom-up approach in fisheries governance

The primary issue identified through CLR analysis is the absence of a 'precautionary approach' and 'institutional capacity' because TAC and MSY are not integrated into any legislation in Pakistan. SDG 14 has been overlooked in Pakistan's agenda of SDGs because the institutions working in the marine and fisheries areas have not taken policy measures for such implementation (Zhang et al., 2023b). The institutional capacity of SDG 17 for policy coherence and improving capability is not incorporated into fisheries policy and agenda in Pakistan (Khan and Khan, 2021). The institutions lack effective monitoring and reporting mechanisms for assessing the fish stocks and licensing (Nazir et al., 2015).

Another main issue identified through CLR analysis is the rationality and interests of the various institutions. Moreover, local stakeholders are not prioritised in the policymaking process, and industrial stakeholders reserve their interests in decision-making (Butt et al., 2021a). Therefore, there is a lack of 'cooperation' among the institutions, which definitely impacts the 'ecosystem-based approach' to fisheries as part of a larger ocean ecosystem. Moreover, only one institution (Marine Fisheries Research Laboratory) at the federal level is working for fisheries preservation with the approach of science-policy integration.

The institutions responsible for implementing SDG 2 are the Fisheries Development Board and the Marine Fisheries Department. These institutions shall develop the capacity to assess the nutritional value of the fish stocks at the national level (Mohsin and Mu, 2019). The institutions working under the federal

government shall coordinate and cooperate with the Maritime Affairs Division and the provincial Directorate General Fisheries Department to effectively implement SDG 2 (Table 6; Figure 5). Furthermore, the fisheries governing institutions (with SDG 14 approaches) can seek assistance from the developed States (such as China) for marine technology transfer and improving institutional capacity in reporting and monitoring mechanisms (Mohammed et al., 2018, p. 14).

Similarly, environmental protection in general and marine environmental protection specifically lack specific mechanisms to assess the situation of fisheries. There are no specific provisions to deal with marine and other coastal pollution. The marine pollution issues shall be dealt with on a priority basis as urbanisation, agriculture, and proposed expansions of ports increase. For such purposes, effective implementation of SDG 6 is required for waste and sewerage prevention from oceans. According to SDG 6, the municipal authorities, environmental and marine authorities, and fisheries governance institutions shall coordinate to mitigate waste and sewerage (Table 6; Figure 6).

Further policy development in fisheries governance shall integrate the Fisheries Development Board and Marine Fisheries Department with the Directorate of Marine Fisheries, Korangi Fisheries Harbour Authority and provincial Directorate General Fisheries Departments (Figure 6). For such purposes, data sharing (with cooperation and science policy integration) and capacity building (through cooperation and ecosystem-based approach) shall be the main components of governance (Table 6, Figure 5) (Zulfiqar and Butt, 2021). More extensive engagement requires cooperation with environmental institutions at national and provincial levels. The Pakistan Environmental Protection Authority, Climate Change Division (under the Ministry of Climate Change), and Provincial Environmental Authorities are relevant institutions that shall coordinate with fisheries institutions for information sharing, which shall be adopted as a precautionary approach.

Further cooperation among Fisheries Training Centre/Deep Sea Fishing Vessel, Office for Promotion of Deep-Sea Fisheries Resources in Exclusive Economic Zone, Marine Fisheries Research Laboratory Karachi and provincial Directorates General Fisheries Department is necessary for the effective adoption of 'precautionary measures' (Table 6; Figure 5). Such measures are also based on an ecosystem-based approach, which requires cooperation and integration at various levels as required by SDG 17 (Table 6, Figure 5). Furthermore, the following section explored regional cooperation options available to Pakistan in fisheries governance. The following section also suggested the required strategy to address the challenges of achieving sustainable fisheries at national and regional levels.

5 Suggestion on the future of fisheries governance in Pakistan

Pakistan's rich coastline along the Arabian Sea offers significant potential for fisheries development. As discussed above, the fisheries sector has long struggled with challenges ranging from overfishing to inadequate regulatory frameworks (Mohsin et al., 2017). Therefore, Pakistan requires an innovative approach to equate its fisheries policies with SDG 14. Pakistan is suggested to adopt an outward sustainability policy to equate its role in fisheries' governance with SDG 14. The initiatives suitable for Pakistan to improve its national fisheries policy and external expansion in the regional and global fisheries governance shall align with SDG 14.

The development of ports and associated infrastructure under regional developments (for example, CPEC) can enhance Pakistan's capabilities for fishery-related activities such as processing, storage, and export (Panneerselvam, 2017). Improved port facilities can streamline logistics, reducing post-harvest losses and increasing the value of the fishery sector. Furthermore, investments in fisheries infrastructure and technology from (multinational) fisheries companies can modernise Pakistan's fishing industry. This may include the introduction of advanced fishing vessels, aquaculture technologies, and cold chain systems, thereby boosting productivity and efficiency (Dadwal and Purushothaman, 2017).

Multistakeholder partnerships in fisheries through investment opportunities come with significant challenges. A surge in fishing activities can exacerbate existing issues of overfishing and IUU fishing in Pakistan's seas. Due to regional developments (for example, CPEC and BRI), there will be an influx of foreign

TABLE 6 Results of CLR.

Sr no	Required Update in Legislation	Coordinating Department	Goal-Based Approach	Governance Principles
1	Fisheries Act for Fisheries Production and Sustainable Utilisation	Fisheries Development Board and Marine Fisheries Department with Maritime Affairs Division	SDG-2 for nutrition and SDG-14 for sustainable production of fisheries	Cooperation and Ecosystem-based approach
2	Environmental Protection Law and Fisheries Laws	Maritime Affairs Division, Provincial Directorate General Fisheries Department	SDG-6 for Waste and Sewerage mitigation and SDG-14 for protection of ocean ecosystems	Precautionary Measures and Science-policy Integration
3	Climate Change Laws and Fisheries Preservation Law	Maritime Affairs Division, Provincial Directorate General Fisheries Department and Climate Change Division	SDG-13 for Climate Change Mitigation and SDG-14 for Ocean Acidification and Sea Level Rise	Precautionary Measures, Ecosystem-Based Approach and Science-policy Integration
4	A Comprehensive Fisheries Policy	All relevant Institutions, as mentioned	SDG – 17 Policy Coherence for SDGs	All given principles

Source: CLR Analysis – Supplementary Data Available.

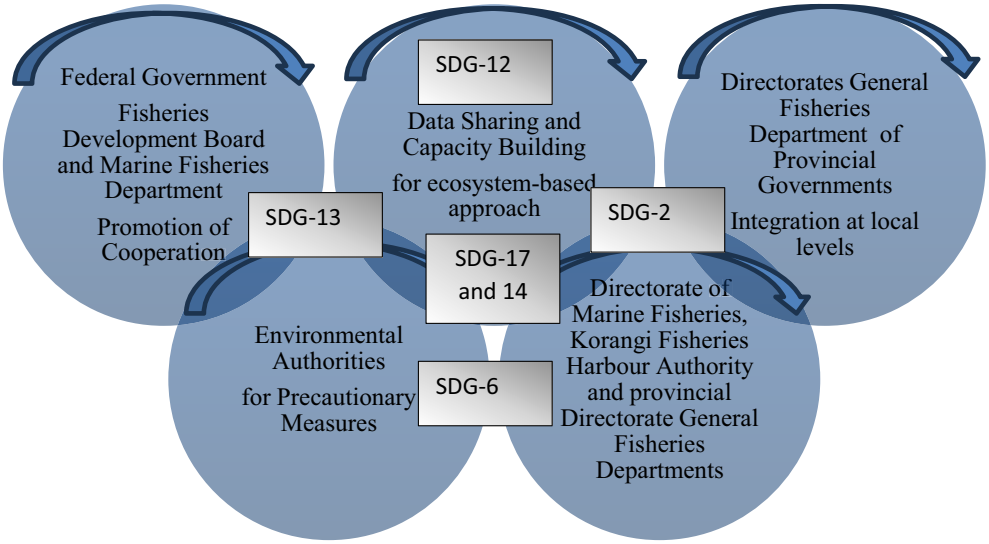


FIGURE 5
Results of CLR Analysis – Required Approach for Fisheries Governance in Pakistan. Source: CLR Analysis – Results and Suggestions.

vessels. This will include Chinese fishing fleets that will challenge the fisheries governance mechanism of Pakistan (Hashmi, 2019). Moreover, the potential for environmental degradation due to the construction of port infrastructure and associated projects through such regional developments cannot be ignored. Habitat destruction, pollution, and disruption of marine ecosystems threaten fish stocks and the livelihoods of coastal communities dependent on fisheries.

Regarding governance, the rapid pace of development under CPEC and BRI may outstrip the capacity of regulatory institutions to manage and oversee fisheries activities effectively. Weak enforcement mechanisms and regulatory loopholes could facilitate unsustainable exploitation of marine resources and undermine efforts for conservation and sustainable management (Garlick, 2018). Addressing these challenges requires a holistic approach integrating environmental sustainability, social equity, and economic development objectives. In the given circumstances, the following suggestions are provided to Pakistan to strengthen its fisheries governance frameworks:

i. A fisheries policy with a novel approach under SDG 14 that must include consultation with various stakeholders – provincial governments, local governments, fishermen, industrial fisheries corporations, national government and private stakeholders;
ii. Cooperation among environmental and fisheries governance institutions;
iii. Coordination in national, provincial and local governments;

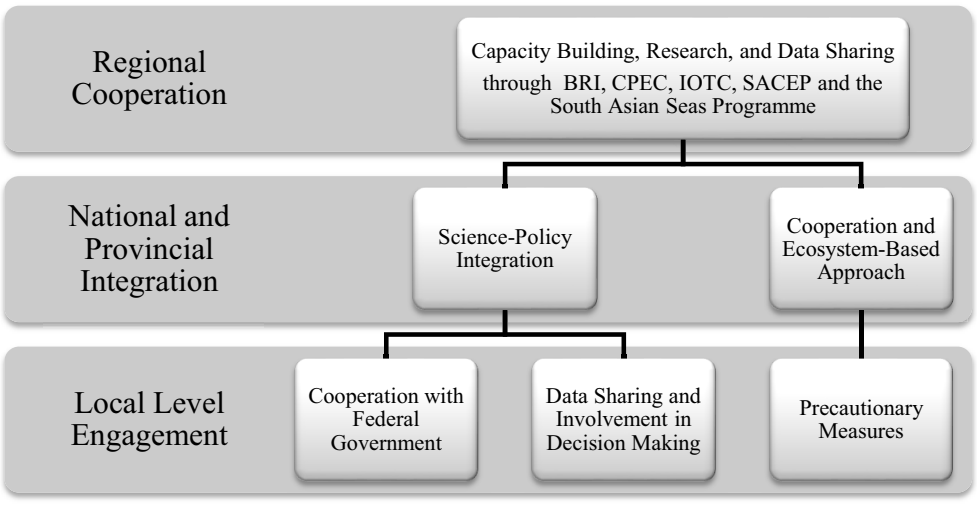


FIGURE 6
Applying the Principles of International Law in Pakistan Fisheries Governance Approach. Source: CLR Analysis and Suggestions.

iv. Effective legislation on fisheries under a particular policy framework highlighting the importance of SDG 14 as mentioned above;
v. institutional capacity for enforcement and implementation with regional collaboration and international coordination;
vi. Cooperation of security forces in curbing IUU fishing;
vii. Development of data-sharing mechanisms within its own governmental systems and at regional levels;
viii. Scientific integration in policy making and implementation;
ix. Precautionary approaches in the exploitation of fisheries as a resource

Such enhancement in policy mechanisms, institutional capacity and effective legislation under the given principles of governance will ensure that the benefits of CPEC and BRI are realised without compromising the long-term sustainability of fisheries.

6 The potential role of Pakistan in regional integration and international cooperation in fisheries governance

Collaboration with regional institutions can also be vital in promoting responsible fisheries practices (Fabinyi and Liu, 2014). Technology transfer and adoption, joint initiatives for capacity building, research, and data sharing can enhance transparency and cooperation in managing shared marine resources (including fisheries), as shown in Figure 6. While regional developments offer immense potential for transforming Pakistan's fisheries sector, careful planning and effective governance are essential to mitigate negative impacts and maximise sustainable development outcomes (Coll et al., 2013). By adopting a proactive and inclusive approach, Pakistan can harness the opportunities presented by these initiatives while safeguarding the integrity of its marine environment and securing the livelihoods of coastal communities.

To become a regional player, Pakistan requires a two-pronged approach: i) bottom-up and ii) top-down. The bottom-up approach involves policy measures at the local level and practical implementation at national, regional, and international levels (Ahsan and Khawaja, 2013). The top-down approach requires consultation with RFMOs for the long-term sustainability of regional fisheries. Consultation with RFMOs before policy and decision-making processes is mandatory under IFL (Soomai et al., 2013). In this scenario, RFMOs can also assist in the specific implementation of special laws, regulations and rules related to the conservation of endangered fish stocks (Hosch et al., 2011). These suggestions are made under SDG 17, which urges local and provincial integration and cooperation of national and regional institutions.

The top-down approach involves technology transfer and developing effective reporting and monitoring mechanisms. Regional convergence for fisheries governance will further explore Pakistan's potential in fisheries. Through sustainable fisheries policies and governance mechanisms, Pakistan can become a market player in marine fisheries. Moreover, Pakistan's capacity in the CPEC of BRI can enhance its fisheries' market development venues. Under CPEC, Pakistan can learn from China in developing fisheries governance, sustainable catches and effective implementation of MSY and TAC.

Such transformation in fisheries governance requires 'cooperation' among governing institutions, including environmental and marine environmental institutions. Policymaking through local input at the national level and a regional policy is required to address the issues of 'sustainable fisheries' with 'scientific information', 'precautionary measures' and 'ecosystem-based approach'. This transformation will improve the technical capability of the institutions through marine technology transfer with regional arrangements and expand coordination for reporting and monitoring mechanisms (Figure 6).

7 Conclusions

This research paper contributed to the formation of policy under SDG 14 and IFL at the national level. For such purposes, this paper adopted the CLR methodology and suggested that a coordinated governance mechanism is required for effective fisheries governance. Effective fisheries governance means that there shall be means for the abolition of harmful fishing practices, IUU fishing, and overfishing. Furthermore, fisheries' governance mechanisms shall include policy frameworks for mitigating environmental pollution and climate change. Based on these arguments, this paper suggested that non-compliance with the IFL could negatively affect government initiatives to achieve SDGs connected with fisheries governance.

This paper first analysed the literature on new means of fisheries governance under SDG 14 and IFL. The results forwarded a novel approach to fisheries governance (governance principles) to be implemented at national levels. The primary motivation behind this paper was to analyse Pakistan's national fisheries governance framework. Therefore, the analysis of Pakistan's fisheries governance provided significant suggestions to be considered. Pakistan is required to address the fisheries issues with a policy development mechanism by integrating multiple and multilevel stakeholders.

Furthermore, Pakistan should also consider regional cooperation for institutional capacity building and developing data-sharing mechanisms. Regional stakeholders are crucial to developing effective fisheries policy and legislation in Pakistan. Pakistan should adopt principles of governance to achieve sustainable fisheries at national, provincial and local levels. The success of implementation shall be measured through assessment by the institutions involved in fisheries. The future research agenda in the field of fisheries governance in Pakistan shall be based on the practical implementation of given principles in policy mechanisms, legislative development and governance systems.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding authors.

Author contributions

LL: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing. MZB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This fieldwork is supported by the China National Social Science Foundation Art Project: Research on Legal Issues in the Development of Cultural Products in Chinese Museums (Grant No 22EH217).

Acknowledgments

The authors acknowledge the resources provided through China National Social Science Foundation Art Project: Research on Legal Issues in the Development of Cultural Products in Chinese Museums (Grant No 22EH217).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2025.1503748/full#supplementary-material

References

Achbari, A. (2015). Building networks for science: conflict and cooperation in nineteenth-century global marine studies. *Isis* 106, 257–282. doi: 10.1086/682020

Agreement for the establishment of the Indian Ocean Tuna Commission 1993. (Enforced - 1996) (1927 UNTS). Available online at: https://treaties.un.org/pages/showDetails.aspx?objid=08000002800a7f47 (Accessed January 22, 2024).

Agreement for the implementation of the provisions of the United Nations convention on the law of the sea of 10 December 1982 relating to the conservation and management of straddling fish stocks and highly migratory fish stocks. 01, UNTS 37924. (1995).

Ahmed, S., Ali, A., Kumar, D., Malik, M. Z., and Memon, A. H. (2019). China Pakistan Economic Corridor and Pakistan's energy security: A meta-analytic review. *Energy Policy* 127, 147–154. doi: 10.1016/j.enpol.2018.12.003

Ahsan, I., and Khawaja, S. A. (2013). *Development of Environmental Laws and Jurisprudence in Pakistan* (Islamabad, Pakistan: Asian Development Bank). Available at: https://www.adb.org/sites/default/files/publication/31140/environmental-law-jurisprudence-Pakistan.pdf (Accessed October 12, 2024).

Al Arif, A. (2017). Legal status of maximum sustainable yield concept in international fisheries law and its adoption in the marine fisheries regime of Bangladesh: a critical analysis. *Int. J. Mar. Coast. Law* 32, 544–569. doi: 10.1163/15718085-12323054

Alencar Mayer Feitosa Ventura, V. (2020a). "Brazilian legal framework applicable to the blue amazon's seabed: an assessment of consistency with international law," in *Environmental Jurisdiction in the Law of the Sea: The Brazilian Blue Amazon*. Ed. V. Alencar Mayer Feitosa Ventura (Springer International Publishing, Cham), 297–351. doi: 10.1007/978-3-030-50543-1_10

Alencar Mayer Feitosa Ventura, V. (2020b). "Jurisdictional intersections between the continental shelf and other maritime spaces: exclusive economic zone, high seas and the area," in *Environmental Jurisdiction in the Law of the Sea: The Brazilian Blue Amazon*. Ed. V. Alencar Mayer Feitosa Ventura (Springer International Publishing, Cham), 109–139. doi: 10.1007/978-3-030-50543-1_5

Ali, S. H. (2008). Water politics in South Asia: technocratic cooperation and lasting security in the Indus Basin and beyond. *J. Int. Aff.* 61, 167–182.

Ali, M. R. (2018). Small-scale fisheries in Pakistan. *Small-Scale Fish. South Asia* 81, 763.

Allison, E. H. (2001). Big laws, small catches: global ocean governance and the fisheries crisis. *J. Int. Dev.* 13, 933–950. doi: 10.1002/jid.834

Allison, E. H., Perry, A. L., Badjeck, M., Neil Adger, W., Brown, K., Conway, D., et al. (2009). Vulnerability of national economies to the impacts of climate change on fisheries. *Fish Fish.* 10, 173–196. doi: 10.1111/j.1467-2979.2008.00310.x

Andrew, N., and Lugten, G. (2008). Maximum sustainable yield of marine capture fisheries in developing archipelagic states—Balancing law, science, politics and practice. *Int. J. Mar. Coast. Law* 23, 1–37. doi: 10.1163/092735208X272229

Anwar, A. (2020). *South Asia and China's Belt and Road Initiative: Security Implications and Ways Forward* (Daniel K. Inouye Asia-Pacific Center for Security Studies). Available online at: https://www.jstor.org/stable/resrep26667.15 (Accessed February 16, 2022).

Arlinghaus, R., Abbott, J. K., Fenichel, E. P., Carpenter, S. R., Hunt, L. M., Alós, J., et al. (2019). Governing the recreational dimension of global fisheries. *Proc. Natl. Acad. Sci.* 116, 5209–5213. doi: 10.1073/pnas.1902796116

Atkins, J. P., Burdon, D., Elliott, M., and Gregory, A. J. (2011). Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. *Mar. pollut. Bull.* 62, 215–226. doi: 10.1016/j.marpolbul.2010.12.012

Awais, M., Samin, T., Gulzar, M. A., and Hwang, J. (2019). The sustainable development of the China Pakistan economic corridor: synergy among economic, social, and environmental sustainability. *Sustainability* 11, 7044. doi: 10.3390/su11247044

Beunen, R., Patterson, J., and Van Assche, K. (2017). Governing for resilience: the role of institutional work. *Curr. Opin. Environ. Sustain.* 28, 10–16. doi: 10.1016/j.cosust.2017.04.010

Birnie, P. (1999). New approaches to ensuring compliance at sea: the FAO agreement to promote compliance with international conservation and management measures by fishing vessels on the high seas. *Rev. Eur. Comp. Intl Envtl L* 8, 48. doi: 10.1111/reel.1999.8.issue-1

Butt, M. J., and Chang, Y.-C. (2021).Regulation of Autonomous Maritime Weapon Systems under the Governance Framework of International Law. In: *Marine Scientific Research, New Marine Technologies and the Law of the Sea* (Brill Nijhoff). Available online at: https://brill.com/view/book/edcoll/9789004469372/BP000008.xml (Accessed January 30, 2022).

Butt, M. J., Chang, Y. C., and Zulfiqar, K. (2021a). A comparative analysis of the environmental policies in China and Pakistan: developing a legal regime for sustainable China-Pakistan economic corridor (CPEC) under the belt and road initiative (BRI). *IPRI J.* 21, 83–122. doi: 10.31945/iprij.210104

Butt, M. J., Chang, Y.-C., and Zulfiqar, K. (2021b). "Applicability of international law in development of sustainable port policy: an analysis of good practices and future policy of Gwadar Port," in *International Association of Maritime Universities (IAMU) Conference* (A Publication of International Association of Maritime Universities, Alexendria, Egypt). Available at: https://www.researchgate.net/publication/355718582_Applicability_of_International_Law_in_Development_of_Sustainable_Port_Policy_An_Analysis_of_Good_Practices_and_Future_Policy_of_Gwadar_Port (Accessed March 23, 2022).

Butt, M. J., Zulfiqar, K., Chang, Y.-C., and Iqtaish, A. M. A. (2022). Maritime Dispute Settlement Law towards Sustainable Fishery Governance: The Politics over Marine Spaces vs. Audacity of Applicable International Law. *Fishes* 7, 81. doi: 10.3390/fishes7020081

Carlisle, K. M., and Gruby, R. L. (2018). Why the path to polycentricity matters: evidence from fisheries governance in Palau. *Environ. Policy Gov.* 28, 223–235. doi: 10.1002/eet.1811

Chircop, A. (2010). Regional cooperation in marine environmental protection in the South China Sea: A reflection on new directions for marine conservation. *Ocean Dev. Int. Law* 41, 334–356. doi: 10.1080/00908320.2010.499300

Cicin-Sain, B., and Knecht, R. W. (1993). Implications of the earth summit for ocean and coastal governance. *Ocean Dev. Int. Law* 24, 323–353. doi: 10.1080/00908329309546016

Coll, M., Libralato, S., Pitcher, T. J., Solidoro, C., and Tudela, S. (2013). Sustainability implications of honouring the Code of Conduct for Responsible Fisheries. *Glob. Environ. Change* 23, 157–166. doi: 10.1016/j.gloenvcha.2012.10.017

Constitution of the Islamic republic of Pakistan 1973: as amended up-to-date. Lahore: all Pakistan legal decision 2015.

Convention on international trade in endangered species of wild fauna and flora 1973 (Enforced 1975).

Convention for cooperation in the protection and sustainable development of the marine and coastal environment of the northeast Pacific. (E-XE4161 - UNEP; F-XF4234) Convention on Biological Diversity came i3. (2002).

Convention on biological diversity. (1992).

Cormier, R., and Elliott, M. (2017). SMART marine goals, targets and management – Is SDG 14 operational or aspirational, is 'Life Below Water' sinking or swimming? *Mar. pollut. Bull.* 123, 28–33. doi: 10.1016/j.marpolbul.2017.07.060

Dadwal, S. R., and Purushothaman, C. (2017). CPEC in Pakistan's quest for energy security. *Strateg. Anal.* 41, 515–524. doi: 10.1080/09700161.2017.1343270

Deep Sea Fishing Policy of Pakistan (Islamabad, Pakistan: Ministry of National Food Security and Research). (1995). Available at: https://faolex.fao.org/docs/pdf/pak18969.pdf (Accessed April 12, 2024).

(2018). *Deep Sea Fishing Licensing Policy*. Available online at: https://moma.gov.pk/SiteImage/Misc/files/DSFL%20Policy-2018%20notified.pdf (Accessed July 1, 2024).

Dereynier, Y. L. (1998). Evolving principles of international fisheries law and the North Pacific Anadromous Fish Commission. *Ocean Dev. Int. Law* 29, 147–178. doi: 10.1080/00908329809546121

Fabbri, K. P. (1998). A methodology for supporting decision making in integrated coastal zone management. *Ocean Coast. Manage.* 39, 51–62. doi: 10.1016/S0964-5691(98)00013-1

Fabinyi, M., and Liu, N. (2014). The Chinese policy and governance context for global fisheries. *Ocean Coast. Manage.* 96, 198–202. doi: 10.1016/j.ocecoaman.2014.03.022

(2016). *Final list of proposed Sustainable Development Goal indicators*. Available online at: https://sustainabledevelopment.un.org/content/documents/11803Official-List-of-Proposed-SDG-Indicators.pdf (Accessed May 29, 2024).

Fousteris, A. E., Didaskalou, E. A., Tsogas, M.-M. H., and Georgakellos, D. A. (2018). The environmental strategy of businesses as an option under recession in Greece. *Sustainability* 10, 4399. doi: 10.3390/su10124399

Friess, D. A., Aung, T. T., Huxham, M., Lovelock, C., Mukherjee, N., and Sasmito, S. (2019). SDG 14: life below water–impacts on mangroves. *Sustain. Dev. Goals* 445, 445–481.

Garlick, J. (2018). Deconstructing the China–Pakistan economic corridor: pipe dreams versus geopolitical realities. *J. Contemp. China* 27, 519–533. doi: 10.1080/10670564.2018.1433483

Hashmi, S. D. (2019).China and central Asian republics' Connectivity through CPEC. Available online at: https://moderndiplomacy.eu/2019/01/01/China-and-central-asian-republics-connectivity-through-cpec/ (Accessed January 6, 2020).

Hosch, G., Ferraro, G., and Failler, P. (2011). The 1995 FAO Code of Conduct for Responsible Fisheries: Adopting, implementing or scoring results? *Mar. Policy* 35, 189–200. doi: 10.1016/j.marpol.2010.09.005

Hunt, A., and Watkiss, P. (2011). Climate change impacts and adaptation in cities: a review of the literature. *Clim. Change* 104, 13–49. doi: 10.1007/s10584-010-9975-6

Hussain, M., and Bhatti, S. H. (2023). A review article on an appraisal of maritime laws as a mechanism of community governance for sustainable development goals. *Pak. J. Humanit. Soc Sci.* 11, 1–10. doi: 10.52131/pjhss.2023.1101.0325

Ibrahimi, K. (2017). A theoretical framework for conceptualizing seaports as institutional and operational clusters. *Transp. Res. Proc.* 25, 261–278. doi: 10.1016/j.trpro.2017.05.393

Kaczan, D. J., and Patil, P. G. (2020). Potential development contribution of fisheries reform: evidence from Pakistan. *J. Environ. Dev.* 29, 275–305. doi: 10.1177/1070496520925878

Kaebnick, G. E., Heitman, E., Collins, J. P., Delborne, J. A., Landis, W. G., Sawyer, K., et al. (2016). Precaution and governance of emerging technologies. *Science* 354, 710–711. doi: 10.1126/science.aah5125

Khan, S. R., and Khan, S. R. (2011). Fishery degradation in Pakistan: a poverty–environment nexus? *Can. J. Dev. Stud. Can. Détudes Dév.* 32, 32–47. doi: 10.1080/02255189.2011.576140

Khan, S. R., and Khan, S. R. (2021). "Reversing unsustainable policies and practices in the fisheries sector: A chronology of collective action by the Pakistan fisheries forum," in *Social Capital and Collective Action in Pakistani Rural Development* (Springer International Publishing, Cham), 187–222. doi: 10.1007/978-3-030-71450-5_7

Khawaja, M. A., Saeed, S., and Urooj, M. (2018). *Preliminary Environmental Impact Assessment, Study of China-Pakistan Economic Corridor, Northern Route Road Construction Activities in Khyber Pakhtunkhwa, Pakistan* (Islamabad, Pakistan: Sustainable Development Policy Institute). Available at: https://www.sdpi.org/publications/files/Preliminary-Environmental-Impact-Assessment-Study-of-CPEC-NRRC-Activities-in-KPK-Pakistan(PB-59).pdf (Accessed August 23, 2024).

Kim, S. (2023). Adaptive capacity and local-level fisheries co-management activities: A case of South Korea. *Mar. Policy* 154, 105665. doi: 10.1016/j.marpol.2023.105665

Kumar, S. ,. S. (2021). Applicability of UNCLOS for Landlocked states: The case of Chabahar port and Afghanistan. *Marit. Aff. J. Natl. Marit. Found. India* 17, 58–72. doi: 10.1080/09733159.2021.1939869

Mamun, A. A., Brook, R. K., and Dyck, T. (2016). Multilevel governance and fisheries commons: Investigating performance and local capacities in rural Bangladesh. *Int. J. Commons* 10, 45–70. doi: 10.18352/ijc.568

Matz-Lück, N., and Al-Hajjaji, S. (2024). "The international legal framework for area-based marine management tools," in *Area-Based Management of Shipping: Canadian and Comparative Perspectives*. Eds. A. Chircop, F. Goerlandt, R. Pelot and C. Aporta (Springer Nature Switzerland, Cham), 69–90. doi: 10.1007/978-3-031-60053-1_4

Mehmood, A., Sial, M. H., Sharif, S., Hussain, A., Riaz, M., and Shaheen, N. (2020). Forecasting the fisheries production in Pakistan for the year 2017-2026, using box-jenkin's methodology. *Pak. J. Agric. Res.* 33, 140–145. doi: 10.17582/journal.pjar/2020/33.1.140.145

Mohammed, E. Y., Steinbach, D., and Steele, P. (2018). Fiscal reforms for sustainable marine fisheries governance: Delivering the SDGs and ensuring no one is left behind. *Mar. Policy* 93, 262–270. doi: 10.1016/j.marpol.2017.05.017

Mohsin, M., and Mu, Y. T. (2019). An economic analysis of fisheries and molluscan fisheries nexus in Pakistan 1950-2014. *J. Anim. Plant Sci.* 29, 1455–1465.

Mohsin, M., Mu, Y., Memon, A. M., Mehak, A., Shah, S. B. H., Kalhoro, M. T., et al. (2017).Capture fisheries production and its economic role in Pakistan. Available online at: https://nopr.niscpr.res.in/handle/123456789/42015 (Accessed December 10, 2023).

Mustafa, K., and Ahmad, S. (2003). Barriers against agricultural exports from Pakistan: the role of WTO sanitary and phytosanitary agreement [with comments. *Pak. Dev. Rev.* 42 (4), 487–510.

National Policy and Strategy for Fisheries and Aquaculture Development in Pakistan - Part - I (Islamabad, Pakistan: Ministry of Food, Agriculture and Livestock, Government of Pakistan, Islamabad, Pakistan). (2007). Available at: https://faolex.fao.org/docs/pdf/pak150786.pdf (Accessed June 13, 2024).

Nazir, K., Yongtong, M., Kalhoro, M., Memon, K., Mohsin, N., and Kartika, S. A preliminary study on fisheries economy of Pakistan: plan of actions for fisheries management in Pakistan. *Can. J. Basic Appl. Sci.* 03, 7–17.

Noman, M., Mu, Y. T., Nisar, U., Mohsin, M., and Memon, A. M. (2022). Constraint analysis of major problems facing the marine fisheries sector in accordance with the national fisheries policy of Pakistan. *Indian J. Geo-Mar. Sci. IJMS* 51, 94–103.

Pakistan and Cabinet Division. (1973). *Rules of Business (As amended up to 3rd March 2017)* (Islamabad, Pakistan: Government of Pakistan). Available at: http://cabinet.gov.pk/cabinet/userfiles1/file/ROB-amended-03-03-2017.pdf (Accessed October 1, 2024).

Pakistan Environmental Protection Agency, Archives (2012). *Brief on Pakistan Environmental Protection Act 1997* (Islamabad, Pakistan: Ministry of Climate Change, Pakistan). Available online at: http://www.environment.gov.pk/images/webcontent/brf-act1997.pdf (Accessed February 1, 2020).

Panneerselvam, P. (2017). Maritime component of China–Pakistan economic corridor (CPEC): India–China competition in the Arabian Sea. *Marit. Aff. J. Natl. Marit. Found. India* 13, 37–49. doi: 10.1080/09733159.2017.1412577

Papaioannou, D., Sutton, A., Carroll, C., Booth, A., and Wong, R. (2010). Literature searching for social science systematic reviews: consideration of a range of search techniques. *Health Inf. Libr. J.* 27, 114–122. doi: 10.1111/j.1471-1842.2009.00863.x

Programme, S. A. C. E., and Programme, U. N. E. (1997).South Asia Handbook of Treaties and other Legal Instruments in the Field of Environmental Law - SACEP/UNEP/NORAD Publication Series on Environmental Law and Policy No. 1. Available online at: https://stg-wedocs.unep.org/xmlui/handle/20.500.11822/30488 (Accessed January 18, 2022).

Rahman, M. A. (2023). Global marine governance and oceans management for the achievement of sustainable development goals and blue growth. *Int. J. BioLife Sci. IJBLS* 2, 59–61. doi: 10.22034/jbs.2023.178661

Riskas, K. A., Tobin, R. C., Fuentes, M. M. P. B., and Hamann, M. (2018). Evaluating the threat of IUU fishing to sea turtles in the Indian Ocean and Southeast Asia using expert elicitation. *Biol. Conserv.* 217, 232–239. doi: 10.1016/j.biocon.2017.10.011

Rotenberg, M., and Jacobs, D. (2013). Updating the law of information privacy: the new framework of the European Union. *Harv. J. Law Public Policy* 36, 605.

Schubert, S., and Gupta, J. (2013).Comparing global coordination mechanisms on energy, environment, and water. Available online at: https://www.jstor.org/stable/26269303 (Accessed June 16, 2021).

Shafique, F., and Mahmood, K. (2008). Indicators of the emerging information society in Pakistan. *Inf. Dev.* 24, 66–78. doi: 10.1177/0266666907087698

Shahzad, S. M., and Gillani, A. (2022). Maritime security: A case study of Pakistan. *J. Naut. Eye Strateg. Stud.* 2, 25–32.

Siddiqi, A. H. (1992). Fishery resources and development policy in Pakistan. *GeoJournal* 26, 395–411. doi: 10.1007/BF02629820

Sinan, H., and Bailey, M. (2020). Understanding barriers in Indian Ocean tuna commission allocation negotiations on fishing opportunities. *Sustainability* 12(16), 6665. doi: 10.3390/su12166665

Soomai, S. S., MacDonald, B. H., and Wells, P. G. (2013). Communicating environmental information to the stakeholders in coastal and marine policy-making: Case studies from Nova Scotia and the Gulf of Maine/Bay of Fundy region. *Mar. Policy* 40, 176–186. doi: 10.1016/j.marpol.2013.01.017

Spijkers, J., Mackay, M., Turner, J., McNeill, A., Travaille, K., and Wilcox, C. (2023). Diversity of global fisheries governance: Types and contexts. *Fish Fish.* 24, 111–125. doi: 10.1111/faf.12713

Territorial Waters and Maritime Zones Act 1976. (1976).

United Nations Conference on Environment and Development/Rio Declaration on Environment and Development. (1992).

United Nations Convention on Law of the Sea. (1982).

United Nations Framework Convention on Climate Change. (1992).

Wyns, A. (2022). Disaster diplomacy in the wake of the 2022 Pakistan floods. *Lancet Planet. Health* 6, e855–e856. doi: 10.1016/S2542-5196(22)00240-6

Zhang, S., Butt, M. J., Iqatish, A., and Zulfiqar, K. (2023a). China's belt and road initiative (BRI) under the vision of'maritime community with a shared future'and its impacts on global fisheries governance. *Heliyon*. 9 (4). doi: 10.1016/j.heliyon.2023.e15398

Zhang, S., Butt, M. J., and Zulfiqar, K. (2023b). Interconnected principles of ocean governance through science-policy integration under the judgements of the international dispute settlement bodies. *Sci. Prog.* 106, 368504231205395. doi: 10.1177/00368504231205395

Zhang, S., Wu, Q., Butt, M. M. Z., Lv, (. Y.-M., and Yan-E-Wang,-(Judge), (2024). International legal framework for joint governance of oceans and fisheries: challenges and prospects in governing large marine ecosystems (LMEs) under sustainable development goal 14. *Sustainability* 16, 2566. doi: 10.3390/su16062566

Zulfiqar, K., and Butt, M. J. (2021). Preserving community's environmental interests in a meta-ocean governance framework towards sustainable development goal 14: A mechanism of promoting coordination between institutions responsible for curbing marine pollution. *Sustainability* 13, 9983. doi: 10.3390/su13179983

frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 13 March 2025
DOI 10.3389/fmars.2025.1442572

Check for updates

OPEN ACCESS

EDITED BY
Yen-Chiang Chang,
Dalian Maritime University, China

REVIEWED BY
Yusheng Zhou,
Hong Kong Polytechnic University, Hong Kong SAR, China
Guangnian Xiao,
Shanghai Maritime University, China
Nermin Hasanspahić,
University of Dubrovnik, Croatia

*CORRESPONDENCE
Min-seop Sim
tla6355@g.kmou.ac.kr
Jeong-min Lee
jmjm3646@g.kmou.ac.kr
Yul-seong Kim
logikys@kmou.ac.kr
Dong-ho Jung
dhjung@kriso.re.kr
Chang-hee Lee
chlee@kmou.ac.kr

RECEIVED 02 June 2024
ACCEPTED 17 February 2025
PUBLISHED 13 March 2025

CITATION
Sim M-s, Lee J-m, Kim Y-s, Jung D-h and Lee C-h (2025) Strategic integration of data envelopment analysis and backcasting theories for zero-emission transition in global container shipping companies: pathways and frameworks.
Front. Mar. Sci. 12:1442572.
doi: 10.3389/fmars.2025.1442572

COPYRIGHT
© 2025 Sim, Lee, Kim, Jung and Lee. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Strategic integration of data envelopment analysis and backcasting theories for zero-emission transition in global container shipping companies: pathways and frameworks

Min-seop Sim[1]*, Jeong-min Lee[1]*, Yul-seong Kim[2]*, Dong-ho Jung[3]* and Chang-hee Lee[4]*

[1]Department of Convergence Interdisciplinary Education of Maritime & Ocean Contents (Logistics System), National Korea Maritime and Ocean University, Busan, Republic of Korea, [2]Department of Logistics, College of Engineering, National Korea Maritime and Ocean University, Busan, Republic of Korea, [3]Offshore Platform Research Division, National Korea Research Institute of Ship and Ocean Engineering, Daejeon, Republic of Korea, [4]Division of Navigation Convergence Studies, College of Maritime Sciences, National Korea Maritime and Ocean University, Busan, Republic of Korea

While previous research on environmental efficiency examines data from the annual reports of shipping companies, this study takes a novel approach. It applies data envelopment analysis (DEA) and backcasting theory to assess environmental efficiency and plan the transition to cleaner fuels among global container shipping companies. Companies are categorized as first movers, second movers, and last movers based on their environmental efficiency. This categorization provides a new perspective on strategic differentiation and improvement tactics for each group. It allows for the development of strategic frameworks tailored to the unique positions of different shipping companies, aiding them achieve the International Maritime Organization's net-zero target by 2050. The study's originality lies in its use of DEA to evaluate efficiency and backcasting for strategic planning. This combination provides policymakers and industry leaders with actionable insights and a robust methodological framework for promoting sustainable maritime management. The dual approach not only contributes to academic literature, but also aids in navigating the complexities of green transitions in the shipping industry.

KEYWORDS

environmental efficiency, strategic planning, data envelopment analysis, backcasting theory, net-zero emissions

1 Introduction

Global container shipping companies (GCSCs), pivotal in the global supply chain, are striving to meet the International Maritime Organization's (IMO) commitment to sustainable shipping (Bilgili, 2021; Hellenic Shipping News Worldwide, 2021; Maersk, 2023). The IMO has developed a phased regulatory approach aimed at reducing greenhouse gas (GHG) emissions by 50% by 2050 compared with the 2008 levels (Marine Environment Protection Committee [MEPC], 2023). In response, these companies are developing strategies for the gradual introduction of carbon-neutral and eco-friendly marine fuels, supplementing existing sulfur oxides (SO_X) and nitrogen oxides (NO_X) emission regulations (Lee et al., 2024). They advocate for sustainable fuel switching through legal and institutional interventions (Lister, 2015), and are actively discussing the development and commercialization of eco-friendly marine fuel oils to reduce ship air pollution (Bilgili, 2021; Deniz and Zincir, 2016). These companies are considering eco-friendly alternative fuels such as hydrogen, ammonia, electricity, and biofuels to comply with GHG emission reduction regulations. The implementation of these regulations, led by the IMO, depends on individual company circumstances. For example, A.P. Moller - Maersk ordered a methanol-powered ship in 2022 (Maersk, 2023), while HMM established a plan to have 80% of its ships powered by eco-friendly fuels by 2050, as outlined in its '2050 Carbon Neutrality Strategy' (Hellenic Shipping News Worldwide, 2021). However, with approximately 26 years remaining until the initial IMO GHG Strategy is achieved in 2050, there is a lack of medium- to long-term direction and practical alternatives to cleaner marine fuels for the sustainability and competitiveness of these companies (Hellström et al., 2024). Recent geopolitical issues, including the US-China hegemonic rivalry in 2018, the global pandemic of 2019-2020, the Ukraine-Russia war in 2022, the Israel-Hamas war in 2023, and the Israel-Iran armed conflict in 2024, have posed challenges to meeting the IMO's 2050 carbon reduction targets (Acheampong et al., 2023). Furthermore, it is essential to comprehend how society views climate change and its dangers (Kyriakopoulos and Sebos, 2023). Consequently, in order to meet the global demand for emission reductions and ensure the sustainable development of the shipping industry, decarbonization is crucial (Xiao et al., 2025).

Global liner shipping companies are confronting escalating pressure to enhance cost competitiveness and transition to cleaner fuels. These pressure stems from both internal factors and external demands for new cargo as global supply chains restructure. In this competitive landscape, it is crucial for these companies to undertake a thorough efficiency analysis, tailored to the transition to cleaner fuels. This analysis should assess their strengths and weaknesses and evaluate their sustainable performance accordingly. This study reviews previous research on the competitiveness and environmental impact assessment of global liner shipping companies. It aims to distinguish itself by identifying and addressing gaps in previous studies, thereby proposing novel improvements. The study ultimately aims to enhance the competitiveness of shipping companies, foster environmental responsibility, and devise a comprehensive strategy for a sustainable future.

First, Data Envelopment Analysis (DEA) is a widely used tool in academic literature for assessing the managerial efficiency of shipping companies. For example, Gong et al. (2019); Lun and Marlow (2011); Mantalis et al. (2015), and Panayides et al. (2011) employed DEA to evaluate the operational efficiency of shipping companies. They found a strong correlation between ship operation costs and company revenue. Bang et al. (2012) compared the operational and financial efficiency of 14 leading global liner shipping companies in terms of tonnage. Their findings suggested that tonnage, ship size, and new building inputs positively influence the financial performance of liner shipping companies. However, vessel age and linearity insignificantly impacted operational and financial performance. Gutiérrez et al. (2014) noted that strategic alliances among major global liner shipping companies have not improved logistics efficiency and reliability amid a global supply chain crisis. Wang et al. (2021) evaluated shipping management efficiency using a congestion index approach developed through two-stage DEA. Their study underscored that the characteristics of shipping companies significantly influence efficiency. Chao et al. (2018) conducted a study to evaluate the annual efficiency of global liner shipping companies and the efficiency of different types of vessels. Their findings affirmed that optimal input sharing and fleet capacity adjustment are vital for achieving sustainable performance for shipping companies.

Second, Cariou (2011); Cariou and Cheaitou (2012); Eide et al. (2013), and Vakili et al. (2022) posit that the growth of environmental science and rising public environmental consciousness negatively affect the sustainable development of global liner shipping companies. This is because of the unregulated emissions of pollutants from ships, which impact environmental efficiency. Gong et al. (2019) compared the economic, environmental, and operational efficiency of these companies, considering ship emissions. The study employed total assets, capital expenditure, capacity, number of ships, employees, and fuel cost as input variables, and revenue, cargo, CO_2, SO_X, and NO_X as output variables. Wang et al. (2019) assessed the company's environmental efficiency from 2010 to 2015, considering undesirable outputs such as air emissions, sewage, wastewater, and solid waste. Hsieh et al. (2021) evaluated the environmental efficiency of global liner shipping companies from 2013 to 2017, focusing on shipboard air pollutant emissions. They compared the evaluation variables for each company and suggested improvements. Kuo et al. (2020) analyzed the factors affecting the efficiency of shipping operations using four inputs (employees, operating costs, owned-in fleet capacity, and chartered-in fleet capacity) and two outputs (revenue and lifting). The study demonstrated the link between the reduction of shipboard pollutant emissions and profits. Liao and Lee (2023) estimated the environmental efficiency of 11 global shipping companies from 2019 to 2021, proposing measures to reduce CO_2 emissions to achieve environmental goals. The study employed the directional distance function based on two inputs (Capacity and Fuel), one desirable output (Cargo), and one undesirable output (CO_2 emissions).

Existing literature examines the CO_2 emissions of global shipping companies. However, these studies rely solely on data from companies' annual reports, despite the fact that CO_2 emissions calculations depend on each company's constraints and

considerations. Previous studies identified a lack of comprehensive academic research and practical alternatives for global liner shipping companies to promote a green shift in marine fuel oil. This shift requires decision-making that incorporates information, funding, and infrastructure investments necessary for long-term growth and to reach net-zero emissions, as outlined in the 2023 IMO strategy for the reduction of GHGs from ships. This study differs from previous research by offering practical goals and strategic plans for global liner shipping companies regarding the eco-friendly conversion of marine fuel oil. It employs backcasting theory to set a desirable future as a managerial tool, and provides practical strategic plans based on academic theory verification to achieve this goal.

This study assesses the environmental efficiency of global liner shipping companies using an undesirable output model. It proposes strategies for achieving the IMO, 2020 Net-Zero goal in the shipping industry, drawing on eco-friendly ship fuel conversion and backcasting theories. To substantiate the study's purpose, we analyzed the 2022 operating and financial reports of 20 global liner shipping companies. These companies represent over 80% of the container cargo capacity in the global shipping market. The analysis was conducted using data from the companies' official websites, Yahoo Finance statistics, and cargo capacity data from 1995 to 2022 obtained from the Clarksons Research Portal. Eight global liner shipping companies were selected as decision-making units (DMUs) to analyze their environmental efficiency. This study differs from previous ones in that it evaluates the environmental efficiency of global liner shipping companies by considering their willingness to switch to eco-friendly ship fuel. This willingness is considered an input variable tied to the company's own vessel capacity. The study also investigates the detailed specifications of each company's vessel, such as its use of eco-friendly ship fuel and eco-friendly electric engines. This allows for a more objective calculation of CO_2 emissions, ensuring the scientific verifiability and logical completeness of the study. Furthermore, this study offers policy implications for global liner shipping companies aiming to achieve the IMO 2050 Net-Zero goal. Therefore, we review the ship ordering status of global liner shipping companies up to 2027, based on data from Clarksons Research Portal and the Environmental, Social, and Governance (ESG) section of sustainability reports posted on the companies' individual websites. This information is then used to derive policy implications using backcasting theory.

The research questions are as follows. First, this study, guided by the 3W1H approach, aims to empirically investigate the strategic direction and purpose behind the eco-friendly fuel conversion of global liner shipping companies. The 3W1H approach, a structured problem-solving method that facilitates logical exploration and informed decision-making (Jabbari et al., 2023), has been widely employed in various studies (Batool et al., 2023; Gu et al., 2022; Malik et al., 2020). This study applies the 3W1H approach to understand the eco-centric objectives of global liner shipping companies, focusing on four aspects: who, why, what, and how. The "who" refers to global liner shipping companies operating the world's greenest and most efficient container ships. The "why" analyzes the reasons behind the relatively low efficiency of these companies, using high environmental efficiency companies as benchmarking targets. The "what" pertains to the 2050 full-cycle net-zero GHG emissions target for global liner shipping companies, consistent with the IMO's shipboard carbon emissions regulation. The "how" presents practical measures for these companies to meet the IMO's 2023 GHG reduction strategy, using backcasting theory. Figure 1 presents the research questions derived from the 3W1H approach

Second, Figure 2 presents the research process. Accordingly, Chapter 3 discusses the need and justification for transitioning to eco-friendly ship fuel, driven by the paradigm shift toward environmental friendliness. It also explores the rationale for proposing a different strategic direction from existing literature, using backcasting theory. This chapter describes the DEA methodology and the data to be analyzed for global liner shipping companies. Chapter 4 presents empirical results and responses to key questions, based on environmental efficiency analysis results, Slack information, future ship orders of global liner shipping companies, green targets consistent with the IMO's 2023 GHG reduction strategy, and backcasting theory. Chapter 5 discusses the policy, social, and originality/value implications of this study. Lastly, Chapter 6 summarizes the study, draws conclusions, and identifies the study's limitations and contributions.

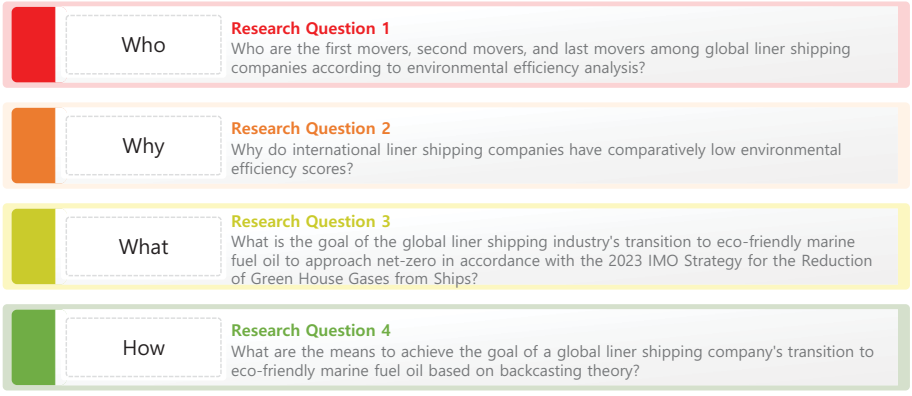


FIGURE 1
Research questions derived from 3W1H approach. Source: Author's own compilation.

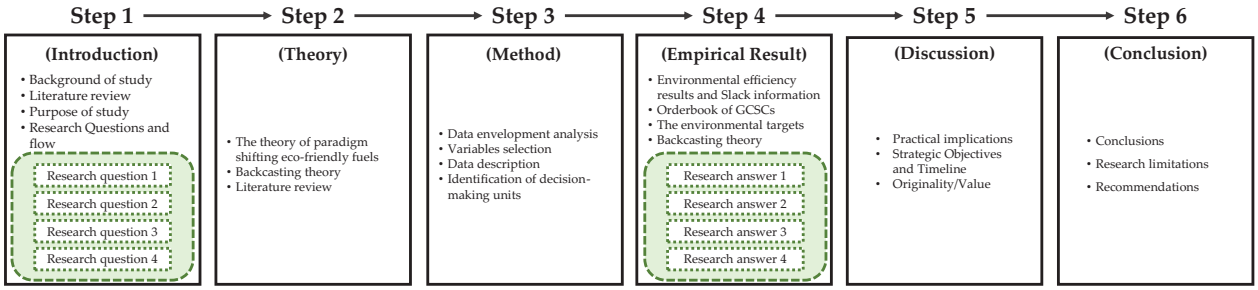


FIGURE 2
Process of research. Source: Author's own compilation.

2 Theory

2.1 Paradigm-shifting eco-friendly fuels by global container shipping companies

The global community faces a shared challenge that necessitates collective action through international or regional agreements. Transboundary air pollution contributes to global warming, extreme weather events, and other environmental issues (Manisalidis et al., 2020). Global liner shipping companies are working to implement ESG principles to meet shippers' expectations regarding environmental, socio-technical, and business risks, while also creating opportunities for a sustainable future and complying with international environmental regulations (Lee et al., 2024).

In response to the transboundary nature of ship-borne air pollution, these companies adopted the Ship Energy Efficiency Management Plan for all internationally voyaging ships at the 62nd session of the MEPC in 2011. The Committee (MEPC) approved an amendment to Annex VI of MARPOL 73/78 in 2011 to regulate GHG emissions from container ship operations (Fan et al., 2024). In March 2024, the World Shipping Council (International Chamber of Shipping), representing shipping companies, highlighted at the 81st session of the IMO's MEPC that ships engaged in international navigation vary in age. To address the practical limitations of replacing all ships simultaneously with environmentally-friendly marine fuel ships, it emphasized the importance of creating an environment where ships and energy suppliers can use a variety of fuels, energy sources, and technologies. This approach is based on a paradigm shift toward greener marine fuel through the joint implementation of pollutant emission regulations and the sequential replacement of ships.

Applying Thomas Samuel Kuhn's concept of a paradigm shift from "Structure of Scientific Revolutions" (Shapere, 1964) to the shipping industry reveals that current global liner shipping companies actively prioritize eco-friendliness, reflecting societal needs over cost reduction and profit generation to maintain sustainability. Shippers may perceive this as a symbolic representation of a standardized global liner shipping company undergoing a paradigm shift (Kovacs, 2022). Therefore, global liner shipping companies must diverge from the previous paradigm of solely pursuing commercial interests, such as containerized cargo transport and profit-making. Instead, they should focus on sustainable development and long-term economic value creation based on environmental justice theory (Li et al., 2023). Global stakeholders are urging these companies to shift toward the use of cleaner marine fuels to ensure the marine environment's sustainability for future generations. This shift should reduce the impact of ship-borne air pollution through the introduction of sustainable and environmentally-friendly marine fuel oils, efficient ship operation management, and related technologies (Wang et al., 2023). Consequently, global liner shipping companies primarily aim to operate vessels that use environmentally-friendly marine fuel oil, ensuring the sustainability of the ESG domains. This approach allows them to fulfill their environmental responsibilities, promote environmental justice in the long term, and lay the foundation for future generations.

2.2 Backcasting theory to address eco-friendly fuel adoption issues

The dialogue on the shift toward sustainable socio-technical systems has advanced given accelerated global climate change, increased use of low-carbon energy in land and maritime transport, and other aspects of the sustainability transition. Backcasting method proves effective in formulating strategies to achieve concrete objectives (Bibri, 2018). Historically, global shipping companies' transition to environmentally-friendly marine fuel oil has relied on forecasting methods. These methods focus on designing internal strategies to maintain or enhance ship operations at a low cost within the existing Bunker C framework. This approach, however, has been unable to adapt to changing circumstances and conditions. To address these limitations, this study adopts backcasting, an approach that contrasts with forecasting. Backcasting sets the green vision and goals for the future shipping industry from a long-term perspective, and then identifies the institutions, policies, and technologies necessary to realize them (Danish et al., 2024). This study, therefore, employs backcasting as a research method, which is ideal for setting growth strategy targets based on a clear future direction toward greener marine fuels in the global liner shipping industry.

Backcasting theory provides a suitable theoretical framework to solve the problem through a normative-strategic approach. This theory relies on context and empirical analysis, linking the conditions and tasks for realizing a viable global liner shipping company to the methodology of the normative model (Tuominen et al., 2014).

In conclusion, the backcasting methodology used in this study is a normative approach that pre-establishes the desired future state. It aims to align the shipping company with net-zero emissions consistent with the 2023 IMO strategy for reducing GHGs from ships. This allows global liner shipping companies to present the most effective policies to achieve a quantum leap, defined as a catch-up plan (Bibri and Krogstie, 2019). By using backcasting theory to identify strategic tasks for global liner shipping companies, it is possible to develop a concrete action plan for second and third-tier companies to reach the status of top-tier global shipping companies that have successfully transitioned to eco-friendly ship fuel.

2.3 Literature review

Previously, various studies have been conducted to understand the regulations on eco-friendly ships and the current market situation. Serra and Fancello (2020) explained that fundamental changes in fuel, technology, operations, and business practices in the shipping industry must be implemented to comply with the new IMO's regulations. Balcombe et al. (2019) explained that the path to achieving GHG reduction by 2050 is unclear, but multi-faceted responses are needed for in-depth decarbonization. He further explained that in the long run, deeper decarbonization requires strong financial incentives. Lee and Nam (2017) identified regulations on eco-friendly ships in major countries such as Europe, the United States, Japan, China, and South Korea, and explained that South Korea needs strategies such as establishing a shipping-ship cooperation network, sharing shipping-ship business information and reducing joint costs, investing in eco-friendly ship research and development, and expanding LNG fuel ship support. Halim et al. (2018) explained that international shipping companies' barriers to achieving decarbonization include sunk costs, path dependence, carbon emissions as negative externalities: the Climate as Unprecedented Public Good, Incentives, and Information Asymmetry. Ann et al. (2023) identified the impact of energy efficiency and decarbonization on Korean container ships in accordance with IMO regulations, and explained that eco-friendly technologies such as engine output limitations, energy-saving devices, and alternative marine fuels should be reviewed. Afterwards, it was explained that it is most desirable to introduce LNG fuel on Korean container ships based on the marginal abatement cost for the fleet.

Consistent with these changes, global container shipping companies are actively converting eco-friendly fuels. In March 2022, Maersk entered a strategic partnership with six companies worldwide to secure green methanol (biometall and e-methanol) on large scale by 2025. MSC further presented a plan in response to the European Green Deal to reduce CO2 emissions using alternative fuels (Grzelakowski et al., 2022). However, various studies are being conducted to analyze the economic and environmental effects of global container ships' fuel conversion according to the eco-friendly fuel conversion of global container ships. Elkafas et al. (2021) analyzed the environmental and economic benefits of replacing diesel oil with the natural gas-diesel dual fuel for container ships. The analysis was conducted on A7 container ships owned by Hapag-Lloyd, and the proposed dual fuel engine showed that carbon dioxide, nitrogen oxides, sulfur oxides, particulate matter, and carbon monoxide (CO) emissions were reduced by 20.1%, 840 $/ton, 9,864$/ton, 27,761$/ton, and 4,307$/ton cost-effectiveness, respectively. Additionally, Elkafas et al. (2022) analyzed large container ships operating on the East-West trade, and explained that dual fuel engines that operate with natural gas reduce carbon dioxide, sulfur oxides, and nitrogen oxides by 28%, 98%, and 85%, respectively, compared with diesel engines. Additionally, it was explained that when a dual fuel engine powered by methanol is used, the reduction effect reaches 7%, 95%, and 80%, respectively. Based on these results, it was argued that the use of dual fuel engines would improve the ship's energy efficiency index by 26% and 7%, respectively. Ammar (2019) conducted an environmental analysis of methanol-diesel fuel engines on cellular container ships, and explained that when using the fuel engine, nitrogen oxides, sulfur oxides, carbon monoxide, carbon dioxide, and particulate matter emissions were reduced by 76.78%, 89%, 55%, 18.13%, and 82.56%, respectively.

Considering previous studies, various technical and policy measures for reducing greenhouse gas emissions and sustainable shipping activities are being discussed, according to IMO regulations. In fact, it was confirmed that the economic and environmental effects of using alternative fuels for the zero-emission transition of global container shipping companies were evaluated. However, global shipping companies' predictions on the conversion of eco-friendly ship fuel oil mainly focus on how to maintain or improve ship operations at low costs in the existing Bunker C using forecasting method, and there is a limit to not achieving the goal according to changes in circumstances and conditions. To solve this problem, this study adopts environmental efficiency analysis through Undesirable output DEA analysis and backcasting theory to fill the gap between goal and reality, and overcome challenging limitations.

3 Method

3.1 Data envelopment analysis

The DEA model, a widely recognized tool for efficiency analysis, compares and evaluates the relative efficiency of DMUs by analyzing the weighted magnitudes of various input and output variables. DEA models are divided into two categories: the Charnes, Cooper, and Rhodes (CCR) model, which assumes Constant Returns to Scale, and the Banker, Charnes, and Cooper (BCC) model, which assumes Variable Returns to Scale. As long as the target DMUs' ratio does not surpass one and the weights of each input and output are greater than zero, the DEA-CCR model, a linear fractional programming technique, maximizes the ratio of the output-weighted sum to the input-weighted sum of the DMUs.

However, because it cannot differentiate between scale and pure technical efficiencies and assumes that the return to scale is constant, the CCR model has limitations. The estimation by the CCR model can appear inefficient, if the production technology is a variable return to scale, while it actually is an efficient DMU. Therefore, in order to overcome this, Banker et al. (1984) proposed the BCC model, which adds the convexity requirement and relaxes the restriction on the constant returns to scale, using the assumption of variable returns to scale. The DEA model can also identify scale efficiency (SE) by comparing the efficiencies of the CCR and BCC models. However, the DEA model, which evaluates organizational performance efficiency, overlooks the slack between inputs and outputs. It operates under the assumption that inputs or outputs increase or decrease proportionally, which is a limitation of the radial model derived from DEA analysis. This model fails to rank the most efficient DMUs. Furthermore, the DEA model is an oriented model with a specific direction, such as input-oriented or output-oriented, which does not provide individual efficiency information for inputs or outputs.

To address these issues, this study adopts the Slack-Based Measure of Efficiency (SBM)-DEA model, which compensates for the DEA model's limitation of calculating the efficiency value as 1 despite the inefficient state of residual variables. The SBM-DEA model, proposed by Tone (2001), not only evaluates the efficiency between DMUs using the same distance concept as the DEA model, but also considers the slack overlooked in DEA. The non-radial SBM-DEA analysis does not assume a proportional increase or decrease in inputs or outputs, and derives optimal efficiency by considering both input residuals and output shortages simultaneously. The non-oriented SBM model (SBM Non-oriented) improves inputs and outputs simultaneously, considering both radial and non-radial slacks, allowing for the optimization of inputs and outputs without a specific direction. Consequently, the SBM-DEA model, which clearly reveals rankings among DMUs (Tone, 2002), is a more reasonable efficiency evaluation method than the DEA model.

Cooper et al. (2006) proposed the undesirable output model to consider undesirable outputs in the SBM model proposed by Tone (2001). This model derives efficiency by considering undesirable outputs in addition to the inputs and outputs covered in DEA analysis. Equation 1 presents the output formula of the undesirable output model:

$$\begin{aligned} \rho = min & \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{io}}}{1+\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{ro}^g}+\sum_{r=1}^{s_2}\frac{s_r^b}{y_{ro}^b}\right)} \\ & subject\ to\ x_o = X\lambda + s^- \\ & y_o^g = Y^g\lambda - s^g \\ & y_o^b = Y^b\lambda + s^b \\ & s^-, s^g, s^b, \lambda \geq 0 \end{aligned} \tag{1}$$

Cooper et al. (2007) assume there are n DMUs with three variables—inputs, good outputs, and bad outputs—represented by three vectors— $x \in R^m$, $y^g \in R^{s_1}$, and $y^b \in R^{s_2}$—respectively. The matrices X, Y^g, and Y^b are then defined as follows: $X = [x_1, \cdots, x_n] \in R^{m\times n}$, $Y^g = [y_1^g, \cdots, y_n^g] \in R^{s_1\times n}$, and $Y^b = [y_1^b, \cdots, y_n^b] \in R^{s_2\times n}$, where $X > 0$, $Y^g > 0$, $Y^b > 0$, and $\lambda \in R^{s_1\times n}$ is the intensity vector. The vector $s^g \in R^{s_1}$ represents shortages in good outputs, whereas the vectors $s^- \in R^m$ and $s^b \in R^{s_2}$ expresses excesses in inputs and bad outputs, respectively. In the undesirable output model, DMUs are only efficient when $\rho = 1$, $s^- = 0$, $s^g = 0$, and $s^b = 0$.

3.2 Variables selection and data description

To facilitate the scientific analysis of this study's results, it is crucial to select input and output variables based on their potential implications, as they significantly impact the DEA results. A thorough review of previous efficiency analysis studies of general shipping companies suggests that the environmental efficiency of global liner shipping companies can be estimated using various variables, including total assets, fleet size, number of ships, revenue, and pollutant emissions. The selection of variables for this study was guided by three principles to ensure their appropriateness and reliability. First, the optimal number of variables for DEA analysis was determined considering the reliability of the results, which is achieved when the number of DMUs is at least twice the sum of the input and output variables (Dyson et al., 2001; Golany and Roll, 1989; Homburg, 2001). Second, the DEA should select and analyze variables for DMUs to identify relatively inefficient variables and select those that can be improved, as the DEA is aimed at maximizing output. Third, the variables should be directly related to DMUs, and subjective judgment should be excluded. Consequently, we selected two inputs: total assets (in billion USD) and ownership (in TEU), one desirable output: turnover (in billion USD), and one undesirable output: CO_2 emissions (in million tons), based on the variables used in previous studies on the efficiency of general shipping companies. The data used for this study's analysis was obtained from Clarkson Research statistics, annual reports, financial reports, and websites of global liner shipping companies up to 2022 through a scientific data preprocessing process. Figure 3 illustrates the data collection process.

However, this study acknowledges the limitation that CO_2 emissions are calculated differently across global liner shipping companies given varying constraints and considerations, and objective CO_2 emissions data are not readily available. To address these limitations, this study derives a formula for calculating CO_2 emissions based on the Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines. This formula considers factors such as fuel usage, fuel type, and emission factors, and relies on official information obtained through a review of authorized reports (IMO, 2020). In estimating the CO_2 emissions from vessels operated by global liner shipping companies, this study builds upon existing research (Czermański et al., 2021). It assumes that container vessels operate for 250 days per year at a speed of 17 knots. The emission factor per vessel, based on fuel consumption according to vessel size, is calculated using data from IMO (2020). Notably, IMO (2020) suggests that a potential reduction of CO_2 emissions by 0.25% can be achieved by improving the performance of the main engine by 2030. This implies that if a ship is equipped

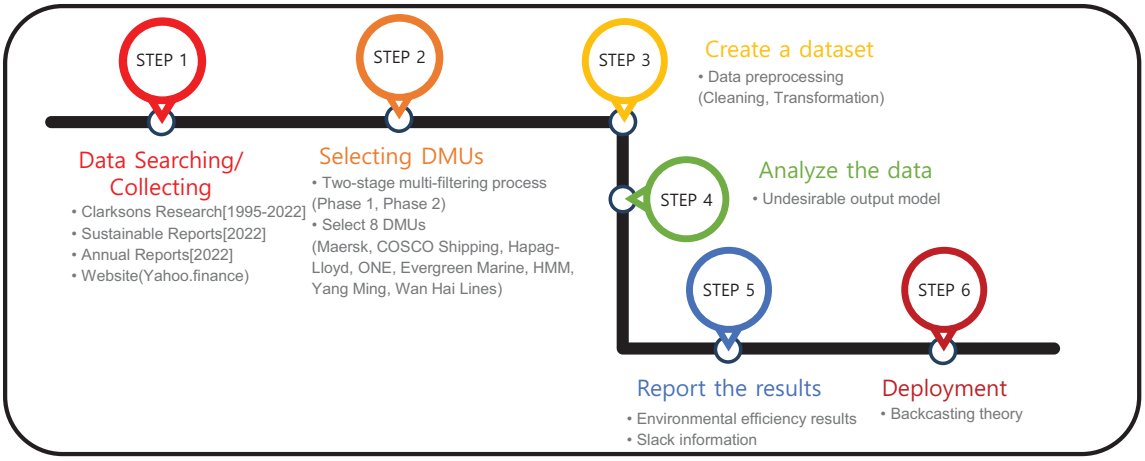


FIGURE 3
Journey through dataset analysis. Source: Author's own compilation.

with an electronically controlled main engine, the CO_2 emissions can be reduced to 99.75% of those from a conventional mechanically controlled engine. Equation 2 expresses the CO_2 emissions formula proposed in this study:

$$CO_2\ emissions = \sum_{ij}(FC_i \times EF_{ij} \times EE_i) \quad (2)$$

$$subject\ to\ FC_i, EF_{ij}, EE_i \geq 0,$$

where FC_i denotes the fuel consumption of vessel i, EF_{ij} denotes the emission factor for vessel i fuel j, and EE_i denotes the engine efficiency. Table 1 shows the sources of the variables used in the global liner shipping enterprise efficiency analysis.

Table 2 presents the inputs and outputs for the global liner shipping company DMUs.

Table 3 presents the basic statistics for the global liner shipping company DMUs' inputs and outputs.

3.3 Identification of decision-making units

This study scrutinizes the environmental efficiency of 20 major global liner shipping companies, collectively representing over 80% of container vessels, therefore ensuring a representative sample of the global shipping market based on freight space (Chao et al., 2018; Kuo et al., 2020). This focus is motivated by the ongoing efforts to expand cargo capacity related to eco-friendly marine fuel-powered vessels in a bid for self-reliance, especially given the impending abolition of the European Union's Consortia Block Exemption Regulation (CBER) on April 25, 2024 (Reed Smith, 2024). As in Table 4, the initial data processing step involved excluding MSC, CMA CGM, PIL, SITC, IRSIL, and Sinokor Merchant Marine from the DMU given the difficulty in obtaining financial information, as these are privately held shipping companies. In this study, total asset is used as input variable and Revenue is used as desired output variable in environmental efficiency analysis. Therefore, financial information on the two variables must precede before the analysis of environmental efficiency. So we had no choice but to exclude companies that did not provide financial information from the analysis.

TABLE 1 The source of input and output variables.

Type	Variables	Unit	Data sources
Inputs	Total assets	Billion USD	Annual reports, Finance reports, Website
	Own Capacity	TEU	Clarkson research
Output	Revenue	Billion USD	Annual reports, Finance reports, Website
Undesirable output	CO2 emission	Million Ton	Authors' proposed formulation

Source: Authors' own compilation.

In the second data preprocessing phase, several liner shipping companies (ZIM, X-Press feeders Group, KMTC, UniFeeder, Sea Lead shipping, Sinokor Merchant Marine, and Zhonggu Logistics Corp.) were excluded per Clarkson Research data. These companies were deemed unsuitable for comparison within the DMU given their relatively small capacity.

In this study, eight global liner shipping companies (Maersk, COSCO Shipping, Hapag-Lloyd, ONE, Evergreen Marine, HMM, Yang Ming, and Wan Hai Lines) were chosen as DMUs. Their selection followed a two-stage multiple filtering procedure (Figure 4), implemented considering specific limiting factors.

4 Empirical Results

4.1 First movers, second movers, and last movers according to the environmental efficiency

The undesirable output model analysis considers desirable and undesirable outputs to assess the effectiveness of environmental

TABLE 2 Inputs and outputs of individual decision-making units (2022).

Global shipping lines	Inputs		Desirable output	Undesirable output
	Total assets (billion USD)	Own Capacity (TEU)	Revenue (billion USD)	CO_2 emission (million Ton)
Maersk	55.27	2,398,256	48.10	16.04
COSCO Shipping	35.46	2,137,198	27.09	11.74
Hapag-Lloyd	25.16	1,068,103	22.46	6.15
ONE	28.63	868,969	16.80	5.22
Evergreen Marine	15.91	908,107	11.25	5.57
HMM	14.13	614,229	10.11	2.79
Yang Ming	5.30	258,084	3.92	2.00
Wan Hai Lines	7.86	367,851	5.57	3.49

Source: Clarkson research and financial reports from each company.

efficiency enhancements. From Table 5, the CCR model identifies Hapag-Lloyd as the most environmentally efficient among global shipping companies. The BCC model, however, ranks Maersk, Hapag-Lloyd, HMM, and Yang Ming at the top for environmental efficiency. Therefore, Hapag-Lloyd emerges as the most efficient according to the SE model. categorization of DMUs into three groups: first movers, second movers, and last movers, as depicted in Figure 5. This categorization was followed by the identification of areas for environmental efficiency improvement. The first movers group comprises leading global liner shipping companies with environmental efficiency significantly above the average. Specifically, in this study, Maersk and Hapag-Lloyd are classified as first movers, reflecting their leadership in achieving the IMO's 2050 Net-Zero commitment. First movers are those that have pioneered new sales markets to secure large global shippers' volumes and have the potential to enhance their brand image through green shipping technological innovations. Despite the potential competitive advantage in the absence of competitors, first movers face challenges such as high initial costs, risks, and uncertain market response.

The second movers group consists of global liner shipping companies with eco-efficiency comparable to the sample average, including HMM and ONE. Second movers are companies that enter the global liner shipping market following the first movers, who have already established a robust presence. They can gain a competitive edge by identifying and addressing the first movers' weaknesses. However, they may encounter high entry barriers and competition between shippers and long-established shipping companies. The last movers group includes DMUs that need substantial environmental efficiency improvements. Yang Ming, COSCO Shipping, Wan Hai Lines, and Evergreen Marine fall into this category. In this study, last movers are defined as the final entrants into the global liner shipping market after several players have already entered. They may enter the market by identifying the weaknesses of the first and second movers, and learning from their failures. However, they may still face significant competition from incumbents given the saturation of the global liner shipping market.

4.2 Why the efficiency of global container shipping companies is lower than a model company

This study investigates the reasons behind the relatively low environmental efficiency of global liner shipping companies by comparing them with first movers. The research found that high

TABLE 3 Descriptive statistics for input and output variables.

Global shipping lines	Inputs		Desirable output	Undesirable output
	Total assets (billion USD)	Own Capacity (TEU)	Revenue (billion USD)	CO_2 emission (million Ton)
Avg	23.46	1,077,599.63	18.16	6.62
Max	55.27	2,398,256.00	48.10	16.04
Min	5.30	258,084.00	3.92	2.00
Mid	20.54	888,538.00	14.02	5.40
St Dev	15.42	735,636.46	13.56	4.53

Source: Authors' own compilation.

TABLE 4 Decision-making unit selection among 20 Global container shipping lines.

Ranking	Global shipping company	Private corporation*	Under 100,000TEU Own Capacity**	DMU
1	MSC	O***	–****	–
2	Maersk	–	–	✓*****
3	CMA CGM	O	–	–
4	COSCO Shipping	–	–	✓
5	Hapag-Lloyd	–	–	✓
6	ONE	–	–	✓
7	Evergreen Marine	–	–	✓
8	HMM	–	–	✓
9	Yang Ming	–	–	✓
10	ZIM	–	O	–
11	Wan Hai Liens	–	–	✓
12	PIL	O	–	–
13	SITC	O	–	–
14	X-Press feeders Group	–	O	–
15	KMTC	–	O	–
16	IRSIL Group	O	–	–
17	UniFeeder	–	O	–
18	Sea Lead shipping	–	O	–
19	Sinokor Merchant Marine	O	O	–
20	Zhonggu Logistics Corp	–	O	–

*Annual reports (2022) and Website (Yahoo Finance).
**Clarksons Research (1995–2024).
Source: Authors' own compilation.
***O means it is included in the criteria.
****– means it isn't included in the criteria.
*****✓ represents the company has been selected as DMU.

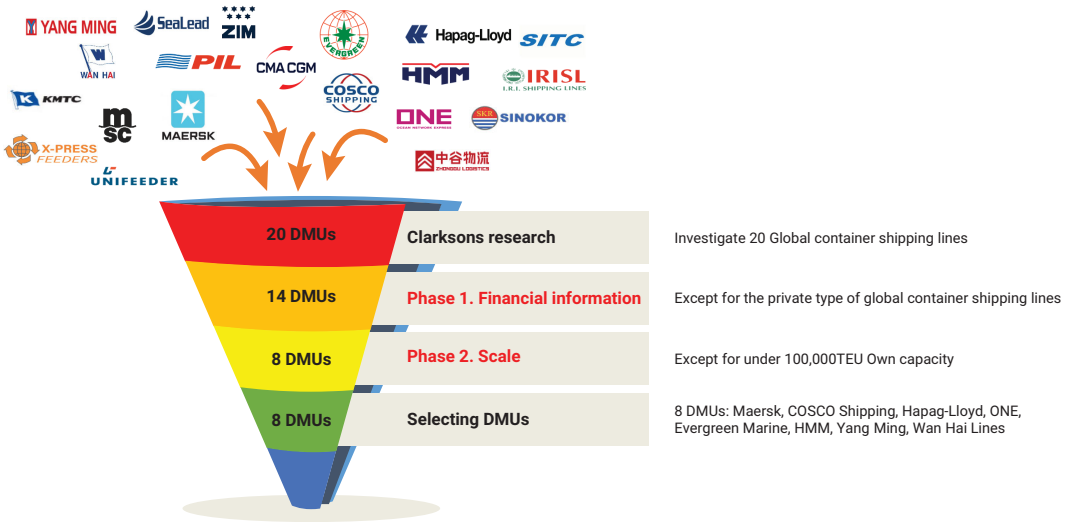


FIGURE 4
Multi-filtering process for selecting DMUs. Source: Author's own compilation.

TABLE 5 Environmental efficiency results of global container shipping companies (GCSCs) in the undesirable output model.

GCSC	Charnes, Cooper, and Rhodes	Banker, Charnes, and Cooper	Scale efficiency
Maersk	0.885	1.000	0.885
COSCO Shipping	0.616	0.635	0.970
Hapag-Lloyd	1.000	1.000	1.000
ONE	0.744	0.780	0.954
Evergreen Marine	0.564	0.623	0.905
HMM	0.789	1.000	0.789
Yang Ming	0.630	1.000	0.630
Wan Hai Lines	0.591	0.774	0.764
Average	0.727	0.852	0.862

Source: Authors' own compilation.

levels of green efficiency were achieved by optimally adjusting the free variables (inputs and outputs in the dataset). For example, Evergreen Marine, which displayed the lowest relative green efficiency in the CCR model, had an efficiency of 0.564. This efficiency was closest to the target when Hapag-Lloyd's weighting reached 50% (Table 6). The study revealed that Evergreen's total assets, own capacity, and CO2 emissions exceeded its total assets by USD 3.316 billion, 373,329,151 TEUs, and 2.487 million tons, respectively, contributing to its low efficiency.

Clarkson Research, in a separate study, analyzed container ship orders through 2027 to identify trends in global liner shipping companies' transition to cleaner alternative fuels (Table 7). The findings showed that first movers consistently plan to order containerships powered by cleaner alternative fuels. Hapag-Lloyd, the carrier with the highest environmental efficiency, has announced plans to order eco-friendly containerships with capacities of 70,980 TEUs, 168,040 TEUs, and 70,500 TEUs between 2023 and 2025. Maersk, the DMU with the largest capacity, also plans to build environmentally-friendly container ships with capacities of 2,100 TEU, 121,200 TEU, 162,600 TEU, 45,000 TEU, and 9,000 TEU from 2023 to 2027. Additionally, HMM, a second-mover, plans to deploy green container ships with capacities of 160,752 TEUs, 54,000 TEUs, and 27,000 TEUs in 2024, 2025, and 2026, respectively. In contrast, most last movers still plan to order containerships that use traditional Bunker C fuel. Therefore, it is expected that a significant environmental efficiency gap will be bridged among global liner shipping companies at each tier level.

4.3 Environmental targets based on the international maritime organization's commitment

This study examines the objectives and strategies of shipping companies transitioning to eco-friendly marine fuel oil, drawing on the sustainability reports of global liner shipping companies. Figure 6 illustrates the findings.

The 2023 IMO strategy for reducing GHGs from ships imposes stricter regulatory standards and incentives than its predecessor. The IMO has set GHG reduction targets, including a 20% reduction by 2030 and a 70% reduction by 2040, relative to 2008 levels, with the ultimate goal of achieving net-zero emissions by around 2050. The strategy includes a plan to convert at least 5% of the total energy used in international shipping to zero or near-zero technologies and eco-friendly marine fuels by 2030. An analysis of ship orders for cleaner marine fuel oil, shown in Table 7, reveals that all but one of the seven shipping lines have set specific GHG reduction targets for 2030, aiming for net-zero by 2050, consistent with the 2023 IMO

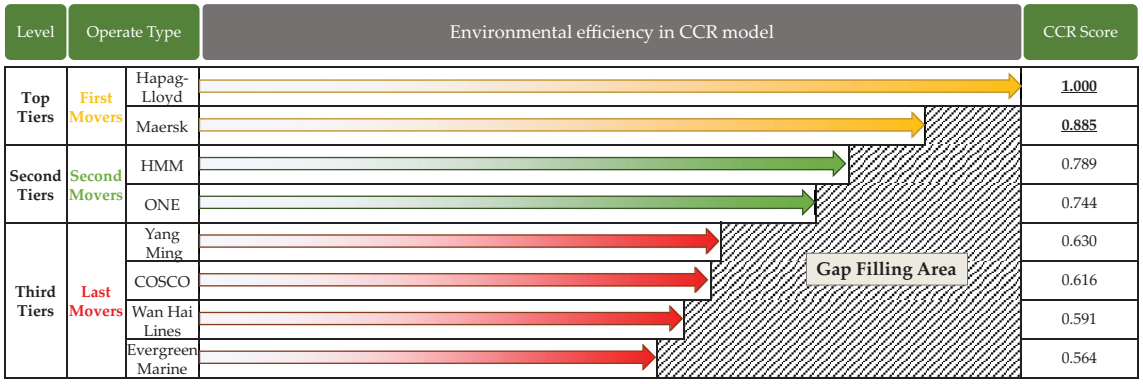


FIGURE 5
Gap filling area by dividing GCSCs into 3 groups based on the environmental efficiency results. Source: Author's own compilation.

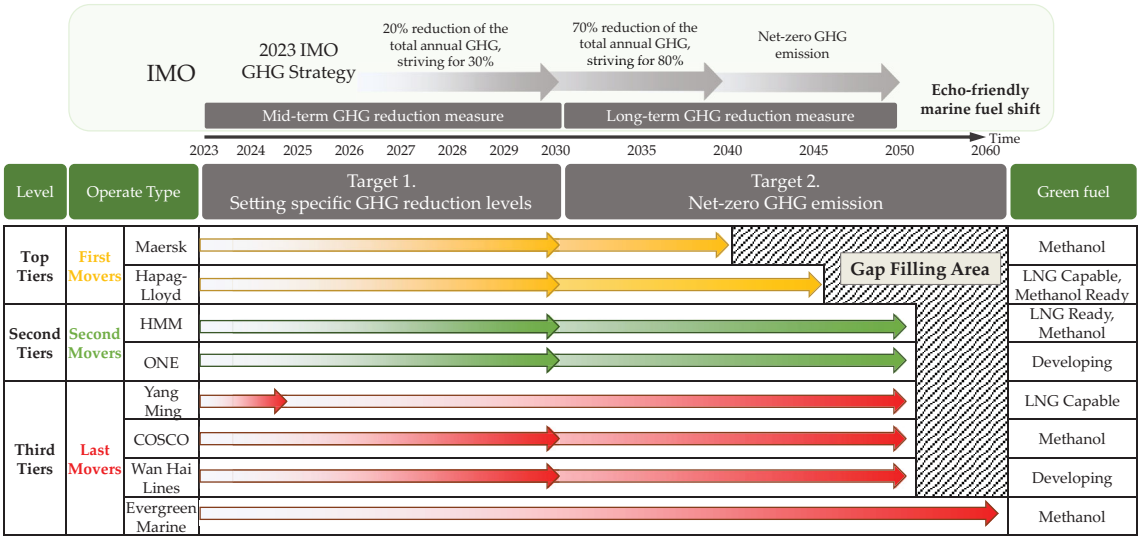


FIGURE 6
Environmental strategies of shipping companies compared to the IMO schemes. Source: Author's own compilation.

TABLE 6 Slack information based on the closest target in the Charnes, Cooper, and Rhodes models.

Variables (unit)	Total assets (billion USD)	Own Capacity (TEU)	Revenue (billion USD)	CO_2 emission (million Ton)
Maersk	1.398	111,113.612	0.000	2.864
COSCO Shipping	5.113	848,974.496	0.000	4.320
Hapag-Lloyd	0.000	0.000	0.000	0.000
ONE	9.820	70,284.215	0.000	0.623
Evergreen Marine	3.316	373,329.151	0.000	2.487
HMM	2.808	133,568.508	0.000	0.019
Yang Ming	0.909	71,631.232	0.000	0.922
Wan Hai Lines	1.615	102,932.770	0.000	1.963

Source: Authors' own compilation.

Strategy. Maersk, the first mover in the top-tier group, aims for net-zero by 2040[1], while Hapag-Lloyd targets 2045[2]. This suggests a leading strategy of transitioning to green shipping fuel. In contrast, COSCO Shipping, the newest member of the third-tier group, has a more gradual target of achieving net-zero before 2060.

The IMO has proposed several GHG reduction strategies for achieving net-zero by 2050, including enhancing energy efficiency design standards and introducing green alternative marine fuels. A detailed review of the eight global liner shipping companies' plans for transitioning to green ship fuels, based on these two strategies, shows that all have plans to improve their vessels' design standards and related equipment for better energy efficiency. These plans include installing energy-efficient propellers, incorporating energy-saving devices, implementing shaft generators, and integrating exhaust/waste heat recycling systems according to the sustainability reports of global liner shipping companies. Specifically, Maersk has set strategies to include new and improved propellers, bulbous bows, shore power enablement and tech solutions like the Maersk's energy efficiency platform StarConnect. Hapag-Lloyd has planned to accommodate duel-fuel propulsion which emit much less CO2. HMM has introduced an energy saving device and ONE has proposed improvement of fuel efficiency and Vessel digitalization program. Yang Ming has adjusted carbon capture devices, bubble drag reduction, energy-efficient wind shields, energy-efficient propellers, shaft generators, and exhaust/waste heat recycling systems. COSCO has announced to implement energy-saving and emission-reduction measures to reduce the use of fuel oil through process control of navigation and shore power transformation.

1 Maersk's sustainability report 2023 (https://www.maersk.com/sustainability/our-esg-priorities/climate-change)

2 Hapag-Lloyd's sustainability report 2023 (https://www.hapag-lloyd.com/en/company/press/releases/2024/03/focus-on-sustainable-shipping–hapag-lloyd-publishes-sustainabil.html)

TABLE 7 Orderbook of global container shipping companies (2023–2027).

Variables	Type	2023	2024	2025	2026	2027
Maersk	General fuels (TEU)	–	–	–	–	–
	Alternative fuels (TEU)	2,100	121,200	162,600	45,000	9,000
COSCO Shipping	General fuels (TEU)	159,220	231,588	144,000	–	–
	Alternative fuels (TEU)	700	700	64,720	24,000	144,000
Hapag-Lloyd	General fuels (TEU)	–	–	–	–	–
	Alternative fuels (TEU)	70,980	168,040	70,500	–	–
ONE	General fuels (TEU)	–	–	–	–	–
	Alternative fuels (TEU)	–	–	–	–	–
Evergreen Marine	General fuels (TEU)	32,648	232,268	148,032	4,600	–
	Alternative fuels (TEU)	–	–	–	192,000	192,000
HMM	General fuels (TEU)	–	5,400	–	–	–
	Alternative fuels (TEU)	–	160,752	54,000	27,000	–
Yang Ming	General fuels (TEU)	–	–	–	–	–
	Alternative fuels (TEU)	–	–	–	77,500	–
Wan Hai Lines	General fuels (TEU)	161,254	70,566	64,620	–	–
	Alternative fuels (TEU)	–	–	–	–	–

Source: Authors' own compilation

Evergreen Marine has replaced old ships with new ones, where optimal energy efficiency and environmental protection are adopted as the concepts of ship design. Furthermore, Evergreen Marine has monitored the fuel consumption of ships and the operating conditions of their main engine to ensure the thrust efficiency of their main engine.

The strategic focus on "green alternative marine fuels" has become crucial in the transition to green marine fuels, particularly in enhancing the competitiveness of global liner shipping companies. Maersk, a pioneer in the top-tier group, led the way by ordering the world's first methanol-powered ship in 2021, spurring the development of green methanol and green ammonia as potential future fuels. In 2023, COSCO Shipping and Evergreen Marine, the last movers in the third-tier group, followed suit by ordering methanol-powered vessels. They are also collaborating with engine manufacturers, shipyards, and marine equipment research institutes on research and development of green methanol, green ammonia, and potential future fuels. Conversely, ONE and HMM, the second movers in the second-tier group, have taken a more cautious approach to the development of green alternative marine fuels, adopting a conservative stance.

4.4 How to achieve net-zero 2050 via the perspective of backcasting theory

To achieve net-zero GHG emissions by 2050, GCSCs must align their strategic plans with the IMO's 2023 strategy for ship emission reduction. This strategy begins with a thorough analysis of the current situation. Companies like Maersk and Hapag-Lloyd are classified as first movers given their superior environmental efficiency. HMM and ONE, with moderate efficiency, are considered second movers, while COSCO Shipping, Evergreen Marine, Yang Ming, and Wan Hai Lines, with low efficiency, are categorized as last movers. Identifying these gaps is crucial for strategic planning. The main gaps include technological challenges given underdeveloped scalable clean fuel technologies, regulatory gaps from the absence of supportive transition policies, and economic gaps from the high costs and financial risks of early green technology adoption.

Figure 7 shows the environmental strategic objectives and carbon neutrality pathways for shipping companies. Strategic targets are set over different time horizons to ensure a structured transition. The initial period (2023-2030) focuses on the development and testing of alternative fuels, implementation of fuel efficiency measures, securing initial funding for pilot projects, and engaging in policy discussions to shape a supportive regulatory environment. The medium-term goals (2031–2040) aim to increase the use of alternative fuels across fleets, expand funding mechanisms, influence global shipping regulations, and promote a wider adoption of energy-saving practices.

The long-term goals (2041-2050) aim for a full transition to sustainable fuels, regulatory support for net-zero goals, sustained investment in green technologies, maintenance of zero-emission operational excellence, and strategy adaptation for all movers to meet environmental standards. The monitoring and evaluation process includes developing and tracking Key Performance Indicators related to fuel use, emissions reductions, and efficiency improvements. Regular assessments will adjust strategies based on technological and regulatory changes, ensuring alignment with global sustainability goals. This comprehensive approach provides

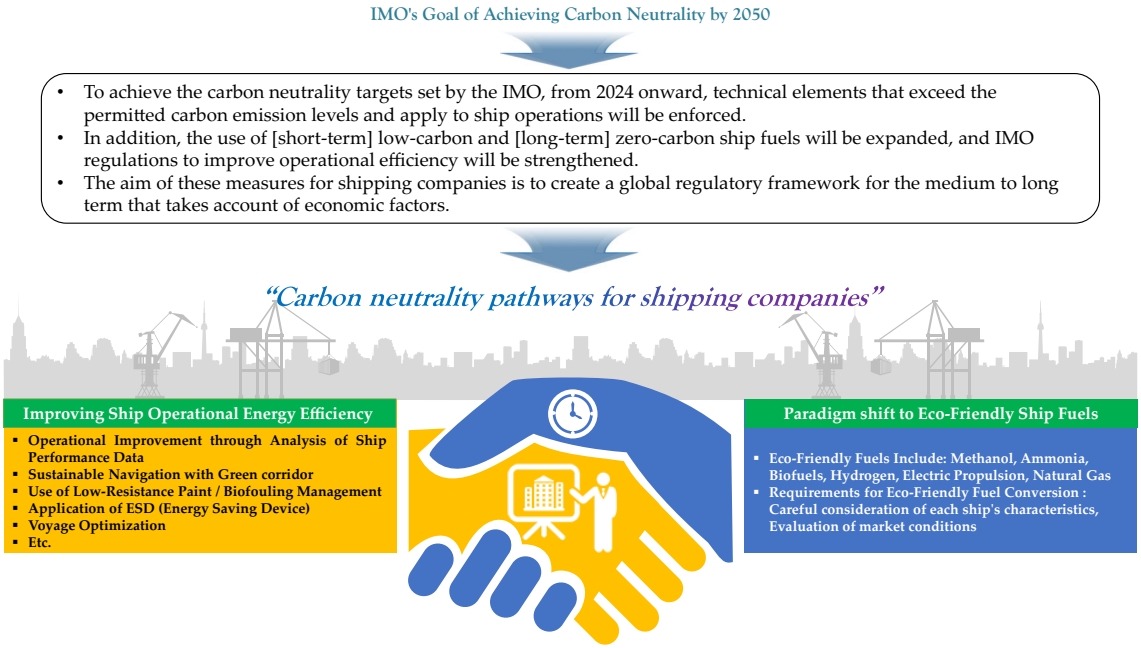


FIGURE 7
Environmental strategic objectives and carbon neutrality pathways for shipping companies. Source: Author's own compilation.

a clear pathway for the shipping industry toward the 2050 net-zero goal, ensuring that the strategic steps are actionable and aligned with global environmental goals.

5 Discussion

Previous research predominantly examines the financial and operational dimensions of shipping efficiency, often overlooking the integration of environmental strategies. Our study employs an extensive dataset to evaluate the effects of adopting green fuels. It provides empirical evidence supporting the strategic benefits of such initiatives, which extend beyond compliance with international regulations to the enhancement of corporate sustainability profiles. This research fills a significant void in the literature concerning the environmental efficiency of GCSCs transitioning to cleaner fuels. With the maritime industry's pressing need to align with the IMO's 2050 net-zero goals, this study is of paramount importance. It illuminates not only the technological and strategic routes that leading GCSCs are adopting, but also underscores the broader implications of such transitions for global supply chains and environmental sustainability. Additionally, this study is important because proposes a formula for calculating CO_2 emissions based on the 2006 guidelines of the Intergovernmental Panel on Climate Change (IPCC) to get around the problem that CO_2 emissions are computed differently by international liner shipping companies owing to different constraints and considerations.

Our analysis-derived environmental efficiency scores underscore the imperative for all GCSCs to continually innovate in fuel technology and fleet management to meet and surpass the stringent IMO emissions targets. Moreover, through the environmental efficiency analysis of GCSCs, we found that Hapag-Lloyd and Maersk are first movers, HMM and ONE are second movers, and Yang Ming, COSC, Wan Hai Lines, and Evergreen Marine are last movers. Moreover, the Gap filling area was examined based on the environmental efficiency score for each of the three groups and the environmental policies according to IMO regulations. Moreover, our findings suggest that the application of backcasting environmental strategies, as proposed in this study, can provide a structured framework for GCSCs to effectively strategize and execute their transitions to sustainable fuels. As a strategy to realize IMO Net-Zero 2050, 6 objectives were set up: Technological Innovation, Regulatory Advocacy, Economic Incidents, Operational Adjustments, Stakeholder Engagement, Scale, and Adaptation. Moreover, for 6 purposes, a detailed strategy was established by dividing it into short-term (2023-2030), medium-term (2031-2040), and long-term (2041-2050) timelines, as depicted in Table 8. In order to achieve technological innovation, developing and testing alternative fuels should be done in the early stages, scale alternative fuel usage across fleets in the mid-term, and achieve full transition to sustainable fuels in the long term. To accomplish regulatory advocacy, policy discussions must be held early on, global shipping regulations must be influenced in the mid-term, and regulations must support Net-Zero goals in the long term. So as to generate economic incentives, pilot projects should receive early funding, middle-stage funding mechanisms should be expanded, and long-term investments in green technologies should be maintained. Implementing fuel efficiency measures early, broadcasting energy-saving practices in the middle, and maintaining operational excellence with zero missions over the long term are all necessary to achieve operational adjustments. Building relationships with important

TABLE 8 Environmental strategic objectives and timelines.

Goal	Objective	Short-term (2023–2030)	Medium-term (2031–2040)	Long-term (2041–2050)
IMO Net-Zero By 2050	Technological Innovation	Develop and test alternative fuels.	Scale alternative fuel usage across fleets.	Achieve full transition to sustainable fuels.
	Regulatory Advocacy	Engage in policy discussions.	Influence global shipping regulations.	Ensure regulations support Net-Zero goals.
	Economic Incentives	Secure initial funding for pilot projects.	Expand funding mechanisms.	Sustain investments in green technologies.
	Operational Adjustments	Implement fuel efficiency measures.	Broad adoption of energy-saving practices.	Maintain operational excellence with zero emissions.
	Stakeholder Engagement	Build partnerships with key stakeholders.	Strengthen collaborations.	Lead global efforts in sustainability.
	Scale and Adaptation	Pilot projects in lead companies.	Widespread adoption by second movers.	Adapt strategies for last movers.

Source: Authors' own compilation.

stakeholders in the early stages, collaborating strongly in the middle, and leading global benefits in the long run are all essential to achieving stakeholder engagement. With a view to achieving scale and adaptation, lead companies must carry out pilot projects in the early stages, be applied throughout the industry by second movers in the mid-term, and last movers should develop strategies in the long run.

To reinforce GCSC's practical strategy in the transition to green fuels, it is critical to integrate advanced digital technologies with alternative fuels to optimize operational efficiency and environmental performance, considering environmental strategic objectives and timelines.

6 Conclusion

This study thoroughly analyzes the environmental performance of GCSCs during their transition to eco-friendly fuel alternatives. It underscores a substantial disparity in environmental performance between early and late adopters. Pioneers, spearheaded by firms like Maersk and Hapag-Lloyd, are at the forefront of embracing sustainable practices. They utilize alternative fuels and cutting-edge technologies to achieve the IMO's net-zero targets for 2050. Conversely, late adopters exhibit a slower transition, indicative of their cautious integration and adaptation strategies, which may potentially delay compliance with global emission standards.

The study's robustness stems from its extensive application of DEA to evaluate not only present efficiencies, but also the potential impact of a complete shift to green fuels. However, the study's reliance on self-reported data from GCSCs introduces limitations, as it may not fully capture operational intricacies or the comprehensive environmental impact of their activities. Future research should strive to include more detailed, real-time data to further substantiate these findings. The high performance of early adopters aligns with anticipated outcomes given their access to advanced technologies and capital. However, the moderate to low efficiency of some firms was unanticipated, necessitating a reassessment of factors that impede or delay the adoption of green technologies, such as financial constraints or technological immaturity. This observation provides a nuanced viewpoint that challenges overly optimistic forecasts of green transitions in shipping.

The study's dependence on secondary data, including company reports and industry databases, restricts the depth of real-time operational insights. It may not fully encapsulate the nuanced challenges associated with adopting green technologies in maritime operations. Furthermore, inconsistent reporting standards across regions and companies can skew comparative analyses and compromise the accuracy of efficiency evaluations.

To enhance the practical strategies of GCSCs in their transition to green fuels, it is crucial to amalgamate advanced digital technologies with alternative fuels to optimize operational efficiency and environmental performance. Establishing collaborative networks with technology providers, policymakers, and industry partners can promote the sharing of best practices and improve access to innovative technologies and financing. Moreover, proactive engagement with regulators can enable GCSCs to influence and anticipate changes in environmental policy, manage compliance costs effectively, and avail incentives for early adopters of green technologies.

Future research should consider longitudinal studies to monitor the long-term efficacy and sustainability of green transitions, devise predictive models to evaluate the impact of various strategic options under different economic and regulatory scenarios, and compare transition strategies across different transport sectors to identify unique strategies and potential synergies. Such research endeavors can yield deeper insights into firms' adaptability and policy effectiveness, particularly considering impending environmental regulations. By addressing these areas, future research can bolster the robustness and applicability of the findings, contribute to the academic discourse on sustainable shipping practices, and aid the formulation of industry and regulatory strategies aimed at achieving global environmental objectives. This comprehensive approach will ensure the shipping industry's pivotal role in global efforts to mitigate climate change. Additionally, if a way to calculate bad outputs like NOx and SOx is developed, it will be able to evaluate the environmental efficiency of GCSCs more elaborately.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author/s.

Author contributions

M-SS: Visualization, Writing – original draft, Writing – review & editing. J-ML: Writing – original draft, Writing – review & editing, Visualization. Y-SK: Supervision, Writing – original draft. D-HJ: Funding acquisition, Resources, Writing – review & editing. C-HL: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This study was supported by a grant from the National R&D Project, "Development of LNG Bunkering Operation Technologies Based on Operation System and Risk Assessment," funded by the Ministry of Oceans and Fisheries, South Korea, grant number PMS4310; this research was supported by Korea Institute of Marine Science and Technology Promotion (KIMST) funded by the Ministry of Oceans and Fisheries, grant number 20220603.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Acheampong, A. O., Opoku, E. E. O., and Aluko, O. A. (2023). The roadmap to net-zero emission: Do geopolitical risk and energy transition matter? *J. Public Aff* 23, e2882–e2882. doi: 10.1002/pa.v23.4

Ahn, J., Seong, S., Lee, J., and Yun, Y. (2023). Energy efficiency and decarbonization for container fleet in international shipping based on IMO regulatory frameworks: A case study for South Korea. *J. Int. Maritime Safety Environ. Affairs Shipping* 7, 2247832. doi: 10.1080/25725084.2023.2247832

Ammar, N. R. (2019). An environmental and economic analysis of methanol fuel for a cellular container ship. *Transportation Res. Part D: Transport Environ* 69, 66–76. doi: 10.1016/j.trd.2019.02.001

Balcombe, P., Brierley, J., Lewis, C., Skatvedt, L., Speirs, J., Hawkes, A., et al. (2019). How to decarbonise international shipping: Options for fuels, technologies and policies. *Energy conversion Manage* 182, 72–88. doi: 10.1016/j.enconman.2018.12.080

Bang, H. S., Kang, H. W., Martin, J., and Woo, S. H. (2012). The impact of operational and strategic management on liner shipping efficiency: a two-stage DEA approach. *Maritime Policy Manag.* 39 (7), 653–672.

Banker, R. D., Charnes, A., and Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Manage. Sci* 30, 1078–1092. doi: 10.1287/mnsc.30.9.1078

Batool, A., Zowghi, D., and Bano, M. (2023). Responsible AI Governance: A systematic literature review. *arXiv preprint arXiv:2401.10896*. doi: 10.48550/arXiv.2401.10896

Bibri, S. E. (2018). Backcasting in futures studies: A synthesized scholarly and planning approach to strategic smart sustainable city development. *Eur. J. Futures Res* 6, 1–27. doi: 10.1186/s40309-018-0142-z

Bibri, S. E., and Krogstie, J. (2019). A scholarly backcasting approach to a novel model for smart sustainable cities of the future: Strategic problem orientation. *City Territ. Archit* 6, 1–27. doi: 10.1186/s40410-019-0102-3

Bilgili, L. (2021). Comparative assessment of alternative marine fuels in life cycle perspective. *Renew. Sustain. Energy Rev* 144, 110985. doi: 10.1016/j.rser.2021.110985

Cariou, P. (2011). Is slow steaming a sustainable means of reducing CO2 emissions from container shipping? *Transp. Res. Part D Transp. Environ.* 16 (3), 260–264. doi: 10.1016/j.trd.2010.12.005

Cariou, P., and Cheaitou, A. (2012). The effectiveness of a European speed limit versus an international bunker-levy to reduce CO2 emissions from container shipping. *Transp. Res. Part D Transp. Environ* 17, 116–123. doi: 10.1016/j.trd.2011.10.003

Chao, S.-L., Yu, M.-M., and Hsieh, W.-F. (2018). Evaluating the efficiency of major container shipping companies: A framework of dynamic network DEA with shared inputs. *Transp. Res. Part A Policy Pract* 117, 44–57. doi: 10.1016/j.tra.2018.08.002

Cooper, W. W., Seiford, L. M., and Tone, K. (2006). Introduction to data envelopment analysis and its uses: With DEA-solver software and references. *Springer Sci. Bus. Media*. doi: 10.1007/0-387-29122-9

Cooper, W. W., Seiford, L. M., and Tone, K. (2007). Data envelopment analysis: A comprehensive text with models, applications, references and DEA-solver software. *Springer*. doi: 10.1007/978-0-387-45283-8

Czermański, E., Cirella, G. T., Oniszczuk-Jastrząbek, A., Pawłowska, B., and Notteboom, T. (2021). An energy consumption approach to estimate air emission reductions in container shipping. *Energies* 14, 278. doi: 10.3390/en14020278

Danish, M. S. S., Ahmadi, M., Zaheb, H., and Senjyu, T. (2024). Sustainable Energy Policies Formulation Through the Synergy of Backcasting and AI Approaches. *Int. Conf. Collab. Endeav. Glob. Sustain*. doi: 10.1007/978-3-031-53574-1

Deniz, C., and Zincir, B. (2016). Environmental and economical assessment of alternative marine fuels. *J. Clean. Prod* 113, 438–449. doi: 10.1016/j.jclepro.2015.11.089

Dyson, R. G., Allen, R., Camanho, A. S., Podinovski, V. V., Sarrico, C. S., and Shale, E. (2001). Pitfalls and protocols in DEA. *A Eur. J. Oper. Res* 132, 245–259. doi: 10.1016/S0377-2217(00)00149-1

Eide, M., Dalsøren, S., Endresen, Ø., Samset, B., Myhre, G., Fuglestvedt, J., et al. (2013). Reducing CO2 from shipping–do non-CO2 effects matter? *Atmos. Chem. Phys* 13, 4183–4201. doi: 10.5194/acp-13-4183-2013

Elkafas, A. G., Elgohary, M. M., and Shouman, M. R. (2021). Numerical analysis of economic and environmental benefits of marine fuel conversion from diesel oil to natural gas for container ships. *Environ. Sci. pollut. Res* 28, 15210–15222. doi: 10.1007/s11356-020-11639-6

Elkafas, A., Rivarolo, M., and Massardo, A. F. (2022). Assessment of alternative marine fuels from environmental, technical, and economic perspectives onboard ultra large container ship. *Int. J. Maritime Eng* 164, 125–134. doi: 10.5750/ijme.v164iA2.768

Fan, L., Yang, H., and Zhang, X. (2024). Targeting the Effectiveness Assessment of the Emission Control Policies on the Shipping Industry. *Sustainability* 16, 2465. doi: 10.3390/su16062465

Golany, B., and Roll, Y. (1989). An application procedure for DEA. *Omega* 17, 237–250. doi: 10.1016/0305-0483(89)90029-7

Gong, X., Wu, X., and Luo, M. (2019). Company performance and environmental efficiency: A case study for shipping enterprises. *Transp. Policy* 82, 96–106. doi: 10.1016/j.tranpol.2018.04.008

Grzelakowski, A. S., Herdzik, J., and Skiba, S. (2022). Maritime shipping decarbonization: Roadmap to meet zero-emission target in shipping as a link in the global supply chains. *Energies* 15, 6150. doi: 10.3390/en15176150

Gu, S., Rong, G., Zhang, H., and Shen, H. (2022). Logging practices in software engineering: A systematic mapping study. *IEEE Trans. Software Eng* 49, 902–923. doi: 10.1109/TSE.2022.3166924

Gutiérrez, E., Lozano, S., and Furió, S. (2014). Evaluating efficiency of international container shipping lines: A bootstrap DEA approach. *Maritime Econ. Logist* 16, 55–71. doi: 10.1057/mel.2013.21

Halim, R. A., Kirstein, L., Merk, O., and Martinez, L. M. (2018). Decarbonization pathways for international maritime transport: A model-based policy impact assessment. *Sustainability* 10, 2243. doi: 10.3390/su10072243

Hellenic Shipping News Worldwide (2021). *HMM vows to halve carbon emission by 2030*. Available online at: https://www.hellenicshippingnews.com/hmm-vows-to-halve-carbon-emission-by-2030/ (Accessed April 26, 2024).

Hellström, M., Rabetino, R., Schwartz, H., Tsvetkova, A., and Haq, S. (2024). GHG emission reduction measures and alternative fuels in different shipping segments and time horizons–A Delphi study. *H. U Mar. Policy* 160, 105997. doi: 10.1016/j.marpol.2023.105997

Homburg, C. (2001). Using data envelopment analysis to benchmark activities. *Int. J. Prod. Econ* 73, 51–58. doi: 10.1016/S0925-5273(01)00194-3

Hsieh, H. P., Kuo, K. C., Le, M. H., and Lu, W. M. (2021). Exploring the cargo and eco-efficiencies of international container shipping companies: A Network-based ranking approach. *Managerial Decis. Econ* 42, 45–60. doi: 10.1002/mde.v42.1

IMO (2020). *Fourth IMO GHG Study 2020*. (London, UK: International Maritime Organization).

Jabbari, M., Fonseca, F., Smith, G., Conticelli, E., Tondelli, S., Ribeiro, P., et al. (2023). The pedestrian network concept: A systematic literature review. *J. Urban Mobility* 3, 100051. doi: 10.1016/j.urbmob.2023.100051

Kovacs, O. (2022). Inclusive industry 4.0 in Europe—Japanese lessons on socially responsible industry 4.0. *Soc Sci* 11, 29. doi: 10.3390/socsci11010029

Kuo, K.-C., Lu, W.-M., Kweh, Q. L., and Le, M.-H. (2020). Determinants of cargo and eco-efficiencies of global container shipping companies. *Int. J. Logist. Manage* 31, 753–775. doi: 10.1108/IJLM-01-2020-0016

Kyriakopoulos, G. L., and Sebos, I. (2023). Enhancing climate neutrality and resilience through coordinated climate action: review of the synergies between mitigation and adaptation actions. *Climate* 11, 105. doi: 10.3390/cli11050105

Lee, T., and Nam, H. (2017). A study on green shipping in major countries: in the view of shipyards, shipping companies, ports, and policies. *Asian J. Shipping Logistics* 33, 253–262. doi: 10.1016/j.ajsl.2017.12.009

Lee, J., Sim, M., Kim, Y., and Lee, C. (2024). Strategic Pathways to Alternative Marine Fuels: Empirical Evidence from Shipping Practices in South Korea. *Sustainability* 16, 2412. doi: 10.3390/su16062412

Li, G., Guo, Y., Jiang, H., Kong, L., Zhou, Y., and Wang, W. (2023). Green ship evaluation based on improved AHP-FCE-ODM model from the perspective of shipbuilding supply chain. *Int. J. Logist. Res. Appl*, 1–21. doi: 10.1080/13675567.2023.2213659

Liao, Y.-H., and Lee, H.-S. (2023). Using a Directional Distance Function to Measure the Environmental Efficiency of International Liner Shipping Companies and Assess Regulatory Impact. *Sustainability* 15, 3821. doi: 10.3390/su15043821

Lister, J. (2015). Green shipping: Governing sustainable maritime transport. *Global Policy* 6, 118–129. doi: 10.1111/gpol.2015.6.issue-2

Lun, V. Y., and Marlow, P. (2011). The impact of capacity on firm performance: a study of the liner shipping industry. *Int. J. Shipping Transp. Logist.* 3 (1), 57–71. doi: 10.1504/IJSTL.2011.037819

Maersk (2023). *Maersk signs landmark green methanol offtake agreement, significantly de-risking its low-emission operations in this decade*. Available online at: https://www.maersk.com/news/articles/2023/11/22/maersk-signs-landmark-green-methanol-offtake-agreement (Accessed January 05, 2025).

Malik, S., Chandra, G. M., Rao, A. C., and Arora, S. (2020). 3W1H Approach to Understand the Millennial Generation. In Strategies for Business Sustainability in a Collaborative Economy (pp. 330-346). *IGI Global*. doi: 10.4018/978-1-7998-4543-0.ch017

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., and Bezirtzoglou, E. (2020). Environmental and health impacts of air pollution: a review. *Front. Public Health* 8, 505570. doi: 10.3389/fpubh.2020.00014

Mantalis, G., Lemonakis, C., Garefalakis, A., Vassakis, K., and Xanthos, G. (2015). "Relationship between efficiency and ship class of Greek-owned shipping companies, listed on the NYSE," in *Conference: 4th International Symposium & 26th National Conference on Operational Research* (Chania, Greece).

Mepc, R. (2023). *2023 IMO strategy on reduction of GHG emissions from SHIPS*.

Panayides, P. M., Lambertides, N., and Savva, C. S. (2011). The relative efficiency of shipping companies. *Transp. Res. Part E Logist. Transp. Rev* 47, 681–694. doi: 10.1016/j.tre.2011.01.001

Reed Smith, L. L. P. (2024). *Replacement of CBER by SBER? What lies ahead for the liner shipping industry*. Available online at: https://www.lexology.com/library/detail.aspx?g=a0f85714-08db-4a46-a110-6b604a5812d4 (Accessed January 06, 2025).

Serra, P., and Fancello, G. (2020). Towards the IMO's GHG goals: A critical overview of the perspectives and challenges of the main options for decarbonizing international shipping. *Sustainability* 12, 3220. doi: 10.3390/su12083220

Shapere, D. (1964). The structure of scientific revolutions. *Philos. Rev* 73, 383–394. doi: 10.2307/2183664

Tone, K. (2001). A slacks-based measure of efficiency in data envelopment analysis. *Eur. J. Oper. Res* 130, 498–509. doi: 10.1016/S0377-2217(99)00407-5

Tone, K. (2002). A slacks-based measure of super-efficiency in data envelopment analysis. *Eur. J. Oper. Res* 143, 32–41. doi: 10.1016/S0377-2217(01)00324-1

Tuominen, A., Tapio, P., Varho, V., Järvi, T., and Banister, D. (2014). Pluralistic backcasting: Integrating multiple visions with policy packages for transport climate policy. *Futures* 60, 41–58. doi: 10.1016/j.futures.2014.04.014

Vakili, S. V., Ballini, F., Dalaklis, D., and Ölçer, A. I. (2022). A conceptual transdisciplinary framework to overcome energy efficiency barriers in ship operation cycles to meet IMO's initial greenhouse gas strategy goals: case study for an Iranian shipping company. *Energies* 15, 2098. doi: 10.3390/en15062098

Wang, G., Li, K. X., and Xiao, Y. (2019). Measuring marine environmental efficiency of a cruise shipping company considering corporate social responsibility. *Mar. Policy* 99, 140–147. doi: 10.1016/j.marpol.2018.10.028

Wang, Z., Wu, X., Lo, K. L., and Mi, J. J. (2021). Assessing the management efficiency of shipping company from a congestion perspective: a case study of Hapag-Lloyd. *Ocean Coast. Manage* 209, 105617. doi: 10.1016/j.ocecoaman.2021.105617

Wang, Q., Zhang, H., Huang, J., and Zhang, P. (2023). The use of alternative fuels for maritime decarbonization: Special marine environmental risks and solutions from an international law perspective. *Front. Mar. Sci* 9, 1082453. doi: 10.3389/fmars.2022.1082453

Xiao, G., Pan, L., and Lai, F. (2025). Application, opportunities, and challenges of digital technologies in the decarbonizing shipping industry: a bibliometric analysis. *Front. Mar. Science* 12, 1523267. doi: 10.3389/fmars.2025.1523267

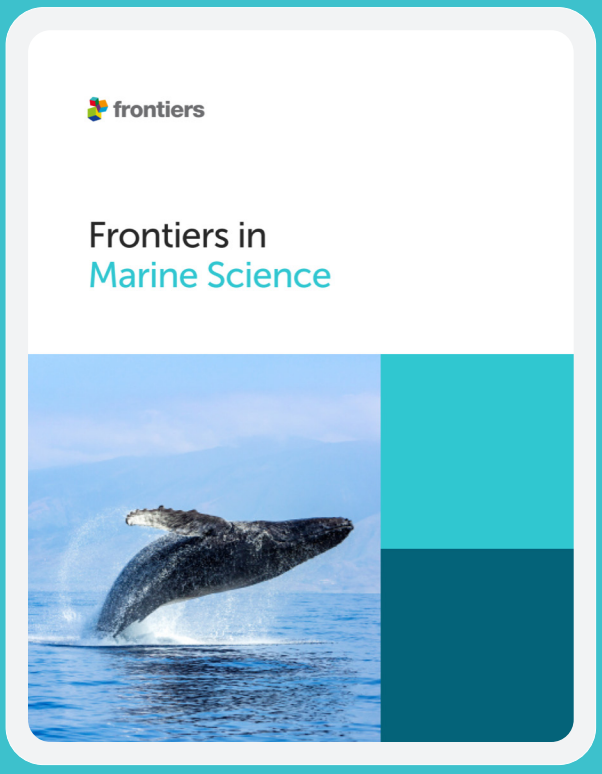
Frontiers in Marine Science

Explores ocean-based solutions for emerging global challenges

The third most-cited marine and freshwater biology journal, advancing our understanding of marine systems and addressing global challenges including overfishing, pollution, and climate change.

Discover the latest Research Topics

See more →



Frontiers

Avenue du Tribunal-Fédéral 34
1005 Lausanne, Switzerland
frontiersin.org

Contact us

+41 (0)21 510 17 00
frontiersin.org/about/contact