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A framework for compiling a blue carbon resource balance sheet: integrating physical and value accounts

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Blue carbon ecosystems are critical natural assets in mitigating climate change and advancing sustainable development. However, the lack of standardized accounting and reporting frameworks has impeded a comprehensive assessment of their full economic and ecological value and has complicated the clear assignment of management responsibilities. To bridge this gap, this study proposes a systematic framework for compiling a balance sheet for blue carbon resources. The framework operationalizes core accounting concepts, including the reporting entity, assets, liabilities, and net assets. Then, it establishes a dual-track reporting system that integrates physical volume and value. This system initiates with baseline condition reports and physical statements of ecological functions. Subsequently, it employs environmental economic valuation techniques to translate heterogeneous physical data into monetary equivalents, thus enabling their consolidation into a comprehensive statement of total asset value. A detailed implementation roadmap is provided, tracing the entire process from data acquisition through to the delivery of the final report. The proposed framework supports systematic assessment, dynamic tracking, and a clear asset-liability structure for the blue carbon asset base, which establishes a scientific foundation for ecological performance auditing and sustainable blue economy governance, and unlocks the potential for assetization and strategic oversight of blue carbon resources. In the future, some challenges need to be solved, such as the refinement of liability accounting standards, the development of robust accounting methodologies for mobile ecosystems, and the establishment of authoritative valuation standards and unified databases through interdisciplinary collaboration.

KEYWORDS

accounting, balance sheet, blue carbon resources, monetary accounting, physical accounting

1 Introduction

Natural resources provide the material basis for human survival and the spatial basis for socio-economic development. They are one of the key factors determining the development and prosperity of human civilization. How to examine the resource status and utilization efficiency from an economic perspective is crucial to promoting development. The Natural Resource Balance Sheet (NRBS) applies economic principles to natural resource accounting. Through statistical analysis of resource types, stocks, flows, and their driving factors, it supports the transition to a regional green economy (Jiao et al., 2018). The systematic compilation of NRBS is a global goal, with nations and regions including Norway, Finland, the European Union, the United States, and China having established environmental accounting systems (Kong et al., 2016; Wang A. G. et al., 2023). The United Nations' System of Environmental-Economic Accounting (SEEA) central framework provides the most authoritative guidance in this field (Edens et al., 2022).

Existing NRBS research focuses on terrestrial and freshwater resources, such as land, forests, water, grasslands, and minerals (Li and Liu, 2019; Obst et al., 2020; Cui and Kong, 2021; King et al., 2024), while research on marine natural resource balance sheets remains relatively limited. As a crucial subset of marine resources, blue carbon resources offer significant potential for climate change mitigation. Healthy blue carbon ecosystems are vital for sustaining fisheries and provide immense, often inestimable, comprehensive ecosystem service value (Chen et al., 2025). However, the compilation of blue carbon resource balance sheets in marine natural resource balance sheets is extremely rare, and research on key aspects such as asset definition, liability classification and accounting content is still in the exploratory stage, which hinders effective ecosystem protection and restoration (Wang et al., 2024). Therefore, specialized research to scientifically compile a blue carbon resource balance sheet is essential. Such a balance sheet, by clearly presenting resource stocks and flows through the correspondence between assets and liabilities, would enable the auditing of the blue carbon asset base, clarify property rights responsibilities, and establish a robust asset accounting system. This, in turn, facilitates the assessment of the comprehensive economic-resource-environmental costs of blue carbon utilization, ensuring the green and sustainable development of the marine economy.

Researchers have conducted relevant studies on natural resource accounting systems, accounting classifications and measurement methods (Huang and Zhao, 2015; Hu and Shi, 2015; Yang and Yan, 2018; Han et al., 2025). Methodologically, research has evolved from physical stock accounting toward monetary valuation and has expanded from a focus on economic value to include ecological value. Early studies predominantly established physical stock accounts for resources (Gao et al., 2023). With advancements in valuation techniques, scholars began to integrate methods such as market pricing and replacement cost to monetize the "triple value" (economic, ecological, and social) of ecosystems (Guo et al., 2021). At the application level, case studies focusing on specific resource types and regions continue to emerge. In fields like forestry, grassland, land, and water resources, scholars have undertaken specific balance sheet compilations by combining methods such as ecological footprint and energy analysis (Zhang, 2020; Huang et al., 2020; Wang, 2021; Xie et al., 2022). Currently, a core theoretical controversy in NRBS frameworks concerns the definition of liabilities. Some scholars advocate emulating corporate accounting, defining liabilities as future economic obligations arising from the need to remediate ecological damage or fulfill environmental responsibilities (Huang and Zhao, 2015; Pan et al., 2019). Conversely, other scholars contend that such future governance costs are fraught with uncertainty and are difficult to measure reliably (Liu et al., 2020). They propose instead that liabilities should be linked directly to resource depletion, framing excessive consumption as a "debt" to natural capital (Song and Han, 2025). These theoretical debates result directly in ambiguity and inconsistency in the definition, categorization, and measurement of natural resource liabilities in accounting practice.

The recognition, measurement, and reporting of blue carbon assets are fundamental to constructing a blue carbon resource balance sheet. Asset recognition begins with defining the scope of blue carbon resources, a concept that originated in the 2009 United Nations Environment Programme (UNEP) report "Blue Carbon: The Role of Healthy Oceans in Binding Carbon", which formally identified the carbon sequestration capacity of marine ecosystems (United Nations Environment Programme, 2009). Initially, the scientific consensus defined blue carbon as encompassing three coastal ecosystems: mangroves, seagrass beds, and salt marshes (Macreadie et al., 2021; Wang F. et al., 2023; Lee and Lee, 2025). As research has advanced, this scope has expanded. Scholars, notably Lovelock and Duarte (2025), advocate for the inclusion of additional coastal and marine ecosystems, encompassing two broad categories: those with significant carbon sequestration potential, such as seaweed beds and supratidal forests, and those with substantial carbon storage capacity, such as marine sediments and coral reefs. This evolving and refined understanding of the blue carbon scope directly determines the asset boundaries within the balance sheet, demands greater comprehensiveness and accuracy in accounting, and provides the scientific foundation for the continued improvement and application of the reporting system.

Research on the marine NRBS is progressively advancing. Gao et al. (2023) proposed a framework incorporating both physical and value accounts, suggesting the measurement of physical quantities at the start and end of a period with monetary valuation based on market prices. From the perspective of natural resource property rights reform, Li et al. (2019) examined the classification of marine resource assets and liabilities. Kong et al. (2023) developed physical measurement indicators for marine natural resource liabilities, focusing on the dimensions of overconsumption, environmental pollution, and ecological degradation. Concurrently, with increasing focus on blue carbon resources, scholars have begun to address the compilation of a dedicated blue carbon balance sheet. For instance, Liu et al. (2024) designed an accounting system for coastal blue carbon ecosystems based on the SEEA. Yu and Li (2020) explored a mangrove resource asset-liability accounting system using Guangxi's mangroves as a case study. Furthermore,

Song et al. (2025) conducted a prospective study on the recognition, measurement, and reporting framework for blue carbon resource assets, clarifying the accounting entity, asset classification, and a system of value accounting indicators.

In summary, while existing research provides a valuable theoretical foundation for blue carbon resource accounting, significant gaps persist in constructing a comprehensive blue carbon resource balance sheet framework. As shown in Figure 1, the transition from theory to practical application is hindered by three primary limitations. The persistent lack of a unified conceptual framework, particularly concerning the definitions of key concepts such as "assets" and "liabilities" and the identification of reporting entities, continues to result in ambiguous accounting boundaries. Moreover, a clear disconnect remains between accounting practices and reporting systems. Existing studies seldom integrate assets, liabilities, and net assets into a coherent structure, and standardized templates capable of simultaneously presenting both physical and monetary values are still underdeveloped. Furthermore, most research remains theoretical in nature, focusing on indicator construction without establishing a systematic operational pathway that guides practitioners from data collection through physical and monetary accounting to final reporting. This absence of a clear workflow hinders practical implementation. Addressing these gaps is essential to develop standardized and applicable blue carbon accounting systems.

To address these gaps, this study proposes a systematic framework for compiling and reporting the blue carbon resource balance sheet. The research is structured in three parts: Firstly, it clarifies the core concepts of assets, liabilities, and the reporting entity to establish a solid conceptual foundation. Secondly, it develops a dual-track accounting and reporting system that integrates physical quantities with monetary values, enabling a complete mapping from the resource baseline to its comprehensive economic-ecological value. Finally, it delineates a standardized compilation pathway from data preparation to report generation. This framework aims to provide an operational guide for the precise accounting and responsible management of blue carbon resources, thereby facilitating their transformation from a natural stock into standardized, institutionalized ecological capital.

2 Definition of prerequisite concepts for the blue carbon resource balance sheet

2.1 Reporting entity

The reporting entity for the blue carbon resource balance sheet is defined as the institution responsible for compiling the balance sheet and ensuring the accuracy and completeness of its

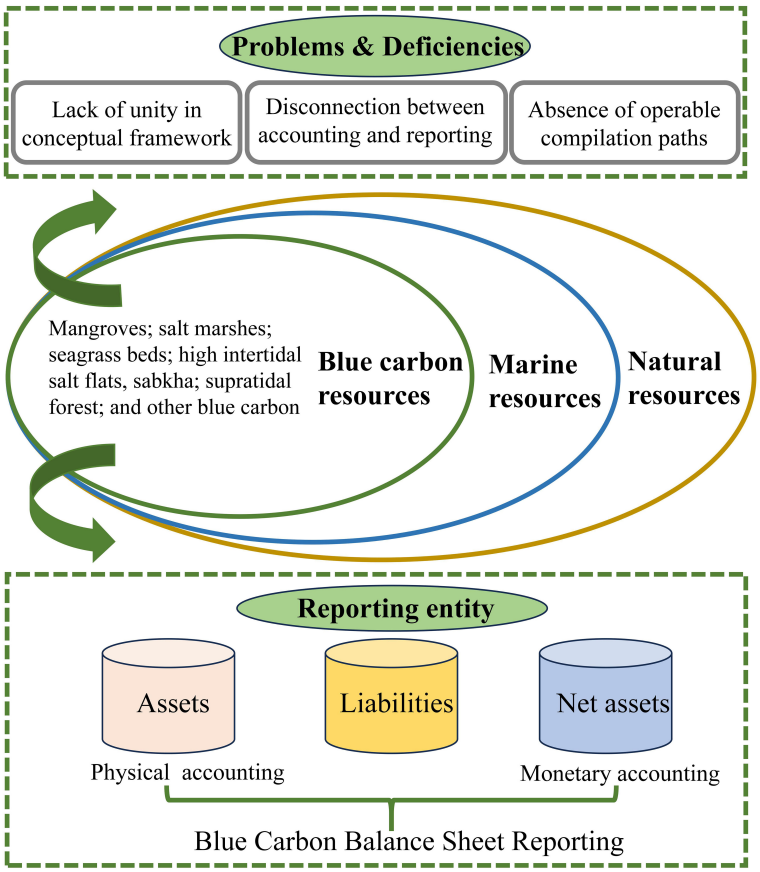

FIGURE 1
Challenges in blue carbon balance sheet compilation.

information. Since blue carbon ecosystems often function as public goods, their management typically spans multiple administrative levels and government departments. Consequently, the reporting entity usually constitutes a multi-tiered, collaborative system, which can be broadly categorized into macro and micro levels from a functional hierarchy perspective. The macro-level reporting entity typically comprises national or federal governments and highly autonomous regional governments. This entity oversees the inventory, valuation, and liability assessment of blue carbon resources within its jurisdiction. It is responsible for compiling a comprehensive balance sheet to inform national strategic planning, ecological performance evaluations, and policy audits. The micro-level reporting entity primarily includes local governments and their associated natural resource or marine management departments. This entity undertakes the routine monitoring, data collection, and accounting for jurisdictional blue carbon resources. It compiles local balance sheets, thereby providing reliable data for higher-level aggregation and analysis (Song et al., 2025). Depending on the national context, non-governmental research institutions and international organizations may also serve as significant collaborators, contributing to methodology development and data verification.

2.2 Blue carbon resource assets

The academic community has yet to reach a consensus on the definition of blue carbon "assets", resulting in vague concepts and unclear accounting boundaries (Li and Kou, 2024; Liu et al., 2024). The definition of this core concept can be derived from basic accounting principles. The blue carbon assets are defined as the components of blue carbon ecosystems that are owned or controlled by a specific management entity, typically a government or authorized agency, and are expected to deliver economic, ecological, and social benefits through their ecosystem services. For recognition, blue carbon assets must satisfy several core criteria: (1) a clearly defined resource type and ownership; (2) the capacity for the management entity to exercise effective control through legal, administrative, or technical means; (3) demonstrable scarcity within a specific spatiotemporal context; (4) the ability to directly or indirectly yield multiple benefits; and (5) the reliable measurability of both physical stock and monetary value using contemporary technologies and methods (Hu and Shi, 2015; Chen and Wang, 2017).

2.3 Blue carbon resource liabilities

The blue carbon resource liabilities are defined as present obligations arising from past unsustainable development or mismanagement that has caused a reduction in quantity, degradation in quality, or functional impairment of blue carbon ecosystems. A specific entity is obligated to undertake future restoration or compensation for these obligations (Li et al., 2019). The blue carbon liability must satisfy the following criteria: (1) the obligation originates from a past event; (2) a future outflow of economic resources is probable, and its trend is clear; and (3) the obligation's magnitude can be reliably measured.

Based on their manifestation, these liabilities are categorized as quantity depletion liabilities and quality impairment liabilities. Quantity depletion liabilities reflect the restoration costs required due to a past reduction in ecosystem area or a direct decline in carbon stocks. Quality impairment liabilities refer to the restoration obligations arising from the degradation of ecosystem functions, even without a significant reduction in area (Pan et al., 2019). For measurement, both types are typically valued based on the extent of resource depletion or functional impairment, multiplied by the corresponding unit restoration cost.

Currently, accounting for blue carbon resource liabilities lacks a standardized framework, with no consensus on key dimensions including scope, measurement methodologies, and disclosure protocols. Given the nascent stage of both theoretical and practical development in this domain, the present study defers a systematic accounting of these liabilities. Subsequent research will address this gap following the establishment of more robust and widely accepted accounting standards.

2.4 Blue carbon resource net assets

Existing studies often focus narrowly on asset accounting or discuss liabilities in a fragmented manner, failing to integrate assets, liabilities, and net assets within a cohesive reporting structure (Ashournejad et al., 2019; Lin et al., 2022; Michael-Bitton et al., 2022). Based on the preceding definitions of assets and liabilities, blue carbon resource net assets represent the residual value of blue carbon assets after subtracting corresponding liabilities. This metric characterizes the net stock and long-term sustainability of regional blue carbon resources. Ecologically, net assets serve as a key indicator for assessing the health of the blue carbon system and management performance. A positive and increasing value signifies robust resource stocks and enhanced resilience, indicating potential for sustainable utilization. Conversely, a negative value reveals a state of "ecological insolvency", where historical degradation has exceeded the ecosystem's carrying capacity. This situation necessitates urgent interventions such as protection, restoration, and development restriction to promote asset recovery and debt reduction, thereby rebuilding the overall sustainability of the system.

3 Framework for compiling and reporting the blue carbon resource balance sheet

3.1 Approach to compilation and reporting

Currently, most research remains theoretical, focusing on indicator construction without providing a systematic, integrated process guiding practitioners from data collection through physical

and monetary accounting to final report generation. This lack of a clear workflow leaves compilation efforts without practical guidance (Han and Song, 2024). Furthermore, standardized report templates that simultaneously present physical quantities and monetary values are lacking (Kong et al., 2023). The Blue Carbon Resource Balance Sheet developed in this study systematically reports the status of blue carbon resource assets, liabilities, and net assets, adopting a format analogous to financial accounting statements. Its compilation follows a sequential pathway: it begins by constructing baseline statements that reflect resource stocks and spatial distribution; subsequently integrates statements assessing ecological functions; and finally consolidates these into a comprehensive value statement. This process establishes a complete accounting system encompassing both physical and monetary dimensions. The framework is designed to scientifically represent the status and dynamics of regional blue carbon resources, thereby providing a decision-making basis for ecological protection and sustainable management. The specific framework and involved concepts are shown in Figures 2, 3.

3.2 Physical accounting of blue carbon

The blue carbon resource physical quantity statement constitutes the foundational data layer of the blue carbon resource balance sheet system. It is compiled from specialized monitoring data, coastal environmental statistical yearbooks, and management archives. Functionally, this statement employs primarily carbon stocks and ecosystem coverage area to characterize the asset status of regional blue carbon resources. The core value lies in its ability not only to statically reflect resource stocks at the beginning and end of a period but also to

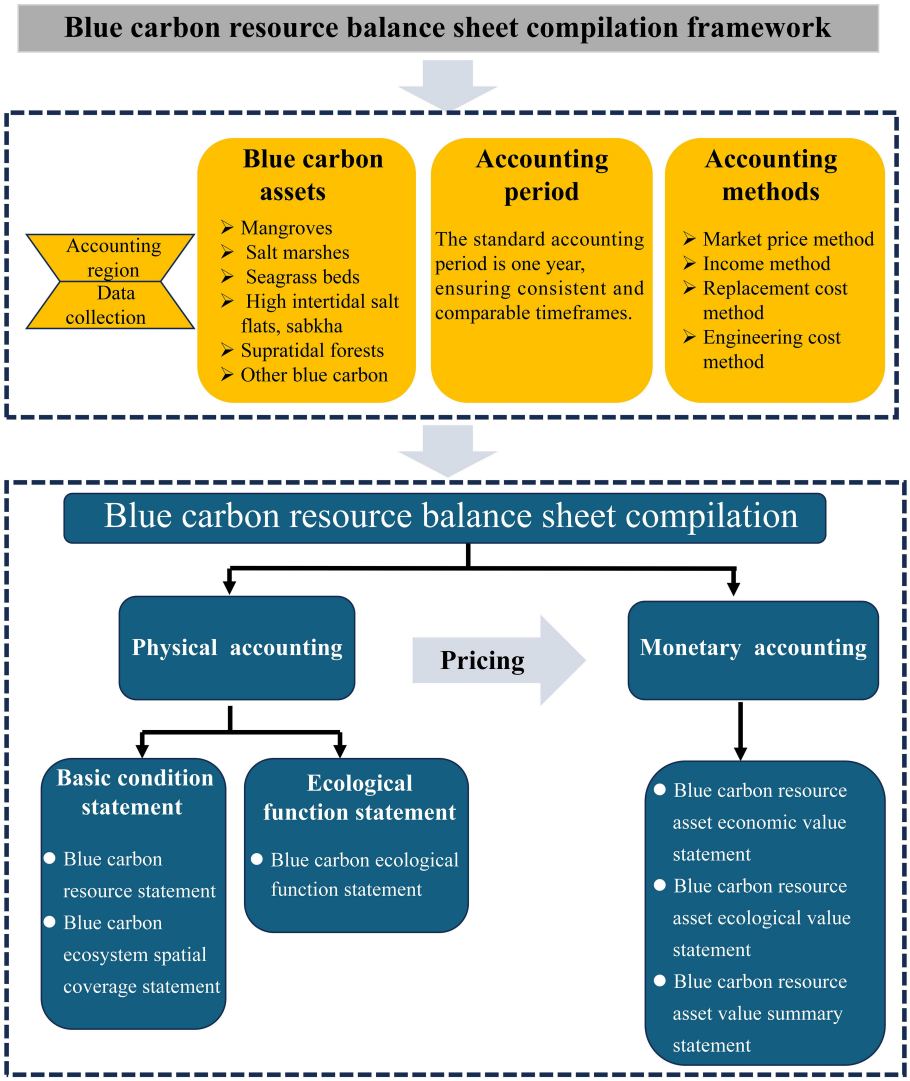

FIGURE 2
Blue carbon resource balance sheet compilation framework.

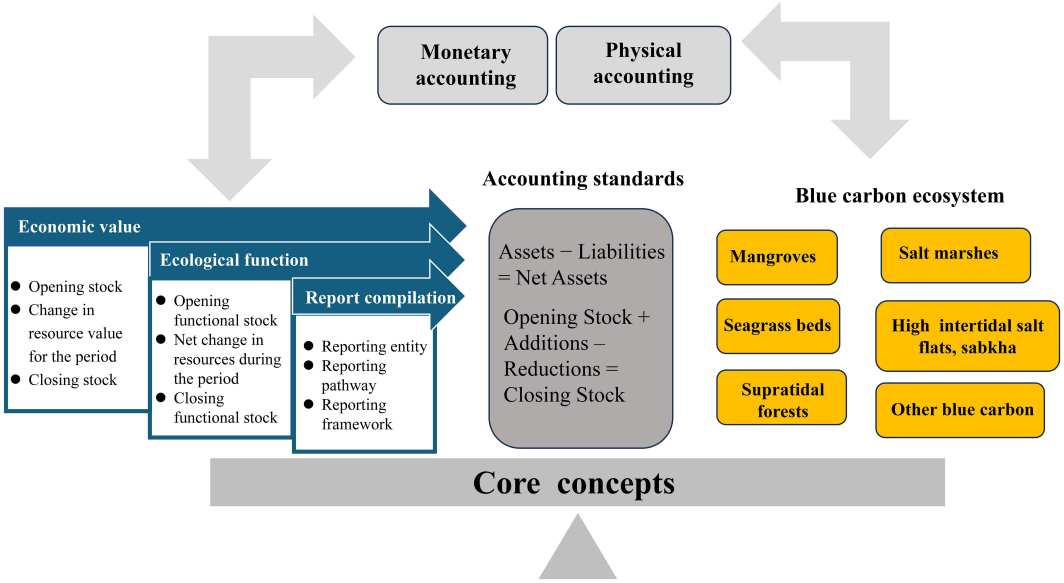

FIGURE 3
Core concepts of blue carbon resource balance sheet.

dynamically track changes and analyze their underlying drivers. Structurally, the physical quantity statement comprises two main components: the basic condition statement of blue carbon resource and the blue carbon ecological function statement. The basic condition statement fulfills the fundamental role of resource inventory, systematically recording the quantity, scale, and spatial distribution of resources. It serves as the logical starting point and data cornerstone of the entire reporting system, forming the basis for all subsequent ecological function analysis and monetary valuation.

3.2.1 Basic condition report of blue carbon resource

The Basic Condition Statement is structured around two complementary dimensions: resource stock and spatial coverage area, reflecting the intrinsic linkage between blue carbon and its ecosystem carriers. The primary data for this assessment comprises two core statements, which delineate the Blue Carbon Resource Stock (Table 1) and the Blue Carbon Ecosystem Spatial Coverage (Table 2). The former quantifies the carbon stock within ecosystems like mangroves and seagrass beds, while the latter records their spatial extent. These statements are interlinked and mutually verifiable, together constituting a complete physical asset inventory. The included ecosystem types are mangroves, salt marshes, seagrass beds, high intertidal salt flats, sabkha, supratidal forests, and other blue carbon ecosystems (e.g., macroalgae, coral reef (limited to lagoons), low intertidal mudflats, coralline algae, marine sediments) (Lovelock and Duarte, 2024).

The proposed compilation employs dual logic of horizontal and vertical analysis. The vertical dimension follows the stock-flow balance principle, satisfying the formula “Opening Stock + New Increase - Decrease = Closing Stock”, where changes are categorized into natural and anthropogenic drivers to track the forces of change. The horizontal dimension adopts an ecosystem-based classification to aggregate data, maintaining a complete balance where the total equals the sum of all categories. This design allows managers to pinpoint dominant asset types and areas experiencing significant change. This structure ensures that reports not only quantify total stock but also reveal structural changes and their potential drivers, thus providing reliable data support for the precise management and protection of blue carbon resources. This structure ensures the statements not only quantify total stocks but also reveal structural changes and their underlying drivers, thereby providing robust data support for precise management and conservation of blue carbon resources.

3.2.2 Blue carbon ecological function statement

The main goal of the blue carbon ecological function statement is to quantify the physical output of ecosystem services provided by blue carbon ecosystems. The compilation is derived from baseline condition statements, utilizing the inventoried ecosystem areas and carbon stocks as the foundational data for the accounting. Unlike the baseline description of resources, this statement focuses on measuring functional intensity. Through the establishment of characteristic functional accounts for processes such as carbon sequestration, oxygen release, wave attenuation, shoreline protection, water purification, and biodiversity maintenance (Macreadie et al., 2021; Bhavesh et al., 2024; Samadder et al., 2025), the ecosystem service capacity of blue carbon resources is systematically characterized.

A salient feature and primary compilation challenge of this statement arises from the disparate measurement units and indicators required for different ecological functions. For example, carbon sequestration is measured in tons per year, wave attenuation as wave height reduction in centimeters or meters, and water purification in kilograms per hectare per year. This fundamental

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TABLE 1 Blue carbon resource statement.

Vertical dimension (Main column)	Mangrove	Tidal marsh	Seagrass	High intertidal salt flats, sabkha	Supratidal forests	Other blue carbon ecosystems	Total
1. Opening Stock							
(% of Total Stock)							100%
2. Current Period Flux							
2.1 Increase for current period							
Natural factors (e.g., natural carbon sequestration)							
Anthropogenic factors (e.g., artificial restoration)							
2.2 Decrease for current period							
Natural factors (e.g., vegetation decline)							
Anthropogenic factors (e.g., development occupation)							
2.3 Net Flux (Increase - decrease)							
3. Closing Stock							
(% of Total Stock)							100%
Report explanation	Opening stock + Increase - Decrease = Closing stock (Applicable to all columns)						

Units are to be specified based on the actual context (e.g., tons of carbon, Tg C).

TABLE 2 Blue carbon ecosystem spatial coverage statement.

Vertical dimension (Main column)	Mangrove	Tidal marsh	Seagrass	High intertidal salt flats, sabkha	Supratidal forests	Other blue carbon ecosystems	Total
1. Opening Coverage							
(% of Total)							100%
2. Area change for current period							
2.1 Area increased for current Period							
Natural factors (e.g., ecological restoration expansion)							
Anthropogenic factors (e.g., constructed wetland construction)							
2.2 Area decreased for current period							
Natural factors (e.g., damage caused by natural disasters)							
Anthropogenic factors (e.g., occupation by construction land)							
2.3 Net change in area for this period (Increase - decrease)							
3. Closing Coverage							
(% of Total)							100%
Report explanation	Opening Coverage + Increase - Decrease = Closing Coverage (Applicable to all columns)						

The unit of measurement (e.g., hectares, km²) should be specified based on the actual context of the data.

heterogeneity prevents the horizontal summation of data across functions to produce a unified "total ecological function" value, unlike in the basic condition statement. Consequently, the statement's design must accommodate this objective reality. Its purpose is not to generate a single aggregate figure but to accurately characterize the independent intensity and dynamics of each function through the parallel presentation of multi-dimensional indicators.

Blue carbon ecological function statement (physical quantity) is structured with the four core ecological function types along its vertical axis as shown in Table 3. The horizontal axis comprises three key dimensions: "opening functional quantity", "periodic change in quantity" and "closing function quantity". This structure clearly represents the physical quantity of each function at the beginning and end of the accounting period. Furthermore, the "changes during the period" column is augmented by a "notes on causes of change" section, providing direct insight into the drivers of functional fluctuations. Crucially, the statement specifies that the accounting object must be the "intact blue carbon ecosystem". This underscores that ecological functions result from the integration of resources, environment, and processes; when divorced from a specific, intact ecosystem carrier, these functions cannot be meaningfully assessed.

3.3 Asset valuation of blue carbon resource

The valuation of blue carbon resource assets is a pivotal step in constructing the blue carbon resource balance sheet. This process entails converting heterogeneous physical data, measured in disparate units, into comparable monetary values using scientific accounting methods. To ensure that the final monetary value accurately reflects the multifaceted inherent value of blue carbon resources, the data is divided into baseline resource data and data characterizing ecosystem services, with differentiated valuation methods applied to these two types of data. Baseline resource data includes mangrove area, seagrass bed carbon storage, etc., and its direct economic value is typically assessed using market price or income approaches. Data characterizing ecosystem services includes carbon sequestration, coastline protection, etc., and its indirect ecological value is typically quantified using replacement cost or engineering cost approaches. This differentiated valuation approach enables a more precise and comprehensive assetization of blue carbon resources by aligning the valuation methodology with the distinct economic and ecological attributes of each data type. The valuables are listed in Table 4.

Blue carbon resource asset economic value statement as shown in Table 5 delineates the mapping from physical quantities to economic value. Categorized by ecosystem type (e.g., mangroves, seagrass beds, salt marshes), the valuation in this table is directly derived from the physical statements. For instance, the economic value of carbon sequestration is calculated as "Carbon Stock × Carbon Market Price", while values for forest land and aquaculture synergy are determined by "Ecosystem Area × Corresponding Market Price or Revenue Share Ratio". Employing a dynamic structure that tracks the components from opening stock to closing stock via changes during the period, the table comprehensively captures the trajectory of economic value. The

TABLE 3 Blue carbon ecological function statement (physical quantity).

Vertical dimension (core column) / Horizontal dimension (function type)	Carbon sequestration and Oxygen release function	Wave attenuation and Coast protection function	Water purification function	Biodiversity maintenance function
1. Opening function quantity				
Accounting indicators and Units	Carbon stock increment (ton C/year), O_2 release (ton O_2/year)	Wave height reduction (cm), coast protection length (m)	Nitrogen removal (kg/ha·year), phosphorus removal (kg/ha·year)	Coastal species quantity (species), habitat area (ha)
2. Periodic change in quantity				
Change reason notes (optional)	E.g., mangrove area increase/degradation, seagrass bed restoration projects, etc.	E.g., storm surge damage, synergistic effect of artificial seawalls, etc.	E.g., changes in watershed pollution input, enhanced purification from ecological restoration, etc.	E.g., habitat restoration, alien species invasion, etc.
3. Closing function quantity				
Accounting indicators and Units	Carbon stock increment (ton C/year), O_2 release (ton O_2/year)	Wave height reduction (cm), coast protection length (m)	Nitrogen removal (kg/ha·year), phosphorus removal (kg/ha·year)	Coastal species quantity (species), habitat area (ha)
Report explanation	(1) This table is compiled based on the basic status statement of blue carbon resources and does not exist independently; (2) Due to differences in unit attributes, each functional indicator does not support horizontal aggregation and only reflects the initial, final, and changes of a single function; (3) The "period change amount" does not subdivide "natural factors/human factors" temporarily, and "notes on change reasons" can be supplemented according to monitoring data; (4) The accounting object is the complete blue carbon ecosystem; (5) The ecosystem service functions in the table are only examples and do not cover all.			

TABLE 4 Variables List.

Symbol	Description
Sbcs	Seagrass bed carbon stock from Baseline Status Statement
Ctmp	Carbon trading market price
Ma	Mangrove area from Spatial Coverage Statement
Celtp	Coastal ecological land transfer price
Iaisba	Increase in aquaculture income within seagrass bed area
Psr	Profit sharing ratio
Tmcs	Tidal marsh carbon stock
Tmsiov	Tidal marsh salt industry output value
Ecc	Ecological contribution coefficient
Acpq	Accounting based on corresponding physical quantities (carbon stock, area)
Ampim	Applicable market price or income method
Acs	Annual carbon sequestration from ecological function statement
Cersc	Carbon emission reduction substitution cost
Aor	Annual oxygen release
Iopc	Industrial oxygen production cost
Whr	Wave height reduction (from Ecological Function Statement)
Ucccs	Unit construction cost of corresponding seawall
Lpc	Length of protected coastline
Npr	Nitrogen and phosphorus removal (from Ecological Function Statement)
Uocstp	Unit operation cost of sewage treatment plant
Ha	Habitat area (from Regional Coverage Statement)
Espc	Endangered species protection cost

balancing relationship, "Closing Value = Opening Value + Net Value Change during Period", ensures accounting rigor, as the period change reflects the combined effects of variations in both physical stocks and market prices.

Blue carbon resource asset ecological value statement as shown in Table 6 systematically presents the monetized outcomes of key ecological functions, including carbon sequestration and oxygen release, shoreline protection, water purification, and biodiversity maintenance, culminating in a total ecological value. For each function, the table lists the opening value, value change during the period, and closing value. The valuation of each function strictly adheres to the replacement cost principle, with its basis and method clearly stated. For instance, the value of carbon sequestration and oxygen release is calculated from the physical quantity (from the Ecological Function Statement) multiplied by the carbon emission reduction cost and industrial oxygen production cost, respectively. Similarly, the shoreline protection value is derived via the engineering cost method, using the wave attenuation data multiplied by the corresponding seawall construction cost and the protected coastline length. The total ecological value represents the sum of all individual functional values. The closing value is derived from the equation: Closing Value = Opening Value + Net Value Change. This net change reflects both alterations in the physical quantities of ecological stocks and updates to the applied valuation parameters. Through this structured approach, the table provides a systematic and operational framework for quantifying the ecological value of blue carbon assets, thereby supporting scientific assessment and ecosystem service management decisions.

The blue carbon resource asset value summary statement as shown in Table 7 serves as the top-level report by aggregating the total values from Tables 5, 6. It consolidates disparate economic value accounts (e.g., for mangroves, seagrass beds) and ecological value accounts (e.g., for carbon sequestration and oxygen release, wave attenuation and shoreline protection) within a unified monetary framework to calculate the "total value of blue carbon resource assets". The framework of the statement organizes value into two primary accounts, "economic value" and "ecological value", with specific sub-accounts categorized under each. The horizontal axis presents the opening stock, changes during the period, and closing stock. This structure tracks the dynamic integration from categorized values to the total asset value. This accounting system, culminating in the value Summary Statement, not only mirrors the form of corporate financial statements but also establishes a solid asset-side foundation for a complete "blue carbon resource balance sheet", pending future advances in liability accounting. The framework is explicitly designed to be extensible, allowing for the future integration of a "liabilities" section once corresponding accounting standards are established.

4 Discussion

4.1 Architecture for a dual-track physical quantity and monetary value mapping system

The Blue Carbon Balance Sheet employs a dual-accounting framework that integrates physical quantity and monetary value accounts. The physical quantity statements can systematically document ecosystem baseline conditions and ecological functions. In contrast, the monetary value statements perform more than a simple unit conversion; they translate physical indicators into a unified monetary scale using established valuation methods such as carbon pricing and replacement cost. This mapping-based framework retains the granular physical details of ecological attributes while overcoming the aggregation limitations posed by disparate physical units. Consequently, it establishes a foundation for a comprehensive asset assessment.

4.2 Going beyond physical quantities for integrated assessment

The main advantage of monetary valuation is to overcome the inherent limitations of physical quantity data, which resist

TABLE 5 Blue carbon resource asset economic value statement.

Blue carbon ecosystem type/ Value dimension		Opening stock	Change in resource value for the period	Closing stock	Basis and method of value accounting
Mangroves	Carbon sink economic value				Sbcs × Ctmp
	Forest land value				Ma × Celtp
Seagrass beds	Carbon sink economic value				Sbcs × Ctmp
	Aquaculture synergy value				Iaisba × Psr
Tidal Marshes	Carbon sink economic value				Tmcs × Ctmp
	Salt industry synergy value				Tmsiov × Ecc
Other blue carbon ecosystems (e.g., salt flats)					Acpq × Ampim
Total economic value		Sum of opening values	Sum of current period changes	Sum of closing values	——
Report explanation		Closing value stock = Opening value stock + Current period value change. Current period value change includes: (1) Value change caused by carbon stock increase/decrease; (2) Value change caused by fluctuations in carbon price/land price.			

aggregation and comparison due to inconsistent measurement units. The assignment of monetary values allows for three critical functions: (1) Additivity, enabling the summation of heterogeneous values from different ecosystems and functions to quantify the total asset base; (2) Comparability, providing a unified benchmark for analyzing changes in blue carbon resources across regions and over time; and (3) Reconfigurability, allowing for the flexible restructuring of reports to meet specific decision-making needs, thereby offering more targeted information support.

4.3 Existing challenges and future directions

Current research confronts several critical challenges. Firstly, the liability accounting framework remains underdeveloped, requiring clear definitions for restoration obligations arising from anthropogenic damage, as well as standardized methods for their measurement and reporting. Secondly, existing accounting methods lack the adaptability needed for mobile ecosystems, creating an urgent

TABLE 6 Blue carbon resource asset ecological value statement.

Blue carbon ecological function type/Value dimension		Opening functional stock	Net change in resources during the period	Closing functional stock	Basis and method of value accounting
Carbon sequestration and oxygen release function	Carbon sequestration value				Acs × Cersc
	Oxygen release value				Aor × Iopc
Wave attenuation and coast protection function					Whr × Uccc × Lpc
Water purification function					Npr × Uocstp
Biodiversity maintenance function					Ha × Espc
Total ecological value		Sum of opening values	Sum of current period changes	Sum of closing values	——
Report explanation		Closing value stock = Opening value stock + Current period value change. Current period value change includes: (1) Value change caused by increase/decrease in ecological function quantity; (2) Adjustment of accounting parameters.			

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TABLE 7 Blue carbon resource asset value summary statement. .

Value account category/Value dimension	Opening value stock	Current period value change	Closing value stock	Data source
1. Blue carbon economic value account	Opening "total economic value" in Table 5	Current period "total economic value" in Table 5	Closing "total economic value" in Table 5	Table 5 Blue carbon resource asset economic value statement
1.1Mangrove economic value	Corresponding opening value in Table 5	Corresponding current period change in Table 5	Corresponding closing value in Table 5	——
1.2Seagrass bed economic value	Corresponding opening value in Table 5	Corresponding current period change in Table 5	Corresponding closing value in Table 5	——
1.3Tidal marsh economic value	Corresponding opening value in Table 5	Corresponding current period change in Table 5	Corresponding closing value in Table 5	——
1.4Economic value of other blue carbon ecosystems	Corresponding opening value in Table 5	Corresponding current period change in Table 5	Corresponding closing value in Table 5	——
2. Blue carbon ecological value account	Opening "total ecological value" in Table 6	Current period "total ecological value" in Table 6	Closing "total ecological value" in Table 6	Table 6 Blue carbon resource asset ecological value statement
2.1Carbon sequestration and oxygen release value	Corresponding opening value in Table 6	Corresponding current period change in Table 6	Corresponding closing value in Table 6	——
2.2Wave attenuation and coast protection value	Corresponding opening value in Table 6	Corresponding current period change in Table 6	Corresponding closing value in Table 6	——
2.3Water purification value	Corresponding opening value in Table 6	Corresponding current period change in Table 6	Corresponding closing value in Table 6	——
2.4Biodiversity maintenance value	Corresponding opening value in Table 6	Corresponding Current period change in Table 6	Corresponding closing Value in Table 6	——
Total blue carbon resource asset value	Opening value of "economic value account" + Opening value of "ecological value account"	Current period change of "economic value account" + Current period change of "ecological value account"	Closing Value of "economic value account" + Final value of "ecological value account"	——
Report explanation	(1) This table is the core summary statement of blue carbon value statements, reflecting the total value of blue carbon assets in a unified monetary unit; (2) The "blue carbon liability" column is temporarily not included and can be added on the right side after the liability accounting standards are clarified; (3) The current period value change shall be accompanied by detailed explanations.			

need for dynamic boundary accounting and cross-scale integration approaches. Finally, the underlying data foundation is inadequate, underscoring the necessity to establish authoritative valuation standards and to construct a unified, high-quality blue carbon database through interdisciplinary collaboration to support robust balance sheet compilation.

Future research must address the fundamental challenges of ambiguous liability attribution and poorly defined property rights regimes in blue carbon ecosystems. The current lack of clarity in property rights significantly impedes sustainable development. Given that blue carbon resources constitute public goods, it is imperative to clearly identify legitimate rights-holders in accordance with core principles of property rights protection. Therefore, subsequent studies should prioritize the elaboration of precise legal definitions, the delineation of entitled entities, and the clarification of liability boundaries. Resolving these legal uncertainties is essential for accurately determining the liability scope of blue carbon resources. Such progress is indispensable for constructing credible natural capital balance sheets and establishing a transparent blue carbon trading framework. Ultimately, these efforts will lay the institutional groundwork for realizing the full ecological and economic potential of blue carbon ecosystems.

5 Conclusion

1. To address the current limitations in blue carbon resource accounting, this study systematically develops a comprehensive framework for compiling and reporting a blue carbon resource balance sheet. The framework is characterized by conceptual clarity, methodological

feasibility, and a complete suite of reporting statements. The main conclusions and contributions are as follows:

2. This study systematically defines the scope and boundaries of blue carbon resource assets, liabilities, and net assets. It establishes a multi-tiered reporting entity system that integrates both macro and micro levels, thereby providing a unified conceptual cornerstone for the accounting process.
3. An innovative, two-stage compilation approach was developed, which prioritizes physical quantities before monetary valuation. The resulting reporting system achieves comprehensive coverage, spanning from baseline resource physical quantities to the quantification of ecological service functions, and finally integrating both economic and ecological monetary values. This effectively overcomes the inherent limitations of physical data regarding aggregation and comparability.

The study provides specific implementation guidance for data collection, categorical accounting, and statement generation, thereby translating the theoretical framework into practice. This operational pathway enhances practical applicability and offers a clear roadmap for regional pilot implementation and eventual institutionalization.

Although this study proposes a novel theoretical framework, the operationalization of the Blue Carbon Resource Balance Sheet still faces several challenges. Future research should address these by focusing on the refinement of liability accounting standards, the development of robust accounting methodologies for mobile ecosystems, and the establishment of authoritative valuation standards and unified databases through interdisciplinary collaboration. Advancing these areas is crucial to solidifying the balance sheet's role as a powerful tool for safeguarding marine ecological security and fostering a sustainable blue economy.

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

PLu: Writing – review & editing, Conceptualization, Methodology, Writing – original draft, Formal Analysis. YL: Conceptualization, Writing – review & editing, Formal Analysis. PLi: Writing – review & editing, Visualization, Formal Analysis.

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