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Unlocking the potential of ocean carbon sinks: opportunities and challenges for China's development

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As global climate change intensifies, the ocean carbon sink has become a crucial natural mechanism for the international community to mitigate and adapt to climate change, owing to its vast carbon storage capacity and continuous absorption capabilities. China has a wealth of blue carbon ecosystems and recognizes the significant potential of ocean carbon sinks in addressing climate change. Currently, China is incorporating the development of blue carbon into its national strategic development plans. Through policy guidance, scientific and technological support, and pilot demonstrations, the country is actively exploring pathways for the protection, restoration, and sustainable use of blue carbon ecosystems. However, issues such as marine habitat degradation, the absence of specific domestic legislation, and an incomplete standards system for ocean carbon sinks are constraining the effectiveness and market-based development of China's carbon sinks. To this end, this study proposes that China should actively promote the restoration of marine ecosystems, strengthen domestic legislation for carbon sink trading, and advance the clarification of property rights and the refinement of market rules. At the same time, China should deepen multi-level international cooperation and accelerate the development of a marine carbon sink standard system with Chinese characteristics that aligns with international standards. Through the synergistic advancement of institutions, technology, and cooperation, the full ecological and economic value of ocean carbon sinks can be unlocked, providing robust support for China to achieve its "dual carbon" goals and participate in global climate governance.

KEYWORDS

ocean carbon sink, climate change, carbon sink trading, international cooperation, China

1 Introduction

Since the Industrial Revolution, the escalating emissions of greenhouse gases, such as carbon dioxide, have exacerbated the global climate change situation. The resulting meteorological disasters threaten the sustainable development of human society. Consequently, how to address the global climate issue has become a topic of significant concern and heated debate within the international community (Jiao, 2021). The ocean, which stores 93% of the Earth's carbon dioxide, absorbs approximately 30% of the anthropogenic CO₂ emitted into the atmosphere annually, owing to its vast capacity for carbon absorption and sequestration. Functioning as a “regulator” within the global climate system, the ocean's fundamental role in the carbon cycle profoundly influences the course of global climate change (Nellemann et al., 2009).

Guided by its “Dual Carbon” goals, and capitalizing on its rich marine ecological resources and an increasingly sophisticated policy framework, China has made active progress in ocean carbon sink restoration, trading pilots, and the development of accounting methodologies. Although China has made initial progress in the protection and utilization of ocean carbon sinks, the further release of their potential still faces many practical difficulties. On the one hand, problems such as the degradation of marine ecosystems, marine pollution, and over-exploitation have weakened the function of these carbon sinks. On the other hand, the market-oriented development of carbon sinks is in urgent need of institutional guarantees. Existing research, however, has mostly focused on the ecological functions and scientific mechanisms of ocean carbon sinks, with a notable lack of systematic discussion on integrating China's macro-level planning for ocean carbon sink development with the construction of its legal and institutional framework. Against the backdrop of the growing integration of global climate governance and sustainable ocean use, establishing a scientifically sound and comprehensive legal and policy framework for ocean carbon sinks is not only crucial for fulfilling China's climate commitments but is also integral to the global carbon neutrality process. To achieve these objectives, this study adopts a qualitative research approach based on document analysis and policy analysis. It systematically reviews international legal instruments, national policy documents, and scientific literature on ocean carbon sinks to clarify the conceptual framework and ecological mechanisms. In addition, a comparative policy analysis is employed to examine China's evolving regulatory and institutional arrangements in light of international practices, highlighting both opportunities and constraints. This methodology allows for a comprehensive evaluation that integrates legal, ecological, and policy dimensions, providing a robust foundation for the proposed pathways for China's ocean carbon sink development.

2 The mechanism of ocean carbon sinks in addressing climate change

In 1992, the Intergovernmental Negotiating Committee reached an agreement on the United Nations Framework Convention on

Climate Change (UNFCCC). This Convention, the first legally binding multilateral treaty adopted by the international community to address climate change, laid the cornerstone for global climate governance. The UNFCCC first introduced the concept of a “sink”, defining it as any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere (Li et al., 2010). Based on the above explanation, a “carbon sink” refers to any process, activity, or mechanism that removes carbon dioxide from the atmosphere.

The scope of carbon sinks is extensive, with terrestrial and ocean carbon sinks constituting the most significant natural sinks in the Earth's ecosystem (Tao et al., 2001). An ocean carbon sink refers to the process by which marine activities and organisms absorb carbon dioxide from the atmosphere, storing and sequestering it in the ocean. Compared to terrestrial carbon sinks, ocean carbon sinks have advantages in both quantity and efficiency. On the one hand, the ocean is the largest carbon sink on Earth, storing 93% of the world's circulating carbon dioxide, totaling approximately 40 trillion tons. Its carbon storage is 53 times that of the atmosphere and 20 times that of terrestrial carbon storage. The ocean absorbs and stores about 30% of the carbon dioxide emitted into the atmosphere by human activities each year (approximately 7.3 GtCO₂). On the other hand, the effective cycle of terrestrial carbon sinks is typically only a few decades, whereas ocean carbon sinks can remain stable for hundreds to thousands of years, thus possessing greater longevity and stability, making them a carbon sink system with immense potential. In 2009, the report *Blue Carbon: The Role of Healthy Oceans in Binding Carbon*, jointly published by the United Nations Environment Programme, the Food and Agriculture Organization of the United Nations, and the Intergovernmental Oceanographic Commission, confirmed the important role and critical position of the ocean in global climate change and the carbon cycle (UN, 2009).

2.1 The biochemical mechanism of ocean carbon sinks

Nature-based solutions to climate change are one of the most cost-effective ways (Howard et al., 2023). Driven by the dual goals of economic development and addressing climate change, the international community is re-examining the oceans, considering nature-based solutions for climate change mitigation and adaptation that are centered on the marine environment (Zhang et al., 2024). With its capacity for carbon storage and its continuous ability to absorb carbon, the ocean effectively slows the rise of greenhouse gas concentrations in the atmosphere.

First, coastal wetland ecosystems (mangroves, salt marshes, and seagrass beds), though covering a small area, possess a carbon sequestration efficiency per unit area significantly higher than terrestrial ecosystems. Their sequestration capacity is approximately 10 times that of forests and 290 times that of grasslands (Mao et al., 2023). More critically, these ecosystems not only rapidly absorb atmospheric carbon dioxide but also

sequester organic carbon in their soils and sediments for the long term through deposition, forming carbon reservoirs that last for hundreds to thousands of years, making them highly effective natural “carbon capture and storage” systems. Secondly, microorganisms (such as phytoplankton and bacteria), which account for over 90% of marine biomass, convert labile organic carbon into refractory dissolved organic carbon (RDOC) through the “Microbial Carbon Pump” (MCP). This process forms a carbon pool of approximately 650 billion metric tons that can be stored in the deep sea for about 5,000 years (Li et al., 2010). Thirdly, the amount of carbon and nitrogen phytoplankton fix annually exceeds the total for all terrestrial plants combined. After phytoplankton are consumed by fish and other organisms through the food web, some carbon is released back into the water column via respiration. However, the particulate organic carbon (POC) formed from their sinking bodies, excretions, and other detritus is transported from the surface ocean to the deep sea via the “biological pump” mechanism, where it is deposited and sequestered for the long term (Li et al., 2018). This continuous process of “carbon sinking” is a core natural mechanism that inhibits the rapid increase of atmospheric CO₂ concentrations and mitigates the greenhouse effect. Deep-sea carbon sequestration is of fundamental importance for regulating the Earth’s long-term carbon cycle and climate stability and is an indispensable part of closing the global carbon cycle.

2.2 The ocean carbon sink as a physical buffer for climate change

The migration and redistribution of carbon within the ocean are not solely dependent on biochemical pathways; a series of physical processes also drive carbon transport. On one hand, carbon dioxide reacts with seawater to form bicarbonate and carbonate ions, transporting it from the ocean surface to its interior in the form of dissolved inorganic carbon (Zhang et al., 2020). On the other hand, turbulent mixing and advection drive the large-scale vertical and horizontal transport of carbon. Carbon dioxide from low-latitude oceans is transported to high-latitude oceans via currents; there, the colder, denser water sinks, carrying the CO₂ into the deep sea, where it enters a carbon cycle on a millennial timescale (Sabine et al., 2004). Furthermore, gas exchange at the air-sea interface is governed by concentration gradients, enabling the bi-directional diffusion of CO₂ between the ocean and the atmosphere. Heat flux exchange at the sea surface directly influences the ocean’s capacity to absorb and release CO₂ by altering seawater temperature and, consequently, solubility. These coupled physical and chemical processes constitute the core mechanism of ocean carbon transport, allowing the ocean to function as a stabilizer in the global carbon cycle. Notably, leveraging its immense heat capacity, the ocean has absorbed not only excess CO₂ but also approximately 90% of the excess heat generated by global warming, thereby acting as an indispensable “thermal regulator” for the global climate system.

In summary, it is precisely because of the vast carbon storage capacity, continuous carbon absorption efficiency, and significant

climate-buffering function of ocean carbon sinks that most coastal countries, including China, view their development as a crucial strategy for achieving carbon neutrality goals and addressing climate change. Currently, China has clearly pledged to achieve peak carbon emissions before 2030 and carbon neutrality before 2060. However, while existing emission reduction pathways have achieved some success in energy transition and industrial restructuring, relying solely on these traditional methods will make it difficult to fully deliver on the “dual carbon” pledge, due to constraints from multiple factors such as the country’s stage of economic development, energy structure, and technological level. Ocean carbon sinks, as a natural and stable “negative emissions” pathway, offer China a path that emphasizes both emission reduction and sink enhancement.

China’s continental coastline stretches for 18,000 kilometers, making it one of the few countries in the world that is home to all three major coastal blue carbon ecosystems: mangroves, seagrass beds, and salt marshes. These unique natural endowments have provided China with rich and high-quality ocean carbon sink storage areas, laying a solid foundation for their development. Developing ocean carbon sinks can not only expand the pathway to carbon neutrality in the long run and generate significant co-benefits for ecological restoration and biodiversity protection, but this nature-based solution is also more sustainable, economical, and ecologically sound compared to high-cost, high-risk environmental technologies like artificial carbon capture and storage. Therefore, scientifically assessing the functional potential of the nation’s ocean carbon sinks, establishing a systematic framework for monitoring, accounting, and evaluation, and effectively protecting and restoring ocean carbon sink ecosystems are not only crucial guarantees for China to achieve its “dual carbon” goals but also an inevitable choice for safeguarding national ecological security and enhancing climate resilience.

3 The policy evolution of China’s ocean carbon sink development

In recent years, ocean carbon sinks have been incorporated into China’s national strategic planning, and related policies and implementation efforts are accelerating. This favorable policy environment offers broad prospects for China to fully realize the potential of its ocean carbon sinks and to expand the scope for blue carbon development.

In the early stages of China’s ocean carbon sink policy development, its focus was on the introduction of the concept and ecological restoration. In 2012, the State Council’s “National 12th Five-Year Plan for Marine Economic Development” was the first national-level document to explicitly propose the development of ocean carbon sinks, marking the gradual incorporation of ocean carbon sinks into national strategic development planning. In 2013, the State Oceanic Administration’s own 12th Five-Year Plan identified the restoration and protection of ecosystems like mangroves, salt marshes, and coastal wetlands as a priority area for the first time (The State Council of the People’s Republic of

China, 2013). Although these policies did not elaborate on the specific content of ocean carbon sink development, their significance lies in establishing the status of ocean carbon sinks in national climate change governance and ecological civilization construction, laying a policy foundation for subsequent institutional development and practical exploration.

As international attention to ocean carbon sinks has increased and related scientific research has continued to make breakthroughs, China's ocean carbon sink policy has begun to shift towards systematic construction and practical application. In 2016, the State Council's "Work Plan for Controlling Greenhouse Gas Emissions" designated the "exploration of pilot projects for carbon sinks in marine and other ecosystems and the promotion of pilot zones for marine carbon sequestration" as key objectives, and subsequently launched a pilot program for blue carbon ecosystem sinks (The State Council of the People's Republic of China, 2016). In 2017, the National Development and Reform Commission and the former State Oceanic Administration jointly released the "Vision for Maritime Cooperation under the Belt and Road Initiative". This document proposed international cooperation on ocean carbon sinks with other Belt and Road countries, focusing on monitoring blue carbon ecosystems, developing standards and research, and collaborating on marine-based approaches to climate change, with the shared goal of creating a Maritime Silk Road blue carbon market (The State Council of the People's Republic of China, 2017). In 2019, the "Implementation Plan for the National Ecological Civilization Pilot Zone (Hainan)", issued by the General Offices of the CPC Central Committee and the State Council, explicitly called for "conducting research on a standard system and trading mechanism for ocean carbon sinks, and exploring the establishment of an international trading platform for ocean carbon sinks" (The State Council of the People's Republic of China, 2019). In 2020, China officially announced its "dual carbon" targets. Later, the country issued further policy documents related to the "dual carbon" goals, including opinions and action plans for carbon peaking, gradually establishing a "1+N" policy framework for achieving carbon peaking and carbon neutrality—a framework that incorporates the development of ocean carbon sinks. All of these policies have further underscored the importance of strengthening the monitoring of ocean carbon sinks, consolidating the carbon sink capacity of marine ecosystems, improving the relevant laws and policies for ecosystem carbon sinks, and promoting the realization of the value of ecological products (Dong et al., 2024).

At the same time, China's current ocean carbon sink policy has linked science with policy and translated theoretical research into practical outcomes. On January 1, 2023, the Ocean Carbon Sink Accounting Method, compiled by the First Institute of Oceanography of the Ministry of Natural Resources, was officially implemented, marking China's first comprehensive standard for ocean carbon sink accounting. In October 2023, the Ministry of Ecology and Environment released the Methodology for Voluntary Greenhouse Gas Emission Reduction Projects: Mangrove Afforestation (Ministry of Natural Resources of the People's Republic of China, 2023). This methodology was developed

specifically considering the characteristics of China's mangrove resources and restoration projects, addressing two main afforestation approaches: planting on unvegetated tidal flats and planting in retired aquaculture ponds. Driven by national policies, pilot work on China's ocean carbon sink market has advanced steadily. The issuance and implementation of these policy documents provide a high-level basis for local governments to implement the "dual carbon" strategy through the development of ocean carbon sinks. They also offer institutional guidance and significant opportunities for creating mechanisms to internalize the external ecological benefits derived from marine ecosystem restoration and protection, such as carbon sequestration. Under the active guidance and support of a series of national policies, the development of China's ocean carbon sink market is proceeding in an orderly manner.

Furthermore, the development of China's ocean carbon sink policy exhibits a notable characteristic of interaction between central guidance, local pilot projects, and regional policy innovation. This policy development model, which combines both bottom-up and top-down approaches, has both mobilized local enthusiasm and creativity and ensured the effective implementation of the overall national strategy. For example, Shandong Province, guided by the central government and based on its own actual conditions, formulated and promulgated the "Action Plan for Building a Strong Maritime Province." This plan explicitly proposes to actively develop ocean carbon sinks, conduct in-depth research on them, and leverage platforms such as the Yellow and Bohai Seas Blue Carbon Monitoring and Assessment Center and the Sanggou Bay Bivalve and Algae Carbon Sink Laboratory (Shandong Provincial People's Government, 2022). Guangdong Province released the "Guangdong Province Mangrove Carbon Inclusion Methodology" to support the use of ocean carbon sinks in local carbon inclusion offset mechanisms (Department of Ecology and Environment of Guangdong Province, 2023). Hainan, Zhejiang, and other regions have successively issued documents such as the "Hainan Province Marine Ecosystem Carbon Sink Pilot Work Plan (2022–2024)" and the "Zhejiang Province Guidance on Enhancing Marine Carbon Sink Capacity," which set forth clear requirements for exploring methodologies for ocean carbon sink projects and striving for a leading role in the international ocean carbon sink market.

Propelled by the policy framework, various regions have actively engaged in the practice of ocean carbon sink trading, giving rise to a number of representative pilot projects that have accumulated valuable local experience and institutional models for nationwide implementation. In 2021, the "Zhanjiang Mangrove Afforestation Project" in Guangdong Province was officially certified by Verra, a leading standard-setter for climate action and sustainable development, becoming the world's first carbon sink project to meet both the Verified Carbon Standard (VCS) and the Climate, Community & Biodiversity (CCB) Standards. The Zhanjiang Mangrove National Nature Reserve Administration, the Third Institute of Oceanography of the Ministry of Natural Resources, and the Beijing Entrepreneur Environmental Protection Foundation signed a transfer agreement for the project's first 5,880

tons of carbon emission reductions, creating China's first blue carbon trading project ([Provincial Development and Reform Commission of Guangdong, 2021](#)). In 2022, Lianjiang County in Fuzhou City, Fujian Province, successfully completed a transaction of 15,000 tons of marine carbon sinks from aquaculture fisheries. This marked the nation's first marine fishery carbon sink transaction ([Academy of Ocean of China, 2022](#)). In 2023, an online auction was held for carbon assets from a mussel aquaculture carbon sequestration project on Dachen Island in Taizhou, Zhejiang ([Academy of Ocean of China, 2023](#)). In 2024, property rights trading organizations from five cities—Ningbo, Xiamen, Shenzhen, Qingdao, and Dalian—jointly issued an innovation initiative for ocean carbon sink trading in Xiangshan, Zhejiang ([The People's Government of Xiangshan County, 2024](#)).

China's ocean carbon sink policy has evolved from its early stages of simple conceptual introduction and ecological restoration to a more advanced phase of systematic application guidance. It is now closely integrated with multiple domains, including marine environmental protection, climate change response, and economic development, with the overarching goal of comprehensively enhancing the contribution of ocean carbon sinks to achieving the “dual carbon” targets and promoting green, low-carbon, high-quality development. From the national to the local level, China's policy not only maintains unity and coherence in its top-level design but also encourages diverse and innovative exploration through local pilot programs, creating a flexible and practical path that can be optimized with timely feedback.

4 Challenges facing China's ocean carbon sink development

Although China has made significant progress in the field of ocean carbon sinks—leveraging its abundant resources and an increasingly refined policy framework—the realization of its full potential still faces systemic constraints. Currently, the three core and intertwined challenges of marine habitat degradation, the absence of a carbon sink trading mechanism, and a fragmented standards system not only weaken the carbon sequestration efficacy of marine ecosystems but also impede marketization processes and international collaboration.

4.1 Degradation of the marine habitat foundation

Healthy marine ecosystems are the indispensable natural foundation for maintaining and enhancing ocean carbon sink capacity. However, on a global scale, marine ecosystems are facing an unprecedented existential crisis, with their rate of degradation and disappearance significantly surpassing that of other natural ecosystems. Continuous land-based pollution, especially the large-scale discharge of pollutants rich in nutrients like nitrogen and phosphorus, has led to severe eutrophication in nearshore waters. This excess nutrient input abnormally stimulates

the activity of marine microorganisms, accelerating their degradation of Recalcitrant Dissolved Organic Carbon (RDOC), which would otherwise remain stable in the marine environment for long periods. The intensification of this biochemical process causes organic carbon—which should have been sequestered for hundreds to thousands of years—to be prematurely mineralized and decomposed, and then re-released into the atmosphere as carbon dioxide. This not only offsets some of the natural carbon sink benefits but can even transform these areas into new sources of carbon emissions. At the same time, large-scale coastal zone development activities—including the conversion of coastal areas into aquaculture farms, residential zones, and industrial land, as well as the construction of extensive seawalls and the removal of key species like *Salicornia*—have led to the direct and indirect loss of coastal carbon sink habitats. Due to the degradation of these ecosystems, their potential for mitigating climate change and providing other environmental functions has been diminished ([Bandh et al., 2023](#)).

According to statistics, China has lost approximately 9,236–10,059 square kilometers of its three major ecosystems—mangroves, salt marshes, and seagrass beds—since 1950 due to various factors, including land reclamation, pollution from aquaculture, sea-level rise, and coastal engineering ([Zhu and Liu, 2021](#)). Taking mangroves as an example, coastal wetland ecosystems have been severely damaged by the impacts of human activities and global climate change, particularly in tropical coastal regions. Mangroves, which provide vital ecological services, are facing the challenge of a sharp decline in biodiversity. In China, nearly half of all mangrove plant species are in various states of endangerment. The proportion of rare and endangered species among China's mangrove plants is not only far higher than the average for all higher plants in the country but also significantly exceeds the global proportion for true mangrove species ([Sun et al., 2024](#)). In other words, while increasing the quantity of restoration, China must place greater emphasis on the holistic recovery of species diversity and ecosystem integrity. Furthermore, although China has implemented the “Mangrove Protection and Restoration Special Action Plan (2020–2025),” which aims to create and restore 18,800 hectares of mangroves by 2025—by afforesting 9,050 hectares and restoring 9,750 hectares of existing ones—the impact is limited. Even if this goal is met, the annual increase in carbon sinks would only be about 222,000 tons of CO₂, which is a small fraction of the global mangrove carbon sink. A significant gap, therefore, persists between the scale of restoration and the full recovery of ecological functions ([Chen et al., 2021](#)).

Furthermore, ocean carbon sink ecosystems possess unique ecological value, offering co-benefits such as coastal protection and biodiversity conservation. Protecting and restoring these ecosystems is a key area for nature-based solutions to climate change. However, the degradation of the marine habitat foundation directly triggers a “dual carbon loss” effect: On one hand, ecosystem destruction leads not only to the re-release of its long-sequestered carbon back into the atmosphere but also reduces its capacity for further sequestration of atmospheric CO₂ ([Donato et al., 2011](#)). On the other hand, the degradation of marine

ecosystems significantly impairs the adaptability of the ocean carbon sink, permanently weakening the ecosystem's future capacity to continuously absorb and sequester atmospheric carbon dioxide. This results in a degrading trend for overall ocean carbon sink resources. Therefore, the degradation of the foundational marine habitats in China is not only reflected in the quantitative reduction or shrinking scope of marine carbon sink ecosystems but more so in their qualitative decline and functional impairment. This degradation is both the direct cause of the diminished carbon sink capacity and the fundamental issue undermining the marine ecosystem's future ability to adapt to and mitigate climate change.

4.2 Lack of domestic legislation hinders ocean carbon sink trading

Promoting the effective development of ocean carbon sink projects requires the establishment of a sound domestic legal framework. From an institutional construction perspective, creating and improving a trading system for ocean carbon sinks is a key pathway to rationally utilizing blue carbon and leveraging its role in addressing climate change. The market for ocean carbon sink trading is built on the foundation of paid use and transfer of these resources (Lin, 2019). Therefore, the clear definition of property rights for ocean carbon sinks is a prerequisite for these sinks and their related products to enter the market. Issues such as unclear ownership, difficult transferability, the absence of benefit-sharing mechanisms, and ambiguous liability will impede their function in mitigating climate change. Secondly, as a traded commodity, ocean carbon sink products have unique characteristics; their value is susceptible to the dual impacts of fluctuating natural conditions and changing policy environments. A lack of effective risk prevention and control mechanisms will significantly inhibit the enthusiasm of market participants to engage in ocean carbon sink trading. Consequently, accelerating the formulation of carbon sink trading rules, constructing a supporting legal system, and simultaneously establishing a comprehensive supervision and regulatory framework are of irreplaceable importance for ensuring the fairness and transparency of the trading process and maintaining the healthy operation of the market.

Currently, several countries have already undertaken comprehensive legislative and institutional efforts. For instance:

- United States: In 2015, the state of Georgia proposed a “Blue Carbon Market Trading Program.” Through state legislation, this initiative integrated mangrove coastal ecosystems into the state's carbon offset registry, thereby clarifying the legal status of ocean carbon sinks. It also mandated the creation of blue carbon accounting standards tailored to the state's mangrove ecosystems for the purpose of issuing carbon offset credits, and these standards were given compulsory legal force through legislation.
- Singapore: In 2019, Singapore enacted the Carbon Pricing Act, which requires taxpayers to purchase carbon credits from the National Environment Agency (NEA) to pay their annual carbon tax. The Act not only designates the NEA as the competent authority for international carbon credit trading but also stipulates detailed provisions for registration and payment systems, information disclosure, and penalties for violations.
- Australia: Australia has not only integrated ocean carbon sinks into its carbon credit trading market through legislation under its carbon crediting framework but has also established a comprehensive regulatory system. Furthermore, Australia initiated the “International Partnership for Blue Carbon” to lead global development and cooperation in the field of blue carbon.

In contrast, China's ocean carbon sink trading is still in its nascent stages, with current domestic laws and regulations lacking clauses that directly regulate such activities. While the State Council has issued numerous normative documents related to ocean carbon sinks, legal frameworks like the Marine Environmental Protection Law of the People's Republic of China and the Regulations on the Administration of the Prevention and Control of Pollution to the Marine Environment by Marine Engineering Construction Projects primarily focus on general marine environmental protection and pollution control. They lack systematic regulations specifically for ocean carbon sinks. Furthermore, the domestic transposition of international treaties is insufficient, creating clear obstacles in legal rule adaptation (Zhang and Liu, 2024). Consequently, China still lacks dedicated legislative support for legal mechanisms aimed at consolidating and enhancing the capacity of ocean carbon sink ecosystems and realizing their ecological value. Although some regions have launched pilot trading programs, the absence of mandatory national standards and legal guarantees for ocean carbon sink projects, coupled with unclear property rights, makes it difficult to establish the trading legitimacy of these products in a unified national market. Moreover, quantifying ocean carbon sinks relies on standardized, scientific methodologies and requires long-term monitoring and independent verification by professional institutions. The absence of a legal framework for supervision can lead to multiple difficulties. If an ocean carbon sink resource is damaged, assessing the actual loss and recovery costs becomes extremely difficult. Not only is it hard to clarify liability, but the ecological damage is also challenging to effectively remedy (Wang, 2022).

Overall, China's current efforts to build a carbon sink trading system face several legal gaps, primarily: ambiguous property rights, an incomplete market system, a lack of supervision mechanisms, and weak international integration. Compared to countries like the United States, Singapore, and Australia, which have already developed relatively mature carbon sink legislation and trading systems, China's challenge is not just to fill these legal voids but to achieve a holistic leap from “top-level legislation” to “nationwide marketization” and “international alignment.”

4.3 Incomplete ocean carbon sink standard system

The recognition of marine ecosystems as a significant carbon sink mechanism by the international community is a relatively recent development. However, due to factors such as the late start of research and high scientific complexity, the international community has yet to form unified international standards for the measurement and monitoring of ocean carbon sinks. This deficiency leads researchers to use varied methods when measuring these sinks, resulting in a lack of consistency in parameter estimation and, consequently, significant discrepancies in the final calculations (Wang and Xiao, 2013). For example, different methodologies yield substantial deviations in the assessment of key data, such as the global coverage of ocean carbon sinks, carbon storage volumes, growth parameters, and carbon capture efficiency, which in turn impairs the accurate quantification of their potential. This uncertainty stems not only from technical challenges but is also closely related to barriers to international data sharing. In many countries, licensing restrictions or incompatible development methodologies make it difficult for ocean carbon sink databases to be interoperable, severely hindering transnational data exchange and collaboration. In the long run, the fragmentation of ocean carbon sink accounting data will erode the real-world support for international standards, thereby delaying the progress of international cooperation and constraining the effective implementation of global strategies to combat climate change (Li and Li, 2022).

In recent years, the development of domestic standards in China has shown initial progress. In 2021, the marine industry standard Carbon Sink Measurement Method for Cultured Macroalgae and Bivalves—Carbon Stock Change Method (HY/T 0305-2021) was officially released. In the same year, after two years of exploration, Shenzhen compiled the nation's first Ocean Carbon Sink Accounting Guide. This guide, referencing the IPCC (2006) and other international frameworks and tailored to Shenzhen's local resource characteristics, established an accounting system covering seven tradable carbon sink types (including mangroves, salt marshes, shellfish, algae, and seagrass) and eleven carbon sink indicators, providing important theoretical support for the capitalization of marine ecological resources in southern China. In September 2022, the Ministry of Natural Resources released the first comprehensive ocean carbon sink accounting industry standard, the Ocean Carbon Sink Accounting Method (HY/T 0349-2022), which filled a domestic gap and clarified the quantification mechanisms for multiple carbon sink types, including mangroves, salt marshes, and phytoplankton (Liu et al., 2025). Furthermore, innovation at the local and institutional levels is also accelerating. For example, the "Technical Guide for Carbon Sink Measurement and Monitoring of Kelp Cultivation Projects," developed by the Weihai Institute of Blue Economy, has passed the review for establishment as an association standard, aiming to solve the challenge of long-cycle measurement for kelp carbon sinks.

Despite this, China's domestic standards system still faces multiple challenges: Firstly, high complexity in monitoring and

accounting. Different types of carbon sinks vary significantly in their carbon fixation efficiency, storage duration, and sedimentation mechanisms. For example, fishery carbon sinks have not yet been fully incorporated into national standards due to disputes over their carbon sequestration duration. Furthermore, insufficient research into mechanisms like the microbial carbon pump (MCP) affects the accuracy and scalability of accounting, making it difficult to scientifically assess and fully utilize the potential of some carbon sinks. Secondly, incomplete coverage of existing standards. Although groundbreaking, existing standards like the Ocean Carbon Sink Accounting Methods cannot fully resolve the monitoring challenges for diverse types of carbon sinks. The carbon sink mechanisms of different marine organisms, such as algae and shellfish, vary greatly, making it difficult for a unified accounting framework to cover all scenarios. Thirdly, weak data foundation and ambiguous resource information. China lacks nationwide survey data on its ocean carbon sink resources. Information regarding carbon stocks, their distribution, and ownership rights remains unclear. This ambiguity hinders the creation of a closed-loop capitalization process and, at the same time, complicates the determination of ecological liability and the enforcement of legal supervision. Lastly, need for stronger international alignment. As the field of ocean carbon sinks develops globally, the international community is gradually establishing standards and trading rules. A failure to effectively align with this future international standards system will constrain the legitimacy, credibility, and trading potential of domestic carbon sink projects in the international market. It will also diminish China's institutional influence and voice in global blue carbon cooperation. Therefore, as China advances its "dual carbon" goals and deepens its understanding of ocean carbon sinks, establishing a scientific, comprehensive, and internationally compatible domestic standards system has become imperative.

5 Pathways for promoting China's ocean carbon sink development

5.1 Actively promoting marine ecosystem restoration

Strengthening marine pollution prevention and control is a critical measure for safeguarding the functionality of ocean carbon sink ecosystems. Currently, various forms of environmental pollution pose a severe threat to the ecological health of coastal wetlands and nearshore marine environments, which in turn significantly weakens their carbon sequestration capacity as vital natural carbon reservoirs. Therefore, achieving stable growth in ocean carbon sinks must be based on the fundamental premise of restoring and maintaining healthy marine ecosystems. To effectively curb this vicious cycle, it is essential to establish and reinforce a comprehensive pollution governance system characterized by integrated land-sea management and systemic coordination.

Firstly, it is necessary to advance the establishment of a total pollutant load control system for discharges into the sea. This

involves using key estuaries and bays as focal points to create a watershed-wide pollutant transfer and accountability mechanism, which clearly defines the types, total amounts, concentration limits, and responsibilities for pollutants entering the sea at cross-regional monitoring points. For coastal industrial parks, management based on “value and volume limits” tied to environmental carrying capacity should be implemented to create emission reduction demonstration zones. Concurrently, supervision of direct-to-sea pollution sources must be intensified, prohibiting the direct discharge of substandard wastewater. A “list-based,” differentiated governance approach should be applied to rivers flowing into the sea, ensuring that major rivers consistently eliminate water quality worse than Grade V and reducing total nitrogen concentrations in provincially-monitored and higher-level rivers. This will alleviate the marine nitrogen load at its source and prevent the offsetting of carbon sink benefits caused by eutrophication.

Secondly, the ecological restoration and protection of coastal wetlands must be enhanced to consolidate existing coastal ecological carbon stocks and expand new carbon sink increments. It is imperative to strictly implement the marine ecological red line system, incorporating sensitive and fragile ecosystems like coastal wetlands into these zones for mandatory protection and management. Destructive development activities must be strictly prohibited to prevent the loss of carbon sink functions. At the same time, efforts should be increased for vegetation restoration on difficult terrains and the ecological rehabilitation of eroded coastlines. “Blue Bay” remediation initiatives should be carried out, with a special focus on intensifying the restoration and protection of typical carbon sink ecosystems, such as mangroves and seagrass beds, to enhance the ocean’s overall carbon sink capacity (McLeod et al., 2011).

5.2 Improving domestic legislation for ocean carbon sink trading

Limited by insufficient foundational research and a lack of complete assessment standards and methodologies, ocean carbon sinks have not yet been fully integrated into the national unified carbon trading market. In practice, trading remains dominated by local pilots and non-standardized exploration (Gan et al., 2016). Although forestry carbon sinks and ocean carbon sinks are both types based on natural ecosystems—relying on the natural carbon sequestration functions of vegetation or biological communities to achieve greenhouse gas removal—forestry carbon sinks have already been incorporated into the national unified carbon trading market. Therefore, the forestry model provides considerable experience for ocean carbon sink trading to draw upon, especially regarding the three-stage project development process: project filing, emission reduction filing, and listed trading. However, a fundamental difference exists between forestry and ocean carbon sink trading in terms of their property rights foundations and legal status. The property rights system for forestry carbon sinks is relatively clear. Chinese law stipulates that forest land ownership belongs to the state or collectives, and

through forest tenure reform, the rights to use the land and own the trees are contracted to farming households (Liu and Li, 2014). The forestry carbon sink right, as an intangible asset attached to the trees, can be separated from the forest resource after verification to form a tradable carbon emission reduction credit, possessing quasi-real-right attributes.

In contrast, ocean carbon sinks face a property rights definition dilemma. The ocean primarily falls under the jurisdiction of public law and is not an object of private property rights. Neither the Constitution nor the Civil Code lists the ocean as an object of ownership, and the Law on the Administration of Sea Area Use does not clarify the ownership of ocean carbon sinks. This legal vacuum creates fundamental obstacles for trading: On one hand, the ocean as a natural resource legally belongs to the state, but direct state participation in trading raises concerns about public power interfering with the market. On the other hand, although sea area use right holders could assert claims to ocean carbon sink benefits, they lack direct legal authorization. It is therefore necessary to rationally optimize the system by clarifying the legal nature of ocean carbon sinks, improving the institutional design for sink enhancement technologies, appropriately leveraging a proactive judicial role, and ensuring robust market rules (Feng and Liao, 2023).

Therefore, drawing on the model of the forestry carbon sink trading system, China should refine the market trading rules for ocean carbon sinks through local and special legislation. Building on these local or specialized pilot programs, the ultimate goal is to establish a sound and nationally unified legal framework for the trading of ocean carbon sinks, which clarifies property rights ownership and resolves issues concerning the qualifications of trading entities, the legal status of the traded asset, and the choice of trading models. This will ensure that there is a legal basis for dispute resolution and that trading parties can promptly seek effective remedies and have a clear basis for liability. Furthermore, a comprehensive information disclosure system for the ocean carbon sink market must be established to guarantee transparency in all trading links (Bai and Hu, 2021). To ensure that trading proceeds in a legal and compliant manner, a dedicated platform or a specialized governing body should be created to ensure the fair and just allocation and management of ocean carbon sinks. This platform would provide real-time monitoring of the environmental and economic benefits generated by trading and dynamically refine legal and institutional designs based on market performance, thereby guaranteeing the orderly operation of the market.

5.3 A dual-track approach to promoting domestic adaptation and international alignment

Advancing the development of ocean carbon sinks requires a synergistic, two-pronged approach, operating at both the domestic and international levels (Mao et al., 2024). This entails establishing a standardized system that is aligned with international norms yet

tailored to China's specific national conditions, while simultaneously integrating actively into the global ocean carbon sink cooperation network to create a collaborative structure defined by interconnectivity and mutual advantages.

On one hand, it is essential to construct a “Chinese-characteristic” ocean carbon sink standards system that is aligned with international norms. This should focus on mature carbon sink types already included in national greenhouse gas inventories by the IPCC—such as mangroves, seagrass beds, and coastal salt marshes—and promote the localization and adaptation of international standards by transforming them to fit China's specific context. This can be achieved by simplifying monitoring methods and reconstructing accounting formulas and reference parameters based on local biogeochemical data, thereby establishing a carbon sink measurement system that is both compliant with international norms and applicable to conditions in China. Concurrently, it is necessary to systematically deepen research into carbon sink mechanisms, guided by the global scientific framework for climate change. This includes strengthening studies on the carbon sequestration processes of ecosystems like mangroves, seagrass beds, and salt marshes, as well as fishery carbon sinks, the marine microbial carbon pump, and the classic biological pump. A key goal is to quantify the sensitivity of these systems to climate stressors, such as warming and acidification, and their corresponding carbon cycle feedbacks. Foundational methodologies for carbon stock surveys, monitoring, and trading accounting standards must be refined, while the development of project-level methodologies should be accelerated. Drawing on the methodological frameworks of international voluntary carbon reduction programs, priority should be given to formulating technical protocols for the development of blue carbon projects applicable to China's maritime domains. These protocols must clearly define core rules, including project boundary definition, additionality assessment, and carbon leakage prevention, in order to provide the certification basis required for ocean carbon sinks to enter both domestic and international carbon trading markets.

On the other hand, it is crucial to engage deeply in major international projects related to global ocean carbon sinks, fostering cooperation with other nations to jointly address global change and protect the environment. To advance its international cooperation on ocean carbon sinks, China should fully activate the strategic fulcrum role of existing multilateral mechanisms, such as the Belt and Road Initiative International Green Development Coalition. Leveraging these platforms, China can continuously broaden the dimensions of its cooperation, actively forge new bilateral, multilateral, and regional partnerships, and simultaneously strengthen its collaborative networks with the international academic community (Yu and Wang, 2023). China should proactively participate in international conferences, expand discussions on global ocean carbon sink topics, and join relevant international working groups. By promoting its own concepts and practical achievements, China can increase its participation and strengthen its voice (discourse power) in the field, while actively driving original innovation in ocean carbon sink theory, assessment methods, and sink-enhancement technologies (Zhao and Hu,

2019). China should seize the current strategic window of opportunity in global ocean carbon sink research to systematically enhance its capacity for the development and application of these resources through multi-level international cooperation.

6 Conclusion

Against the backdrop of deepening global climate governance, the value of ocean carbon sinks as a critical nature-based mechanism for addressing the climate crisis is becoming increasingly prominent. By examining the fundamental concepts and mechanisms of ocean carbon sinks, this article has clarified their significant contribution to both the mitigation of and adaptation to climate change. By examining China's current policies and practices in developing ocean carbon sinks, this article analyzes the severe challenges the country faces—including marine habitat degradation, the absence of domestic legislation, and an incomplete standards system—which constrain the realization of its ocean carbon sink potential. Based on this analysis, the article puts forward several recommendations: strengthening the restoration of coastal ecosystems and pollution control to solidify the natural foundation of the carbon sink; refining the definition of property rights for carbon sinks, as well as the legislation for their trading and supervision, in order to overcome the bottlenecks to marketization; and deepening alignment with international standards and multilateral cooperation. Constructing a collaborative development system that integrates scientific research, legal frameworks, and market operations is of great significance for promoting the sustainable development and application of ocean carbon sink resources.

Data availability statement

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

Author contributions

YW: Data curation, Writing – original draft, Formal Analysis, Writing – review & editing, Conceptualization. YB: Methodology, Writing – review & editing, Conceptualization, Writing – original draft, Funding acquisition.

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Conflict of interest

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