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Decoding drivers of marine ecological culture communication: insights from a Grey-DEMATEL analysis

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Under the macro background of taking the construction of ecological civilization construction as the core and coordinating the promotion of the strategies of "Beautiful China" and "Ocean Power", marine ecological culture, as a composite carrier with ecological value, cultural connotation and governance functions in the national ecological civilization system, is gradually becoming a support for the resource value realization, enhancing cultural soft power and the key link to promote the modernization of marine governance. This study takes Fujian Province as a typical field, extracts the influencing factors of marine ecological culture communication in Fujian Province through grounded theory, constructs a centrality–causality analysis framework based on the Grey DEMATEL model, and systematically identifies and analyzes the driving structure and action path of marine ecological culture communication. The results show that government incentives and support, innovation/digital communication elements, and capital investment are at the core of the factor network. Among them, the first two play a dominant driving role and have a significant spillover effect, while capital investment shows dependence characteristics; the center of the value of marine eco-cultural resources is the highest, which is the core hub for deepening cultural communication and value transformation; resource abundance, purchasing power and tourism demand, and ocean literacy/consumption intention reflect the demand-side traction mechanism and improve the breadth and resilience of communication; the coastal red lines and heritage regulation play a binding intermediary role in the system. The research reveals the inherent structural logic and multi-dimensional driving mechanism of marine ecological culture communication, expands the theoretical boundaries of ecological civilization construction, and verifies the synergy effect of Institutional drivers, innovation synergy, and public participation with Fujian experience, providing a replicable path and policy revelation.

KEYWORDS

ecological civilization construction, Grey DEMATEL model, innovation synergy, institutional drivers, marine ecological culture communication, resource value realization

1 Introduction

Under the new development stage, the national strategies of "Beautiful China", "Ocean Power" and "Ecological Civilization" have been superimposed in coastal provinces, making the creative transformation and dissemination of marine ecological culture an important tool for promoting high-quality development and shaping cultural self-confidence. As China's first National Ecological Civilization Pilot Zone and an early demonstration area, Fujian has long played a pioneering role in marine ecological governance, marine spatial regulation, and the blue economy and—upon being designated a pilot—has produced a set of practices amenable to replication. The State Council subsequently issued an implementation plan that explicitly calls for improving watershed and marine ecological environmental governance mechanisms and establishing sound mechanisms for realizing the resource value of ecological products (J. Chen et al., 2024). These measures provide institutional supply—hence strong Institutional Drivers—for Fujian's Marine Ecological Culture Communication and make the province an ideal case for observing the coupled effects among "ecology–culture–communication–industry." In recent years, a series of national policy documents—including the Opinions on Establishing and Improving Mechanisms for the Resource Value Realization of Ecological Products, the Outline of the 14th Five-Year Plan and Long-Range Objectives through 2035, and the Marine Environment Protection Law (2024 Revision)—have emphasized advancing ecological civilization construction through value realization, institutional supply, and public participation, thereby promoting the expression of ecological-product value and innovation in dissemination pathways. In this study, policy documents at different levels are not reviewed exhaustively but are interpreted according to their functional roles. National strategies provide overarching value orientation, provincial policies offer implementation contexts, and sectoral regulations define operational boundaries. This approach ensures analytical consistency while avoiding uneven descriptive emphasis. Collectively, these macro policies provide a threefold foundation—value, institutions, and scenarios—for Marine Ecological Culture Communication while imposing higher requirements on content, media systems, audience behavior, and governance synergy. Given this policy trajectory and given Fujian's distinctive "mountain–sea adjacency" endowments, identifying the key influencing factors of marine ecological culture communication and clarifying their causal structure is highly important. For consistency, the term "Marine Ecological Culture Communication" is used throughout this paper to denote processes through which marine ecological values and cultural meanings are communicated, interpreted, and socially embedded. Other expressions are employed only to emphasize specific analytical dimensions.

Fujian possesses highly distinctive human–ocean relationships and cultural signifiers: a cluster of maritime cities exemplified by Quanzhou—an important departure point of the Maritime Silk Road; a seaborne belief culture centered on Mazu worship; composite "blue carbon–eco-tourism–public education" settings mediated by mangroves and the coastal zone; and practical experience in marine ecological civilization, integrated management, and coastal-zone restoration across Xiamen, Zhangzhou, and Quanzhou (e.g., mangrove rehabilitation and blue-carbon initiatives in Xiamen Bay, and marine integrated management repeatedly cited in international blue-economy reports) (Ouyang et al., 2024; Qiao et al., 2025; Su and Gasparatos, 2023; Wang, 2024; Winther and Dai, 2020). These settings not only furnish "content resources" for communication (cultural heritage, ecological knowledge, and narrative storytelling) but also provide "physical carriers and public spaces" (eco-museums, World Heritage sites, coastal parks/wetlands, and nature education centers). Through interactions between visitors and residents, they further become a driving force for socially embedded communication.

Nevertheless, three urgent, practice-level challenges remain: (1) A disconnect between the communication supply side and the governance side. Efforts in ecological restoration, marine governance, and cultural heritage protection proceed in parallel, yet they lack translation into communicable, experiential, and marketable content ecosystems and public narratives, hindering the chain from "ecological outcomes → social cognition → market conversion" (McKinley et al., 2020). (2) Insufficient coordination among communicative actors and inadequate rule supply. Although Fujian benefits from its pilot-zone status, Marine Ecological Culture Communication requires cross-departmental and multiactor collaboration; institutionalized alignment is needed regarding "ecological red lines vs. development," "resource value realization and benefit sharing," and "knowledge production and public participation" (recent reforms in water and natural-resource spatial governance and the Marine Environment Protection Law revision emphasize land–sea integration and public participation) (X. Chen et al., 2024; Jin and Yu, 2025). (3) A threshold effect along the audience-side "ocean literacy → behavioral conversion" chain. Recent evidence shows that improving ocean literacy significantly promotes pro-marine conservation behaviors via a chained mediation of "sense of responsibility → values," yet communication reach and conversion mechanisms vary markedly across groups and contexts (Nicola et al., 2025; Wang et al., 2025a, b).

To address the above gaps, this study proposes three solutions: (1) Starting from Fujian—a prototypical context where policy, resources, and practice tightly overlap—we construct a multidimensional factor system for Marine Ecological Culture Communication, remedying the prevailing limitation of "many factors but weak structure." (2) We introduce the Grey DEMATEL model to identify "high-causality–high-centrality" key factors under conditions of expert-judgment uncertainty and complex interfactor interactions and to map the cause–effect structure, thereby providing actionable causal evidence for policy design and communication strategies (Du and Zhou, 2019; Si et al., 2018; Wu, 2008). (3) We embed the resource value realization of ecological products, marine ecological restoration, cultural-heritage communication, and public ocean literacy within a unified analytical framework, exploring coupling pathways among

institutional drivers, media systems, scenario building, and behavioral guidance to inform marine ecological culture communication practices and the high-quality development of the blue economy in Fujian and beyond. Through these efforts, the study goes beyond descriptive analysis by clarifying the causal structure of Marine Ecological Culture Communication and by offering an integrated analytical perspective that links institutional drivers, resource value, and demand-side mechanisms.

2 Theoretical background and literature review

In recent years, scholarship on "marine social science–eco-culture–environmental/marine communication" has rapidly coalesced. At the theoretical level, marine social science argues for integrating the human dimension into mainstream marine-governance agendas and for enhancing governance performance and social legitimacy through public participation, cultural/educational initiatives, and communication tools (McKinley et al., 2020; Spalding and McKinley, 2025). Research on cultural ecosystem services (CES) shows that, within coastal landscapes, cultural values, place attachment, and aesthetic/leisure experiences are closely associated with residents' well-being, conservation intentions, and willingness to pay; moreover, stakeholders perceive CES quite differently (Cabana et al., 2020; You et al., 2025). In the Chinese context, Quanzhou's Maritime Silk Road World Heritage and Mazu culture constitute key carriers of "marine civilization–cross-cultural communication," demonstrating the symbolic capital and public-diplomacy functions of heritage narratives in international communication (Ruan, 2025; Wang, 2024; Zhang et al., 2023), whereas integrated marine management and mangrove restoration in places such as Xiamen provide "visible, tangible, and participatory" settings for communication (Ouyang et al., 2024; Su and Gasparatos, 2023; Winther and Dai, 2020). Moreover, synergies among marine ecological restoration, mangrove blue carbon, coastal space quality enhancement, and tourism/leisure create the material foundations for a chained transformation linking ecology, economy, culture, and communication (Qiao et al., 2025; Sun and Kong, 2025). Taken together, these studies suggest five key dimensions shaping the performance of Marine Ecological Culture Communication: content resources (heritage/ecological knowledge), communication carriers (parks/museums–schools/media), the institutional environment (laws and planning), social–psychological factors (place attachment, responsibility, and values), and market mechanisms—specifically, the realization of the resource value of ecological products.

At the level of methods and tools, DEMATEL and its extended forms—fuzzy variants, grey-based comprehensive approaches, and couplings with interpretive structural modeling (ISM)—are widely used for identifying key factors in social–ecological–managerial complex systems because they excel at handling multifactor causal networks (Chien et al., 2025; Du and Zhou, 2019; Jonnala et al., 2025; Si et al., 2018; Werner-Lewandowska et al., 2025; Wu, 2008; Zhou et al., 2025). Unlike the traditional "correlation–regression–SEM" orientation, DEMATEL focuses on the directionality of "who influences whom" and on centrality/causality rankings, making it well suited to policy-research contexts that weigh expert knowledge and literature evidence under conditions of incomplete information. Grey system theory characterizes uncertainty via interval grey numbers, enhancing robustness when expert ratings are imprecise and preference heterogeneity exists. Consequently, the Grey DEMATEL model has been frequently employed in the fields of environmental governance, supply chain resilience, education, and culture (Du and Zhou, 2019; Jonnala et al., 2025; Werner-Lewandowska et al., 2025). Most of the research has focused on the topic of "economy-technology-management". The application of "ecological and cultural communication", especially in marine scenes, is still scarce, and the comprehensive model of "institutional supply-public literacy-communication behavior-scene construction" has not yet been formed. This gap provides an entry point for the methodology of this article.

At the empirical level of evaluation and dissemination, the psychological link of the public's "marine literacy-responsibility-behavior" has been verified by more and more data, and educational intervention and narrative experiments have shown remarkable results (Nicola et al., 2025; Wang et al., 2025a, b). Moreover, China's institutional instruments for coastal zone governance—such as the bay-chief system, marine parks, and integrated coastal zone legislation—are institutionalizing mechanisms for public participation and building communication platforms, thereby enhancing policy communication efficiency and social trust (X. Chen et al., 2024; Jiang and Sun, 2025; Jin and Yu, 2025). In Fujian, multistakeholder spatial perceptions and cultural value assessments at Quanzhou's Maritime Silk Road heritage sites, science communication on flagship species such as mangroves and dolphins in Xiamen, and coastal restoration and tourism-innovation practices in places such as Pingtan together form a "scientific monitoring–governance and restoration–cultural narrative–tourism conversion–public education" communication loop (Province, 2025; Weng et al., 2024; You et al., 2025). Nevertheless, current research tends to remain siloed—emphasizing either the natural-science underpinnings of ecological restoration, the cultural logic of heritage communication, or the psychological mechanisms of public education—while lacking systematic causal mapping among them. To bridge this gap, the present study, which is situated in Fujian's concrete context, triangulates literature evidence with expert knowledge and employs the Grey DEMATEL model to identify "high-causality–high-centrality" key factors, from which actionable communication strategies are derived.

3 Materials and methods

This study adopts a tri-source evidence framework—policy, literature, and expert: (1) we systematically review national and Fujian-provincial policy texts on marine ecological civilization, mechanisms for resource value realization of ecological products, the marine rule of law, and integrated coastal/marine management; (2) we synthesize up-to-date evidence on marine ecological culture

communication together with coastal cultural ecosystem services (CES), ocean literacy, ecological restoration, and heritage communication; and (3) we convene regional experts in marine ecological governance, cultural heritage and communication, and tourism/education to judge interfactor relationships. Methodologically, drawing on grey system theory and DEMATEL, we implement the Grey DEMATEL model as follows: build the indicator system → construct the direct-influence grey-number matrix → normalize and compute the total-influence matrix → derive the influence score R, the influenced score C, the centrality/prominence P (R+C), and the causality E (R–C) → plot the cause–effect plane and identify key factors. This process can improve robustness when expert opinions are ambiguous and uncertain, and reveal "key minorities" in complex networks. For the technical details, semantic scale, clarification processing and matrix operation process of the method, please refer to the processing specifications of Du and Zhou (2019), Si et al. (2018) on DEMATEL/Grey DEMATEL.

3.1 Data sources

This research takes literature as the main data source, and systematically retrieves databases such as Web of Science Core Collection, Scopus and CNKI published from 2020 to 2025 related to the dissemination of marine ecological culture. High-quality academic literature. In the retrieval process, use "Marine ecological Culture", "Marine Cultural Communication", "Cultural Ecosystem Services" and "Ocean" Keywords such as Literacy, Marine Heritage, Blue Economy are combined with Boolean logic to ensure that the sample coverage is relevant to the theme. Finally, 37 core documents were identified as research samples. The literature covers multiple directions such as marine ecological civilization policy, cultural ecosystem services, marine cultural heritage protection, public marine literacy and digital dissemination, with strong systematicity and representativeness. Twenty-seven of the documents were randomly selected for coding analysis. At the same time, 10 documents of the same subject that were not included in the initial analysis were retained for saturation testing. The literature text is regarded as second-hand qualitative material. Accordingly, grounded theory is employed as a systematic coding framework for influencing-factor identification, rather than for substantive theory construction. It is systematically analyzed and theoretically refined according to the open, spindial and selective coding program of the rooted theory, which provides solid empirical support for the identification of influencing factors of marine ecological and cultural communication and the construction of theoretical models. The specific literature samples are shown in Table 1.

3.2 Coding procedure

Open coding refers to the analysis and distillation of the obtained materials sentence by sentence to restore their original concepts. Use an objective and systematic method to filter the selected meaningless or non-compliant content. On the basis of not expanding the semantics of the original statement, use academic terms to decompose and refine the original information, so that their concepts are independent of each other and not staggered with each other. For example, "Ocean literacy plays a crucial role in promoting sustainable marine conservation behaviors" can be refined into "Marine literacy promotes the public's awareness of sustainable behavior", which is grouped together to express sentences that are similar in essence. At the same time, the initial concept of occurrence of less than 2 times is excluded, and finally 52 initial concepts are given.

Spinal coding is the second stage of rooted theoretical coding. By exploring and analyzing the potential logical relationships between categories, the original concepts with similar meanings are further merged into a wider range of categories. This integration process aims to extract categories in order to better summarize and summarize the research problems. Based on the open coding, the above 52 initial concepts are processed and sorted out, and the logical relationship between various categories is summarized and integrated. For example, "multiple policy tools to promote the integration of culture and tourism" and "the government strengthens marine cultural governance with the ecological red line as the bottom line" are classified as "government incentives and support The category of holding. After many screening and analysis, 13 categories were finally formed. Initial concepts with overlapping meanings were merged based on semantic similarity and functional equivalence, while concepts appearing fewer than two times were excluded to enhance analytical robustness. This process was jointly reviewed by multiple researchers to reduce subjective bias. The results of the spindle coding part of this study are shown in Table 2.

Selective coding is a further refinement of the category, so as to form the main category and obtain a higher level of abstraction. For the 13 categories formed by the spindle coding, combined with

TABLE 1 Basic information of document samples.

Items	Indicator description	Data
Time Coverage	Publication years	2020–2025
Database Distribution	Share of sample by source	Web of Science73.7%,Scopus18.4%, CNKI7.9%
Research Themes	Main research directions	Marine ecological cultural resources; policy & governance; capital & innovation; public ocean literacy; ecological regulation
Research Methods	Type & proportion	Qualitative 68% (content analysis, grounded theory); Quantitative 32% (SEM, Grey DEMATEL, SNA)
Representative Journals	Core outlets in the sample	Ecosystem Services; Frontiers in Marine Science; Ocean & Coastal Management;

TABLE 2 Main axis coding results (partial).

Partial raw data	Initial concept	Category
The advent of the metaverse … presents a novel approach to safeguarding and promoting cultural heritage	Metaverse technology reshapes cultural heritage dissemination	Innovation/Digital Communication Elements
Metaverse can be conceptualized as a relevant tool for preserving and experiencing cultural heritage	Metaverse enhances public cultural engagement	
Only through an organic combination of different policy tools can [culture–tourism] integration be achieved	Policy synergy promotes integrated development	Government Incentives and Support
MSP will … prioritize MERLs as an ecological bottom line in national and provincial plans	Ecological redlines strengthen marine governance	
Tourism investments positively contribute to tourism growth	Capital injection drives sectoral expansion	Capital Investment
Tourism development … increases inequality in lower-income economies but reduces it across high-income nations	Capital investment effects demonstrate regional heterogeneity	
MERLs is an institutional innovation … to balance ecological protection and social development	Institutional innovation mediates development-conservation	Coastal Red Lines and Heritage Regulation
After adjustment … human activities intensity in MERLs declines significantly	Regulatory adjustments effectively mitigate anthropogenic pressure	
Ocean literacy plays a crucial role in promoting sustainable marine conservation behaviors	Knowledge enhancement drives behavioral change	Ocean Literacy/Consumption Intention
Marine responsibility and values mediate the link between ocean literacy and pro-environmental behavior	Psychological constructs enable knowledge-action translation	
Ocean extended reality can benefit marine education and ocean literacy	Immersive technologies create differentiated learning experiences	Audience Heterogeneity
Mapping … cultural ecosystem services in coastal areas informs management decisions	Spatial visualization informs decision-making	Resources and Content

relevant literature and expert verification, the main category and its relationship are finally determined, so as to form a systematic explanation of the influencing factors. The specific main categories are resources and content, elements and supply, system and rules, audience and demand, platform and network. The selective coding results of this study are shown in Table 3.

1. Resources and content. Resources and content are the core dimensions of marine ecological culture communication. Its connotation includes three key indicators: resource diversity, resource abundance and resource value. The diversity of marine eco-cultural resources reflects the composite of regional ecological types, natural landscapes and intangible cultural heritage, providing multi-layer narrative materials and cultural symbols for communication (Banela et al., 2024; Erskine et al., 2021). The abundance of resources reflects the carrying capacity of the ecosystem and the richness of the cultural landscape, which is not only related to the continuity of communication, but also affects its cultural expression (Castaneda-Guzman et al., 2021; Inácio et al., 2022). The amount of resource value integrates the attributes of ecology, culture and economy, which determines the social significance of communication and the intensity of audience perception (Alves et al., 2025; McCook et al., 2025). In the communication system, this dimension plays the dual function of "content supply and value support", which is the fundamental condition for the sustainability and deepening of cultural communication.

2. Elements and Supply. Elements and supply constitute the material and technical support for the dissemination of marine ecological culture communication, including capital investment, innovation/digital communication elements, and talent & scenario infrastructure. Capital investment is the key fulcrum for the transformation of cultural communication into real productivity, and its level directly determines the depth of resource development, content innovation and media expansion (Castilho and Fuinhas, 2025). Innovation/digital communication elements reflect the application of new media forms such as digitalization, immersive experience and short videos in communication, and promote the evolution of culture from one-way communication to multi-dimensional co-creation (Buragohain et al., 2024; Jin and Liu, 2022). Talent & scenario infrastructure provide professional support and communication space, creating conditions for the education, promotion and display of ecological and cultural content (Er-Ramy et al., 2023; Tang, 2024). Overall, this dimension reflects the trend of "technology" and "industrialization" of the communication system, and is the core driving force for promoting the generation of cultural efficiency and the upgrading of communication structure.

3. Institutions and Rules. The dimensions of institutions and rules reflect the macro-governance logic and institutional constraints of marine ecological culture communication, mainly including government incentives and support, resource protection constraints, and coastal red lines and heritage regulation. Government incentives and support are the dominant variables of the communication system. Policy guidance, special support and institutional guarantees jointly build the legitimacy framework and operation boundaries of cultural communication (Qi and You,

TABLE 3 Selective encoding results.

Influencing factors	Symbol	Specific factor indicators	Explanation of indicator connotation	Literature sources
Resources & Content	A_1	Diversity of Marine Eco-Cultural Resources	The variety of eco-cultural types, natural landscapes, and intangible cultural heritage within a region.	(Banela et al., 2024; Erskine et al., 2021; Pellowe and Leslie, 2021)
	A_2	Abundance of Marine Eco-Cultural Resources	The quantity and carrying capacity of resources, including the number of landscapes, species richness, and cultural heritage sites.	(Castaneda-Guzman et al., 2021; Inácio et al., 2022)
	A_3	Value of Marine Eco-Cultural Resources	The comprehensive ecological, cultural, and economic worth of the resources.	(Alves et al., 2025; McCook et al., 2025; Van Schoubroeck et al., 2024)
Elements & Supply	A_4	Capital Investment	The level of financial input from government, enterprises, and society for eco-cultural communication and conservation.	(Castilho and Fuinhas, 2025; Paramati et al., 2018)
	A_5	Innovation/Digital Communication Elements	The application of innovative forms such as digitalization, immersive experiences, and short-form videos.	(Buragohain et al., 2024; Jin and Liu, 2022)
	A_6	Talent & Scenario Infrastructure	The availability of professional communication talent, education/training, and cultural exhibition spaces/facilities.	(Er-Ramy et al., 2023; Tang, 2024)
Institutions & Rules	A_7	Government Incentives and Support	Policy guidance, targeted funding, and institutional safeguards.	(Qi and You, 2024; Tang et al., 2024)
	A_8	Resource Protection Constraints	Restrictions, supervision, and penalties governing the exploitation of ecological resources.	(Choi et al., 2022; Gao et al., 2020)
	A_9	Coastal Red Lines & Heritage Regulation	Rigid controls on coastal zone use and conservation of maritime heritage.	(Rodrigues et al., 2024)
Audience & Demand	A_{10}	Audience Heterogeneity	Differences in cultural cognition, interests, and communication receptiveness among different groups.	(Bastos et al., 2025; Kelly et al., 2022)
	A_{11}	Ocean Literacy/Consumption Intention	Public understanding of marine eco-culture and willingness to participate/consume.	(Fauville et al., 2025; McKinley et al., 2023; Shellock et al., 2024; Soffietti et al., 2025)
	A_{12}	Purchasing Power & Tourism Demand	The economic capacity of the audience and actual demand for marine eco-tourism/cultural creative products.	(Chen and Zhang, 2023; Konu et al., 2025)
Platforms & Networks	A_{13}	Media Matrix & Cross-sector Coordination	Multichannel communication platforms and collaborative mechanisms among departments.	(Fauville et al., 2025; Soffietti et al., 2025)

2024; Tang et al., 2024). Resource protection constraints ensure the sustainable development of ecological resources through supervision and disciplinary mechanisms. (Choi et al., 2022; Gao et al., 2020) Coastal red lines and heritage regulation play a key role in spatial planning and ecological constraints to prevent communication activities from causing reverse invasion of natural heritage (Rodrigues et al., 2024). The role of institutions and rules is to form policy signals and behavioral boundaries, so that communication can achieve a balance between value orientation and ecological protection, reflecting the symbiotic logic of "system-culture" under the Chinese-style marine governance system.

4. Audience and demand. The audience and demand dimensions represent the social response mechanism of the communication system, including audience heterogeneity, ocean literacy/consumption intention, and purchasing power and tourism demand. Audience heterogeneity determine the differentiation of cultural acceptance and communication preferences. The values and cultural backgrounds of different groups affect the adaptability and resonance of communication content (Bastos et al., 2025; Kelly et al., 2022). Marine literacy and consumption willingness reflect the public's cognitive depth and willingness to act on marine ecological culture, which is the key link in the transformation of ecological culture into social practice (Fauville et al., 2025; McKinley et al., 2023). Purchasing power and tourism demand have expanded the market radius of cultural communication through economic will, and realized the derivative transformation of ecological value to consumer value (Chen and Zhang, 2023; Konu et al., 2025). This dimension shows that the sustainability of communication depends not only on the innovation of the supply side, but also on the perception, participation and feedback of the demand side.

5. Platforms and networks. The platform and network dimensions are dynamic intermediaries that connect communication elements and audience needs, which are mainly reflected in the media matrix and cross-sector coordination mechanism. The integration of multi-channel communication platforms makes the information flow more efficient and three-dimensional, and provides technical support for the multi-dimensional presentation of ecological and cultural content (Fauville et al., 2025). The cross-departmental coordination mechanism forms a communication network of co-gunance and sharing through the cooperation of the government, scientific research, education and social organizations (Soffietti et al., 2025). This dimension strengthens the integrity and resilience of the system, turns communication from "single-point voice" to "network resonance", and promotes the communication of marine ecological culture into a new stage of governance, coordination and co-creation and sharing.

3.3 Theoretical saturation test

In order to verify whether the theoretical saturation obtained from this study has really achieved the expected effect, we used the same three steps to code and classify the remaining 10 literatures to verify whether the previous results were stable. Additionally, three experts specializing in marine cultural studies were invited to conduct an external review of the coding results, ensuring greater accuracy and credibility of the analytical outcomes. Throughout the supplementary coding and categorization process, no new logical categories emerged. Instead, through in-depth interpretation and synthesis of the existing results, we refined and streamlined the element classifications and logical framework derived from prior analysis. Consequently, on the basis of a comparative analysis of the research process outcomes, the theoretical saturation of this study is confirmed to have reached the expected standard.

4 Identifying key factors influencing marine eco-cultural communication in Fujian province

4.1 Procedure for identifying key factors

This study employs an analytical framework integrating the Grey-DEMATEL method. The DEMATEL approach is widely applied to identify the interrelationships and causal structures among factors within a complex system, whereas grey system theory effectively overcomes the limitations of expert-based scoring by addressing uncertainty and incomplete information. Therefore, this study introduces interval grey numbers from grey system theory to represent the degree of influence among factors. At the same time, we combine the interval grey number with DEMATEL to express the information obtained from the expert evaluation through the grey number decision-making model, which avoids the situation that the expert evaluation is too absolute, thus improving the objectivity of the data results. In summary, this study comprehensively uses the Grey-DEMATEL analysis method to conduct an in-depth analysis of the 13 influencing factors identified. The specific steps are as follows:

1. Build an indicator system of influencing factors. In combination with the characteristics and objective reality of the dissemination of marine ecological culture in Fujian Province, we first establish an index system of factors affecting the dissemination of marine ecological culture, which serves as the prerequisite for the subsequent research on the identification of key factors.
2. Establish an initial relationship matrix. Invite experts and scholars with experience in research or practice in marine ecological culture communication and other fields to evaluate and score the relationship between factors affecting the marine ecological culture communication in Fujian Province, so as to establish an initial relationship matrix covering all influencing factors.
3. Constructing the grey matrix $\otimes X$. The interrelationships among the influencing factors were classified into five levels: no direct influence, weak influence, low influence, significant influence, and very strong influence. The linguistic variables used by the experts and scholars are presented in Table 4. Following this principle, the initial direct-relation matrix was converted into a grey matrix $\otimes X$. Given that the experts differed in their work experience, research specialization, and subjective understanding of the influencing factors of Marine Ecological Culture Communication, differentiated weights were assigned to their evaluations. The specific linguistic variables and weighting criteria for expert judgments are shown in Table 4.
4. Compute the direct-influence matrix A. Perform clarification of the grey matrix $\otimes X$ according to Equations 1–4, and obtain the direct-influence matrix A. Here, t denotes the number of experts.

① Standardize the upper and lower bounds of the grey numbers.

$$\begin{aligned}\bar{\otimes}\tilde{x}_{ij}^{t} &= \left(\bar{\otimes}\tilde{x}_{ij}^{t} - \min \bar{\otimes}\tilde{x}_{ij}^{t}\right)/\Delta_{\min}^{\max}\\ \underline{\otimes}\tilde{x}_{ij}^{t} &= \left(\underline{\otimes}\tilde{x}_{ij}^{t} - \min \underline{\otimes}\tilde{x}_{ij}^{t}\right)/\Delta_{\min}^{\max}\end{aligned} \tag{1}$$

where $\otimes x$ represents an interval grey number with a range of $[\underline{\otimes}x,\ \bar{\otimes}x]$, where $\underline{\otimes}x$ is the lower bound and where $\bar{\otimes}x$ is the upper bound of the interval grey number. x_{ij}^{t} denotes the evaluation value given by expert t for the degree of influence of factor i on factor j in the context of Marine Ecological Culture Communication in Fujian Province. The relationship satisfies $\otimes x_{ij}^{t} \in [\underline{\otimes}x_{ij}^{t}, \bar{\otimes}x_{ij}^{t}]$ and $\Delta_{\min}^{\max} = \max \bar{\otimes}x_{ij}^{t} - \min \underline{\otimes}x_{ij}^{t}$.

② Whitenization processing.

$$Y_{ij}^{t} = \frac{\left[\underline{\otimes}\tilde{x}_{ij}^{t}\left(1-\underline{\otimes}\tilde{x}_{ij}^{t}\right)+\left(\bar{\otimes}x_{ij}^{t}\times\bar{\otimes}\tilde{x}_{ij}^{t}\right)\right]}{\left(1-\underline{\otimes}\tilde{x}_{ij}^{t}+\bar{\otimes}\tilde{x}_{ij}^{t}\right)} \tag{2}$$

TABLE 4 Semantic variables of expert evaluation and weight.

Expert evaluation linguistic variables			Expert weight linguistic variables	
Linguistic variable	Interval grey number	Evaluation value	Linguistic variable	Interval grey number
No Direct Influence	[0.00, 0.00]	0	Not Important	[0.0, 0.3]
Weak Influence	[0.00, 0.25]	1	Slightly Unimportant	[0.3, 0.5]
Low Influence	[0.25, 0.50]	2	Important	[0.4, 0.7]
Significant Influence	[0.50, 0.75]	3	Relatively Important	[0.5, 0.9]
Extremely High Influence	[0.75, 1.00]	4	Very Important	[0.7, 1.0]

③ Compute the clarified values.

$$Z_{ij}^{t} = \min \underline{\otimes} \tilde{x}_{ij}^{t} + Y_{ij}^{t} \Delta_{\min}^{\max} \tag{3}$$

④ Compute the weighted matrix A for the t experts (direct-influence matrix). Specifically, A_{ij} denotes the element located in the i-th row and j-th column of the weighted direct-influence matrix.

$$A_{ij} = w_1 A_{ij}^{1} + w_2 A_{ij}^{2} + \ldots + w_n A_{ij}^{n} \tag{4}$$

The weighted matrix A—that is, the direct influence matrix—is calculated, where A_{ij} denotes the element in the i-th row and j-th column of the matrix, $\sum_{i=1}^{n} w_i = 1$.

⑤ The comprehensive influence matrix T is calculated. The direct influence matrix A is normalized via Equations 5–6 to obtain the normalized direct influence matrix N. Subsequently, Equation 7 is applied to compute the comprehensive influence matrix T, where $T=[t_{ij}]_{m\times n}$ and where λ_i (1, 2, etc., n) denotes the eigenvalues of the comprehensive influence matrix T.

$$N = S \times A \tag{5}$$

$$S = \frac{1}{\max\limits_{1\le t\le n} \sum_{j=1}^{n} A_{ij}} \tag{6}$$

$$T = N + N^{1} + N^{2} + \cdots = N(1-N)^{-1} \tag{7}$$

When $|\lambda_i|<1$时, $\lim N^{i}=[0]_{m\times n}$.

⑥ Calculation of the influence degree R_i and influence degree C_j. The influence degree R_i is obtained by summing the elements in the i-th row of the comprehensive influence matrix T, representing the combined direct and indirect effects exerted by factor i on all other factors affecting marine ecological culture communication in Fujian Province. The influence degree C_j is calculated by summing the elements in the j-th column of matrix T, reflecting the total direct and indirect effects received by factor j from all other factors influencing the development of the ecological culture industry.

$$R_i = \sum_{j=1}^{n} t_{ij}, \quad \forall_i \tag{8}$$

$$C_j = \sum_{i=1}^{n} t_{ij}, \quad \forall_j \tag{9}$$

⑦ Calculate the centrality degree P_i and the cause degree E_i for each influencing factor. The centrality degree P_i represents the position and overall influence of a factor within the system. A higher P_i value indicates a more important role. The cause degree E_i can be positive or negative. When E_i>0, the factor has a stronger influence on others and is classified as a cause factor; when $E_i < 0$, it is more affected by other factors and is classified as an effect factor.

$$P_i = \{R_i + C_i \mid i = j\} \tag{10}$$

$$E_i = \{R_i - C_i \mid i = j\} \tag{11}$$

⑧ Analyze the calculation results of the model. Take the cause degree and centrality as the horizontal and vertical coordinate axes respectively, construct the Cartesian right-angle coordinate system, draw a causal diagram of influencing factors, mark the position of each influencing factor at the same time, and analyze the causality and centrality of each factor with corresponding importance. A comprehensive analysis is carried out in combination with the ranking of influence, affected, center and cause, and finally effectively identifies the key factors affecting the dissemination of marine ecology and culture in Fujian Province.

4.2 Data analysis results based on the Grey-DEMATEL model

This study invited 22 regional experts in the fields of marine ecological governance, cultural heritage and communication, cultural tourism, and education to compare and score the indicators of the influencing factors based on the 13 factors extracted through grounded theory. These experts represented diverse disciplinary backgrounds, including marine governance, cultural studies, communication, tourism, and environmental policy. Their individual evaluations were subsequently synthesized through a weighted aggregation process to reduce potential individual bias and enhance the robustness of the results. Through Table 4, the expert scoring data is defuzzyed, combined with the expert weight, and the direct influence matrix A is calculated based on formula (1)-formula (5) as shown in Table 5.

The direct influence matrix A was normalized according to Equation 6 to form the standardized influence matrix. On the basis of Equation 7, the standardized direct influence matrix was subsequently computed to obtain the comprehensive influence matrix T, as presented in Table 6.

10.3389/fmars.2025.1764627

TABLE 5 Direct impact matrix A.

A	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}
A_1	0	0.10	0.09	0.07	0.06	0.07	0.08	0.09	0.09	0.05	0.07	0.07	0.06
A_2	0.09	0	0.10	0.08	0.08	0.07	0.08	0.09	0.09	0.06	0.06	0.06	0.07
A_3	0.09	0.10	0	0.09	0.08	0.07	0.09	0.09	0.09	0.06	0.07	0.07	0.07
A_4	0.09	0.09	0.10	0	0.09	0.09	0.08	0.09	0.09	0.05	0.07	0.07	0.07
A_5	0.07	0.06	0.08	0.08	0	0.08	0.08	0.07	0.07	0.08	0.08	0.08	0.08
A_6	0.06	0.06	0.06	0.07	0.09	0	0.07	0.07	0.07	0.07	0.08	0.07	0.08
A_7	0.08	0.09	0.10	0.09	0.10	0.10	0	0.09	0.09	0.05	0.06	0.07	0.09
A_8	0.10	0.10	0.10	0.07	0.08	0.07	0.08	0	0.08	0.05	0.06	0.06	0.07
A_9	0.09	0.08	0.09	0.07	0.07	0.06	0.07	0.08	0	0.04	0.06	0.06	0.07
A_{10}	0.07	0.06	0.07	0.07	0.09	0.07	0.07	0.07	0.07	0	0.09	0.08	0.05
A_{11}	0.07	0.07	0.07	0.09	0.08	0.08	0.08	0.07	0.07	0.07	0	0.09	0.08
A_{12}	0.07	0.08	0.08	0.09	0.09	0.08	0.08	0.07	0.07	0.08	0.10	0	0.06
A_{13}	0.05	0.06	0.07	0.08	0.08	0.07	0.07	0.06	0.07	0.06	0.07	0.07	0

On the basis of the data presented in Table 6, the influence degree (R_i) and influence degree (C_j) were calculated via Equations 8–9. The centrality degree (P_i) and cause degree (E_i) were subsequently derived according to Equations 10–11. The computed results are shown in Table 7.

Using centrality (P_i) and cause degree (E_i) as the horizontal and vertical axes, a "cause–effect" distribution map of the influencing factors in marine ecological culture communication in Fujian Province was plotted, as shown in Figure 1.

5 Analysis of the influencing factors in marine ecological culture communication in Fujian province

5.1 Causal factor analysis

On the basis of the results presented in Table 6 and Figure 1, the interactions and interconnections among the 13 influencing factors of

TABLE 6 Comprehensive impact matrix T.

A	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}
A_1	0.74	0.84	0.88	0.81	0.82	0.77	0.81	0.82	0.83	0.62	0.74	0.72	0.73
A_2	0.86	0.79	0.93	0.86	0.88	0.81	0.86	0.86	0.87	0.66	0.77	0.75	0.77
A_3	0.87	0.88	0.84	0.87	0.89	0.81	0.87	0.86	0.87	0.66	0.78	0.76	0.77
A_4	0.87	0.88	0.93	0.79	0.89	0.83	0.86	0.87	0.88	0.65	0.78	0.76	0.78
A_5	0.80	0.81	0.87	0.82	0.77	0.78	0.81	0.81	0.81	0.64	0.75	0.73	0.75
A_6	0.76	0.77	0.81	0.78	0.81	0.67	0.77	0.77	0.77	0.61	0.71	0.69	0.71
A_7	0.89	0.90	0.96	0.90	0.93	0.86	0.81	0.89	0.90	0.68	0.80	0.79	0.82
A_8	0.84	0.85	0.89	0.81	0.84	0.77	0.82	0.75	0.83	0.62	0.74	0.72	0.74
A_9	0.76	0.77	0.82	0.75	0.77	0.71	0.75	0.76	0.69	0.57	0.68	0.66	0.68
A_{10}	0.77	0.78	0.83	0.78	0.82	0.74	0.78	0.78	0.79	0.55	0.73	0.71	0.70
A_{11}	0.83	0.84	0.89	0.86	0.87	0.80	0.84	0.83	0.84	0.65	0.70	0.76	0.76
A_{12}	0.86	0.88	0.93	0.89	0.91	0.83	0.87	0.86	0.87	0.69	0.81	0.71	0.78
A_{13}	0.72	0.74	0.79	0.75	0.77	0.70	0.74	0.73	0.74	0.57	0.68	0.66	0.61

TABLE 7 Influence, affected, centrality, cause and ranking.

Influencing factors	Influence degree		Influenced degree		Centrality degree		Cause degree		
	(*R*)	Rank	(*C*)	Rank	(*R*+*C*)	Rank	(*R*-*C*)	Rank	Type
A_1	0.909	9	0.929	8	1.874	7	-0.428	9	Result Factor
A_2	0.956	5	0.945	3	1.937	4	-0.078	6	Result Factor
A_3	0.962	4	1	1	2	1	-0.640	11	Result Factor
A_4	0.966	3	0.939	5	1.943	3	0.102	5	Causal Factor
A_5	0.912	8	0.966	2	1.914	5	-0.811	12	Result Factor
A_6	0.865	11	0.887	9	1.786	11	-0.440	10	Result Factor
A_7	1	1	0.933	6	1.970	2	0.544	4	Causal Factor
A_8	0.916	7	0.931	7	1.884	6	-0.365	7	Result Factor
A_9	0.841	12	0.940	4	1.817	10	-1.311	13	Result Factor
A_{10}	0.875	10	0.719	13	1.623	13	1.582	1	Causal Factor
A_{11}	0.939	6	0.851	10	1.823	9	0.799	3	Causal Factor
A_{12}	0.976	2	0.829	12	1.839	8	1.456	2	Causal Factor
A_{13}	0.824	13	0.845	11	1.701	12	-0.409	8	Result Factor

marine ecological culture communication in Fujian Province can be identified. Among them, A_4 (capital investment), A_7 (government incentives and support), A_{10} (audience heterogeneity), A_{11} (ocean literacy/consumption intention), and A_{12} (purchasing power and tourism demand) exhibit positive degrees of cause (E_i>0) and are therefore classified as causal factors. Overall, the causal factors of marine ecological culture communication in Fujian Province are mainly concentrated in the elements and supply and audience and demand dimensions, reflecting a dual supply–demand interaction pattern. Among these, audience heterogeneity, purchasing power and tourism demand, and ocean literacy/consumption intention occupy upstream positions within the structural framework, showing strong driving and guiding effects. These three factors not only directly affect the content choice and form preference of communication, but also indirectly shape the expression and synergy of other elements by affecting the public's cognitive structure and behavioral intention. These demand-side factors exhibit both short-term responsiveness to communication stimuli and longer-term influence by shaping stable participation patterns, consumption preferences, and cultural identification. Audience heterogeneity reflect the hierarchical characteristics of different groups in terms of cultural identity, value orientation and information reception. This difference determines the differentiation and adaptability of the communication process, which is a key prerequisite for the accuracy and diversification of marine ecological cultural communication. The ability to pay and the demand for tourism reflect the motives of cultural consumption under economic constraints, which has an amplifying effect on the market space and transformation efficiency of communication; its

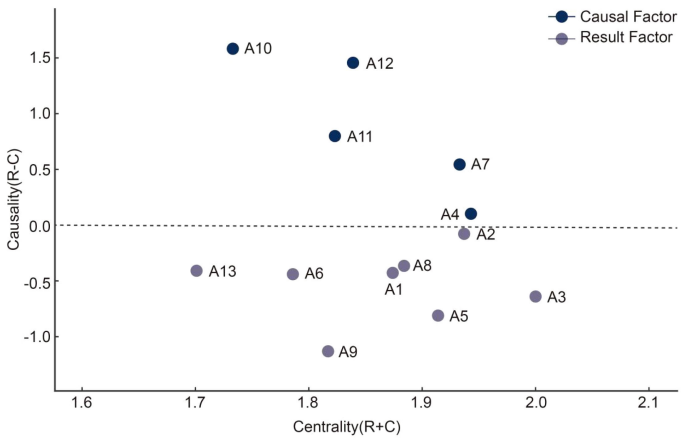

FIGURE 1
"Cause–Effect" diagram of key influencing factors in marine ecological culture communication in Fujian Province.

improvement not only depends on the income level, but also on the public's awareness of the value of ecological products and cultural experience. The rise of marine literacy and willingness to consume means that the public has changed from passive acceptance to active participation, promoting the transformation from "external advocacy" to "endogenous dissemination".

5.2 Result factor analysis

Based on the data in Table 6 and Figure 1, eight factors have negative cause degrees ($E_i < 0$). These include A_1 (diversity of marine eco-cultural resources), A_2 (abundance of marine eco-cultural resources), A_3 (value of marine eco-cultural resources), A_5 (innovation/digital communication elements), A_6 (talent and scenario infrastructure), A_8 (resource protection constraints), A_9 (coastal red lines and heritage regulation), and A_{13} (media matrix and cross-sector coordination). The result factors as a whole reflect the links in the marine ecological and cultural communication system of Fujian Province that are strongly influenced by external drives and upstream factors, mainly focusing on the resource and content levels and the institutional and communication support levels. Among them, the value of marine eco-cultural resources, innovation/digital communication elements and the abundance of marine eco-cultural resources are the most affected, which shows that these factors bear the key function of "undertaking-transformation-diffusion" in the system. As the core content carrier of communication, the value of marine eco-cultural resources directly determines the depth and continuity of cultural communication. However, marine ecological and cultural resources do not directly generate communication effects. Their influence materializes through processes of content selection, narrative framing, and media translation. In Fujian, ecological restoration outcomes, heritage landscapes, and marine cultural symbols are transformed into communication content via institutional guidance, digital mediation, and experiential design, enabling resource value to be cognitively perceived and socially disseminated. Its improvement depends not only on resource endowment itself, but also on the external stimulation of policy guidance and capital investment. The abundance of marine eco-cultural resources reflects the stability and diversity of content supply, which is the basis for ensuring the sustainable development of the communication system. Innovation and digital communication elements play the role of "catalyst". Through technological empowerment, formal innovation and media integration, they promote the multi-channel presentation and social diffusion of resource value, making communication more immersive and interactive.

5.3 Analysis of key influencing factors

The centrality of each factor in the system reflects its relative importance; larger values of centrality ($R+C$) are positively associated with the importance of the factor. In identifying key influencing factors, it is also necessary to consider the rankings of the degree of influence (R) and the degree of influence (C) jointly. By integrating the rankings of R, C, centrality, and degree of cause, we conduct a comprehensive assessment and thereby identify the key factors shaping marine ecological culture communication in Fujian Province. The results are reported in Table 8.

The top five factors by centrality are the A_3 value of marine eco-cultural resources, A_7 government incentives and support, A_4 capital investment, A_2 abundance of marine eco-cultural resources, and A_5 innovation/digital communication elements. This pattern indicates that institutional supply and resource endowment remain the core logic of the system, whereas capital

TABLE 8 Identification results of key influencing factors.

Factor	Centrality ranking	Causality ranking	Influence degree ranking	Influenced degree ranking	Key influencing factor
A_3	1	11	4	1	Yes
A_7	2	4	1	6	Yes
A_4	3	5	3	5	Yes
A_2	4	6	5	3	Yes
A_5	5	12	8	2	Yes
A_8	6	7	7	7	No
A_1	7	9	9	8	No
A_{12}	8	2	2	12	Yes
A_{11}	9	3	6	10	Yes
A_9	10	13	12	4	No
A_6	11	10	11	9	No
A_{13}	12	8	13	11	No
A_{10}	13	1	10	13	No

and innovation act as critical amplifiers in the external incentive mechanism. Specifically, A_3 value of marine eco-cultural resources holds a central position in the system. It serves as a key link connecting ecological resources with communication practices. Its high centrality and high influenced degree show that resource value not only determines the appeal and cultural depth of communication content, but also spreads significantly under the influence of external policies and capital., A_7 government incentives and Support serve as institutional drivers that significantly guide and shape the communication system. Through policy incentives, agenda setting, and resource allocation, they establish a legitimate framework for communication activities. These "institutional signals" influence capital flows and social participation, reflecting how policy logic comes before market logic in China's approach to ecological culture communication. A_4 capital investment functions as the economic foundation of the communication system. It works as a bridge between policy and resources. Its high centrality shows it plays a key supporting role in content production, tech innovation, and communication infrastructure. However, it relies heavily on the policy environment, showing what we call "policy-dependent" characteristics. The high centrality of A_2 abundance of marine eco-cultural resources and A_5 innovation/digital communication elements highlights the synergistic tension between supply and innovation. Resource abundance ensures continuous and meaningful content. Innovation and digital elements use modern technologies like digital tools and interactive experiences to expand communication reach. This helps cultural communication evolve from one-way messaging to collaborative creation.

6 Discussion

Although marine ecological culture communication involves governmental, market, and social actors, this study primarily emphasizes governmental actors as institutional drivers, while treating market participants and social organizations as responsive and co-evolving actors within the system. Based on the Grey-DEMATEL model, this study reveals the multi-dimensional coupling structure and key influence path of the marine ecological and cultural communication system in Fujian Province, confirming that the marine ecological and cultural communication is not a linear diffusion, but a complex system driven by the interaction of multiple elements of the system, innovation, resources, demand and platform. This finding echoes the assertion of Flannery et al. (2022) that the governance of marine cultural heritage needs to rely on "institutional resilience and multi-scale coupling", indicating that the sustainability of marine ecological cultural communication depends on structural institutional supply and dynamic network coordination (Flannery et al., 2022).

1. In terms of institutions and rules, the study found that "Government Incentives and Support" has the highest degree of reason and is the structural driving force that links innovation, capital and public participation. This conclusion confirms that Choi et al. (2022) on the intermediary role of China's "ecological protection red line" system in balancing ecological protection and regional development (Choi et al., 2022), and is also consistent with the "Marine Ecological Red Line Adjustment Mechanism" proposed by Zeng et al. (2024) (Zeng et al., 2024),The latter emphasizes the key role of institutional boundaries in reducing the intensity of human activities and enhancing the coverage of ecologically important regions. Institutional supply not only affects the effectiveness of communication through financial support and policy orientation, but also provides a legal framework and stable expectations in cultural governance, forming an institutional foundation for the dissemination of marine ecological culture. Within the institutional dimension, a functional distinction exists between enabling and restrictive mechanisms. Enabling institutional arrangements, such as government incentives and policy guidance, actively facilitate marine ecological culture communication, whereas restrictive regulations, including ecological red lines and heritage protection rules, primarily define ecological and spatial boundaries. This distinction helps clarify their different roles within the communication system.

2. In the dimension of factors and supply, the elements of innovation and digital communication and the centrality of capital investment are at the forefront, which shows that technological innovation and financial support are the core driving forces to improve communication efficiency. In this study, innovation and digital communication elements mainly refer to digital platforms, social media dissemination, immersive or interactive technologies, and data-enabled narrative formats that enhance participation and communication efficiency. The research of Wang and Meng (2024) pointed out that the digitalization process of museums and cultural heritage is transforming from information display to cognitive experience (Wang and Meng, 2024). The results of this study are consistent with this: digital innovation not only optimizes communication efficiency in the ecological and cultural field, but also reconstructs the mechanism of communication semantics and public co-creation. At the same time, the impact of capital investment is constrained by the policy environment, echoing the research of de Ycaza et al. (2024) on the consistency of blue economic policies and governance coordination, showing that the effectiveness of capital diffusion depends on the degree of institutional coordination and the clarity of the path of technological innovation (de Ycaza et al., 2024).

3. In the dimension of resources and content, the centrality of the value of marine eco-cultural resources is the highest, which shows that it is the core hub for the depth and continuity of communication. The research of Barianaki et al. (2024) further pointed out that the inclusion of cultural values and heritage in marine space planning is an important mechanism for resource protection and cultural dissemination (Barianaki et al., 2024), which is consistent with the "resource hub - system" proposed in this study. The double path logic of the degree guardrail is highly consistent.

4. In the audience and demand dimensions, audience heterogeneity, ocean literacy and consumption intention, and purchasing power and tourism demand together constitute demand-side traction and feedback mechanisms. Lucrezi and Cilliers (2023) found through an international survey that public

volunteerism and environmental engagement form a vital social foundation for marine cultural communication (Lucrezi and Cilliers, 2023). The present study further reveals that variations in public cognition and cultural literacy not only shape information reception and communication depth but also feed back into institutional and supply dimensions through value identification and consumption intention, thereby forming a closed-loop mechanism between demand and supply.

5. In the platform and coordination dimension, although the media matrix and cross-sector collaboration lie on the result side, their coordination thresholds effectively set the upper bound of the diffusion capacity. The evidence shows that collaboration and data sharing in cross-boundary marine spatial planning are critical mechanisms for enhancing the effectiveness of cultural communication (Ansong et al., 2023). Meanwhile, Wang and Meng (2024) show that digital platforms can enhance the immersion and sustainability of cultural communication by strengthening the connection between awareness, identity, technology, and culture (Wang and Meng, 2024). The present study further reveals that media networks in Fujian face issues with similar content and fragmented agendas. There is an urgent need to build stronger communication synergy through cross-department cooperation and digital governance platforms.

In summary, the system effectiveness of marine ecological culture communication comes from the multi-dimensional coupling of institutional supply, innovation empowerment, resource endowment, demand traction and platform coordination. At the same time, it should be acknowledged that intensified communication and commercialization may also generate tensions, such as pressures on ecological carrying capacity or risks of cultural commodification, highlighting the need for appropriate institutional balancing mechanisms. The institutional red line guarantees the boundaries of ecological security, innovation and capital provide a power mechanism, resource value forms the communication core, the demand side co-creates the driving feedback cycle, and the collaborative platform realizes diffusion and integration. This mechanism not only confirms the systematic logic of international marine culture governance, but also provides a theoretical and practical basis for the construction of an integrated path of "ecological protection-cultural dissemination-value realization" in coastal areas.

7 Conclusion and implications

Under the new background of the national strategy of "Beautiful China", "Ocean Strong Country" and "Ecological Civilization", Fujian Province, as the national ecological civilization pilot zone and the core area of the "21st Century Maritime Silk Road", actively implements the strategy of a strong marine province and promotes the construction of marine ecological civilization. Relying on rich marine ecological resources and profound sea silk cultural accumulation, Fujian Province is at the forefront of China in marine ecological protection, cultural inheritance and industrial innovation. The dissemination of marine ecological culture has gradually become a new path connecting ecological protection, cultural identity and industrial development. Effectively identifying the key factors affecting the dissemination of marine ecological culture in Fujian Province is of great strategic significance to early industrial planning, resource allocation and institutional design. The research results show that the formation of the effectiveness of marine ecological culture communication in Fujian Province shows a systematic pattern of "resource-driven-system-driven-demand traction".

1. Government Incentives and Support, innovation/digital communication elements and capital investment constitute the core driving mechanism of the marine ecological and cultural communication system, reflecting the multi-dimensional synergy of institutional supply, technology empowerment and capital momentum. The research results show that the government's policy orientation has the most significant driving and spillover effect in the system. Its policy incentives and institutional supply are the fundamental forces to shape the communication environment and guide the flow of resources. Innovation and digital communication elements have expanded the boundaries of communication through technical application and content innovation, significantly improving the efficiency and audience reach of cultural communication. Capital investment provides a material basis for resource development and communication innovation, but its effectiveness is subject to the dual constraints of policy orientation and the external environment, showing the characteristics of dependence.

2. The value of marine eco-cultural resources occupies a core position in the communication system, and has the dual functions of content supply and value realization. Its centrality and cause rank first, which shows that the value of resources not only directly determines the attractiveness and depth of cultural significance of the communication content, but also indirectly drives the coordinated operation of other elements by influencing public cognition and cultural preferences. As a supporting conditional variable, although resource abundance is biased towards resulting factors, it plays a fundamental role in the generation and transformation of resource value, which determines the continuity of communication content and the plasticity of the ecological and cultural system.

3. Although the demand-side factor is not at the core of the system, it shows significant traction and feedback effects. Purchasing power and tourism demand, marine literacy and the willingness to consume together constitute the endogenous driving force of continuous diffusion and identity construction of communication, which promotes the social embedding of cultural communication and the co-creation of the public. The active participation of the demand side not only affects the acceptance and diffusion path of communication, but also promotes the dynamic optimization of institutional supply and element allocation through the feedback mechanism, forming an interactive symbiotic structure with the core feature of "policy-driven-resource support-demand traction", revealing the dynamic balance mechanism of the marine ecological and cultural communication system under multi-subject coupling.

4. This research not only identifies the key driving factors of the marine ecological culture communication system in Fujian Province, but also provides systematic inspiration for solving the three major dilemmas at the practical level. First of all, in view of the

break between the communication supply side and the governance side, the coupling mechanism of resource value and communication innovation should be strengthened, and a cultural translation and market transformation chain of ecological restoration results should be built. Secondly, in view of the insufficient supply of subject coordination and rules, we should rely on government support and institutional guidance to establish a cross-departmental coordination and diversified participation mechanism, and improve the institutional incentive and revenue distribution system. Finally, in view of the threshold effect of "marine literacy-behavioral transformation" on the audience, the integrated effect of public cognition, emotion and action should be improved through differentiated communication and experiential education, and the two-way gain of ecological protection and cultural communication should be realized. This research path theoretically verifies the communication mechanism under multi-factor interaction, and in practice provides a feasible solution for the construction of an efficient and sustainable marine ecological and cultural communication system in coastal areas.

8 Research contributions

1. Theoretical Innovation: from regional experience to doctrine growth Taking Fujian Province as a typical field, the dissemination of marine ecological culture is placed in the triple context of "ecological civilization-cultural value-institutional governance", and a multi-dimensional interactive model of resource-system-innovation-capital-audience has been built, breaking through the research paradigm of treating ecological culture communication as a linear information flow or policy tool in the past. The research reveals the inherent logic of "system-driven-innovative empowerment-capital collaboration-public co-creation" in the communication of marine ecological culture, and puts forward the systematic mechanism and dynamic structure of ecological culture communication. This not only enriches the theoretical system of ecological civilization dissemination, but also provides a new analytical framework for understanding the cultural translation, social diffusion and institutional embedding of ecological values, marking a paradigm leap from "local practice" to "theoretical contribution".

2. Advanced method: from qualitative induction to structural deduction. Innovative integration of rooted theory and Grey-DEMATEL method realizes multi-level logical progression from conceptual abstraction to structural verification. Through the systematic coding of literature and expert interviews, thirteen core factors are distilled, and their role relationship and influence weight are revealed in the form of a causal matrix, and an analytical framework with both theoretical depth and data support is built. This method integration of "theoretical generation-model verification" provides replicable paths and paradigms for complex systematic research such as ecological culture, environmental communication and cultural ecosystem services, reflecting the research value of interdisciplinary integration and methodological innovation.

3. Global Enlightenment: from regional exploration to shared consensus. Taking Fujian, China as a case, but its core discovery has universal significance beyond the region. The study reveals that under the background of the global sustainable development agenda and the transformation of marine governance, cultural communication is not only a medium for the realization of ecological values, but also an important mechanism for the formation of social consensus and institutional coordination. Fujian's experience shows how to realize the systematic coupling of "ecological governance-cultural communication-public participation" in the construction of local ecological civilization, and provides a practical model for the global coastal areas to explore the institutionalization path, social mobilization mechanism and cultural value transformation of ecological cultural communication. The proposal of the research helps to promote the international community to form a cross-cultural and cross-institutional consensus and action framework in the field of blue economy and cultural sustainability.

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

HW: Writing – original draft, Data curation, Methodology, Investigation, Software, Conceptualization, Visualization, Formal Analysis, Validation. WL: Investigation, Resources, Funding acquisition, Project administration, Supervision, Conceptualization, Writing – review & editing. JH: Writing – original draft, Visualization, Validation, Conceptualization, Data curation. WW: Project administration, Validation, Resources, Writing – review & editing, Supervision, Conceptualization. SL: Writing – review & editing, Supervision, Resources, Conceptualization, Project administration.

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Conflict of interest

The author(s) declared that this work 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) declared that generative AI was not used in the creation of this manuscript.

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