frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 08 January 2024
DOI 10.3389/fmars.2023.1226665

OPEN ACCESS

EDITED BY
Lang Xu,
Shanghai Maritime University, China

REVIEWED BY
Guangnian Xiao,
Shanghai Maritime University, China
Yuan-Wei Du,
Yunnan University, China
Chen Ming Bao,
Macau University of Science and Technology, Macao SAR, China

*CORRESPONDENCE
Di Luan
diluansd@163.com
Hongjun Cao
hongjunsd@163.com

RECEIVED 22 May 2023
ACCEPTED 07 December 2023
PUBLISHED 08 January 2024

CITATION
Luan D, Cao H and Qu T (2024) An analysis of the tripartite evolutionary game for building the ecological security barrier in the Bohai Sea under the threshold of land-sea integration.
Front. Mar. Sci. 10:1226665.
doi: 10.3389/fmars.2023.1226665

An analysis of the tripartite evolutionary game for building the ecological security barrier in the Bohai Sea under the threshold of land-sea integration

Di Luan*, Hongjun Cao* and Tongkun Qu

School of Management, Ocean University of China, Qingdao, China

The construction of marine ecological security barriers (MESBs) is fundamental for the sustainable development of the marine ecological environment and of the marine economy, and is an important component of the strategy of land-sea integration. It is difficult to build an effective MESB simply by relying on the power of the government; therefore, to this respect, it is urgent to encourage the multiple participating subjects to work together. This study takes the Bohai Sea as the research object, and uses evolutionary game theory to construct a game model of decision-making behavior among marine enterprises, local governments, and the public in the process of construction of the MESB in the Bohai Sea, so as to explore the strategic stability equilibrium point through the analysis of the interests of the three decision makers, and lay the foundation for promoting this process. The results are as follows: (1) Local government regulation is key to promote the transformation of the Bohai Sea MESB from policy documents to behavior and from goal to practice; moreover, it directly influences whether the main sources of land-based pollution, i.e., marine enterprises, will abandon the traditional approach to production and development and actively promote the construction of the Bohai Sea MESB. (2) The supervision and reporting of the public can be used as a synergistic, auxiliary supervision means. Thanks to the government's publicity and education, the public will develop social awareness of marine ecological security, which in turn will ensure a better public supervision of the behavior of local governments and, thus, promote the active participation of marine enterprises in the MESB in the Bohai Sea. (3) Participation costs, ecological benefits, corporate social image, fines, and other factors are the main factors considered in the strategic choice of marine enterprises, with different factors having different marginal effects at different stages. Finally, this study proposes

effective measures to further clarify the roles and functions of the stakeholders in the construction of the MESB in the Bohai Sea, balance the interests of the game subjects, and provide an effective implementation path for the realization of the "Ocean Power".

KEYWORDS

maritime power, marine ecological security barrier, land-sea integration, stakeholders, evolutionary game

1 Introduction

Since the beginning of the 21st century, with the increase of human needs and the development of marine exploration and exploitation technology, human beings have pushed the exploitation of the ocean to new heights. However, the weak awareness of marine ecological protection and the existence of a backward marine management model have created serious challenges to the marine economy and ecology. According to the "China Marine Disaster Bulletin" issued by the Department of Marine Early Warning and Monitoring of the Ministry of Natural Resources of China in 2021, China's marine disasters were dominated by storm surges, waves and sea ice disasters, which caused a total of 307,087,380,000 yuan (RMB) in direct economic losses and 28 deaths and disappearances. Marine ecological security is related not only to the sustainable economic development of coastal areas, but also to national security, as well as to the promotion of the destiny of human communities. To this end, as early as in 1969, the U.S. Stratton Commission published "Our Nation and the Sea", which elevated ocean management to the level of national interest (Armstrong and Ryner, 1980). Afterwards, in the 21st century, the U.S. submitted the Ocean Policy Report "Blueprint for the 21st Century" and the Ocean Action Plan (Singh and Mee, 2008). China has also elevated "Ocean Power" to a national strategy (Mallory et al., 2022). Moreover, China has integrated the comprehensive development and utilization of the marine environment into its strategic planning for the development and utilization of China's national territory, proposing a strategic plan for the integration of sea and land, which is evidence of the weight of ocean management in national security management.

Based on the integrated land-sea perspective, the ocean has become an important supplier of resources for human survival and development; especially, marine fishery resources have become a support to global food and nutrition security (Kong et al., 2021). The rapid economic development not only offers convenience to residents but also brings environmental pollution problems that cannot be ignored (Guangnian et al., 2023).

However, with the expansion of the scope and depth of the human development of the ocean, the fundamental contradiction between the limited supply of marine resources and unlimited human demand has been highlighted, which has eventually manifested itself in a serious marine ecological crisis (Gao L. et al., 2022). The issue of marine ecological security has to be faced by marine development and utilization, and is closely related to human activities (Costanza, 1999; Perry et al., 2010; Lazzari et al., 2020). In view of the complementarity of sea and land resources, the interaction of industries and economic linkages are further strengthened, and the economic, ecological, and social integration of sea and land has become the main theme of land-sea integration (Limin and Ning, 2007). From the perspective of land-sea spatial planning, land-sea integration may be achieved in three ways: through Integrated Coastal Zone Management (ICZM; Smith et al., 2011; Walsh, 2021); through the relationship between overlapping jurisdictions in land-sea spatial planning (Zaucha and Gee, 2019); and through the establishment of a spatial plan for a whole region. This situation has been implemented in California, the UK, and in the Dutch part of the North Sea for land and sea management, respectively (Douvere and Maes, 2009; Ministry of Infrastructure and Environment, 2013; Turner and Essex, 2016). This is proof that land-sea integration, as a national strategic, systematic and comprehensive approach (Bao et al., 2011), aims to ensure the safe and smooth operation of human socio-economic systems (Halpern et al., 2008).

In the Chinese context, the land-sea integration strategy emphasizes the development and protection of the two subsystems of sea and land, and the unified optimization and reconfiguration of various elements such as industry, space, people, resources, and environment, in order to achieve the coordinated development of sea and land (Hou et al., 2022). Under the perspective of sea-land integration strategy, coastal areas, with both marine and terrestrial ecological attributes, have become the key research objects. Using Lianyungang, China, as a case study (Wang et al., 2019), proposed a new approach to construct a system of indicators to evaluate the development of the land-sea coordination (LSC) system, which consists of three subsystems, namely the land-side subsystem, the waterfront subsystem, and the port subsystem, highlighting the important roles of economic development, service systems, and resources and the environment (Wang et al., 2019). In the context of territorial spatial planning, LSC is a spatial governance tool that allows to adjust land and sea development disorder in coastal areas (Cheng et al., 2019). In relation to the integrated management of the

coastal zone of the Chiloé Sea (Chile) (Pinillos et al., 2023), pointed out the importance of five criteria: ecological, socio-economic, cultural, political-administrative, and arbitrary criteria (Pinillos et al., 2023). From the practical perspective of sea-land spatial planning (Yue et al., 2023), identified the optimization measures for land-sea integration in China, as combining top-down rigid government management with bottom-up flexible market mechanisms, data sharing between sea and land, and public and stakeholder participation (Yue et al., 2023). Therefore, the comprehensive development and protection of the marine environment is a complex and systematic activity. Accordingly, the issue of how to rely on the marine ecosystem, the current status and characteristics of the marine ecological environment, the role played by multiple subjects, and the building of a protection mechanism with the dual aim to improve the marine ecological environment and promote the sustainable development of the marine economy, have become the focus of marine management.

This study took the Bohai Sea as the research object, and proposes to build a marine ecological security barrier (MESB) in the Bohai Sea to ensure the supply of ecological services and maintain ecological balance (Cunha and Magalhaes, 2019), so that it can become an important hub for the exchange of biomass, energy, and other circulation resources between the ecosystem and human society (Gao J. et al., 2022). used Tianjin and Shanghai, China, as the subject of their study, to measure LSC in China's coastal areas in relation to four aspects: economic development, resource use, ecological environment, and social livelihood. They found that Tianjin, located in the Bohai Sea region, should continue to focus on ecological protection and the improvement of ecological and environmental quality in the whole region (Gao J. et al., 2022).

As the third pole of China's economic growth, the Bohai Sea region, relying on China's only semi-enclosed inland sea, the Bohai Sea, is currently facing the two challenges of ensuring ecological security and economic development. From an ecological perspective, the Bohai Sea is characterized by strong containment and weak self-purification ability; moreover, it is under severe pressure from land-based discharges (Xin et al., 2019; Wang et al., 2020; Yu et al., 2021), especially from total nitrogen discharges from land-based sources, which affect the water quality (Yang et al., 2022). In addition, according to the Communiqué on the State of China's Marine Ecological Environment in 2021 published by the Chinese Ministry of Ecology and Environment, there are 122 phytoplankton species in the Bohai Sea (including Bohai Bay, Laizhou Bay, and Liaodong Bay), i.e., 31.07% less than in 2020. As a result, the Bohai Sea is facing ecological security problems such as a sharp decline in marine biological resources, sea pollution, and marine ecological damage, which make it an ecologically fragile and environmentally sensitive area (Zhang et al., 2021). Thanks to its strategic location, the Bohai Sea is an important link between the Yellow River Basin ecosystem and the Yellow Sea large marine ecosystem, and a key hub linking Beijing, Tianjin, and Hebei. Moreover, it is important for the revitalization of the Northeast, and in relation to other priorities for national synergistic development. In addition, the Bohai Sea is one of China's three major marine economic zones; in fact, the Bohai Sea Economic Zone is the "engine" of economic development in northern China. Therefore, this study proposes to build an MESB in the Bohai Sea, which will help solve the contradiction between the economic and social development of the Bohai Rim, on the one side, and the carrying capacity of the marine environment, on the other side (Liu et al., 2021). Such MESB will ensure the provision of marine ecological services while taking into account the marine ecological balance. This will be important to promote the construction of a marine ecological civilization and achieve the sustainable development of the maritime economy.

This paper is structured as follows. Section 2 briefly reviews the relevant literature and presents the main contributions of this study. Section 3 elaborates the problem, develops the operational model, defines the parameters' notation, and presents the corresponding assumptions. Section 4 presents the results of a three-party decision replication dynamic analysis and of an analysis of the steady state (ESS) of each party's decision. On this basis, Section 5 verifies the effects of different factors on the evolutionary process using simulations. Finally, Section 6 advances management insights and presents the conclusions, research limitations, and future research directions.

2 Literature review

2.1 Connotation and functional positioning of the MESB

Current research on MESB has focused on two main areas. The first strand adopted a "nature view", focusing on the marine ecosystem itself. Related studies focused mainly on marine resource development and sustainable utilization (Jiang and Li, 2021), Control of carbon emissions from marine activities (Lu et al., 2023), marine ecological and environmental carrying capacity (Wang and Du, 2023), marine environmental resource value measurement (Du and Wang, 2021; Du and Cao, 2022; Du and Li, 2022; Du et al., 2022), ecosystem value (Murphy et al., 2021), marine ecosystem restoration (Xia et al., 2022), ocean ecological compensation mechanisms (Jiang et al., 2019), and comprehensive marine governance (Bakker, 2022; Gacutan et al., 2022; Zhang et al., 2022). These works mainly focused on the unique biological resources and ecological environment characteristics, or on the current status of the ocean, and proposed effective solutions for the development of marine resources, the restoration of the marine ecological environment, and the comprehensive development and utilization of the ocean from a multidisciplinary perspective, including ecology, management, law, and economics.

The second strand of studies focused on the physical properties of the "barrier", arguing that MESBs are a barrier that blocks the view, protecting more than exploiting. Although in 2016, the outline of China's 13th Five-Year Plan introduced it for the first time, and in 2021, the 14th Five-Year Plan specifically applied it in practice, but the concept of ecological security barrier has not been unified (Bai and Cheng, 2016). proposed a system for the construction of MESBs originating from the concepts of limits of growth and sustainable development. Moreover, nowadays, the marine ecological red line system has also become an important

institutional innovation for the construction of MESBs (Bai and Cheng, 2016). By performing a multi-scenario simulation of ecosystem service values for land use optimization in the Sichuan-Yunnan ecological barrier, Li et al. (2021) pointed out that key ecological functional areas play an irreplaceable role in ecosystem restoration and protection (Li et al., 2021; Xue et al., 2022). analyzed the spatial and temporal changes and the influencing factors of soil and water conservation on the Qinghai-Tibet Plateau ecological barrier, arguing that default ecological barriers are actually ecosystems with special protective functions established by the special natural geographical form, with the goal of meeting the ecological requirements for human survival and development (Guo et al., 2021; Xue et al., 2022). claimed that ecological security barriers meet such requirements, can play a role in maintaining ecological security, and are in the state of, or evolving toward, the apex community. Moreover, they play a protective role for the ecological environment of the surrounding areas, and even of the whole country and neighboring countries, and have the ecological effect of guaranteeing ecological security (Guo et al., 2021). These scholars also equated ecological security barriers with the ecological protection red line system, and even proposed to break ecological barriers (Millette et al., 2020). This strengthens the function of isolation and obstruction of ecological barriers in the ecological spatial pattern, while physical obstruction works against the coupled and coordinated development of ecological protection and socio-economic development.

In addition (Cao and Han, 2020), took the Bohai Sea as the research object, pointing out that it is affected by serious water quality pollution, high levels of discharge of pollutants into the sea, ecological environment damage, marine ecosystem degradation, and frequent marine disasters. Furthermore, there are inconsistencies among local management levels in the comprehensive management process. These include the fact that the departments involved are fragmented and it is difficult to form synergies for management; and the lack of innovation in the central and local coordination and management mechanism, as well as in the environmental governance information sharing mechanism. To this respect, these authors proposed feasible measures. First, the establishment of the "Bohai Sea chief system", so as to build a management system and mechanism innovation for the Bohai Sea. Second, the construction of the intelligent Bohai Sea information system, so as to ensure information sharing on the marine ecological security of the Bohai Sea. Third, the establishment of a coordination and linkage platform, so as to improve the regional consultation and governance mechanism of the Bohai Sea. Fourth, to play a leading role in the allocation of marine resources in the market, so as to achieve innovation in the operation mechanism of marine resource allocation. Fifth, a supply-side structural reform, as the driving force to achieve the healthy and sustainable development of the Bohai Sea marine industry (Cao and Xie, 2021).

In summary, the "nature view" is based on the natural properties of marine ecosystems and the exploitation and use of marine ecosystems by humans, while the "barrier view" emphasizes the protection of ecosystems for human survival. Ecological security barriers are a buffer zone between natural ecosystems and human society, while MESBs are the exchange field of liquid substances, such as sea and land resources and energy. Therefore, MESBs need to be based on the marine ecosystem, and to be integrated with the uniqueness of the marine ecological environment and the current situation, with the goal of improving the ecological environment of the Bohai Sea and the sustainable development of human beings, as well as of integrating sea and land from the point of view of marine ecological restoration and recovery, marine resources conservation, ecological environment monitoring and early warning. From a narrow perspective, MESBs are a comprehensive ecological security system that integrates the development of land and sea. Accordingly, the establishment of this system often relies on the "hard" or "physical" measures of comprehensive ecological management projects. From a broader perspective, MESBs are a combination of marine engineering "physical barriers" and "intangible barriers" such as institutions, policies, and protection mechanisms (Cao and Han, 2020), which jointly maintain marine ecological security.

MESBs have five main functions. First, they provide ecological services such as climate regulation and air purification (Kaiwen et al., 2004; Jiake et al., 2011). MESBs are based on the ocean; therefore, they can assume the function of ecological services provision in the marine ecosystem, guarantee human ecological security, meet the needs of human survival and development, and help achieve the harmonious coexistence between humans and nature. Second, MESBs can maintain the biodiversity of sea-land composite ecosystems. MESBs are representative spatial zones, an excessive buffer zone or interlacing area. Therefore, the construction of sea-land ecological security barriers not only can guarantee the biodiversity of the land area, but also is an important tool to maintain marine biodiversity offshore. Third, MESBs can prevent the expansion of ecological threats from land-based sources of pollution. Due to the continuity of ecosystems, resulting from the natural confluence of water, the bays and their river basins become an integrated, interconnected system (Doherty et al., 2014; Li et al., 2014; Granit et al., 2017). As a result, rivers can easily carry pollution from land-based sources into the ocean. MESBs, as a systematic project, can establish a three-dimensional defense system for the sea surface, the ocean, and the seabed through measures such as inlet pollution control, marine pasture, and seabed forests, effectively controlling the expansion of land-based pollution and gradually improving marine water quality. Fourth, MESBs can effectively prevent or reduce the damage caused by marine disasters. Coastal ecosystems ensure wind and wave protection through features such as coral reefs and mangroves, which can effectively enhance the ability of coastal cities to withstand marine hazards. However, the destruction of mangrove systems (Alongi, 2002), coral systems (Hughes et al., 2003), and marsh systems (Kirwan et al., 2010) due to human activities has reduced the resilience of coastal areas to marine hazards. To this respect, MESBs not only contribute to the restoration of the original ecosystem, but also can rely on green ocean technology innovation to improve disaster warning and methodological capabilities, thus reducing the loss from marine disasters such as storm surges (Yi et al., 2021).

There are no doubts about the importance of marine ecological security. For this reason, in practice, the Chinese central

government and the local governments of the three provinces and one city (Shandong Province, Liaoning Province, Hebei Province and Tianjin City) of the Bohai Sea are aware of the importance of the ecological environment, and have launched a number of policies and action plans for the management of the ecological environment of the Bohai Sea, including the "Bohai Sea Action Plan", the "Bohai Sea Comprehensive Improvement Plan", the "Bohai Sea Coastal Resources Management Action Plan", and the "Bohai Sea Environmental Management Strategy". In 2018, the State Council issued the "Action Plan for the Comprehensive Management of the Bohai Sea" and officially opened the comprehensive management action of the Bohai Sea. However, due to the unclear responsibilities of the participating subjects and their conflicting interests, which led to the lack of enthusiasm of some participating subjects, the implementation of these policies for the marine ecological environment management of the Bohai Sea enjoyed a large investment but little effect. Therefore, to realize the Bohai Sea MESB, it is necessary to pay attention to the functional roles of the participating subjects and the interactions between them.

In the field of international marine ecosystem security management, Bennett et al. (2019) performed a study of small-scale fishers in 11 marine ecological reserves in 6 countries in the Mediterranean Sea, and found that the establishment of good governance processes and the existence of social impacts locally support conservation more favorably than ecological benefits (Bennett et al., 2019). In relation to the management of marine and coastal protection in Brazil, significant advances have been recorded, such as the creation of new, large mosaics of oceanic protected areas, the recognition of Amazon mangroves were recognized by the Ramsar Convention, and the creation of new mangrove protected areas, besides other ones proposed. Furthermore, project proposals are under development with partners for better funding and sharing of responsibility, and there is a better engagement with stakeholders. As such, the building of the Brazilian Blue Initiative is underway. However, despite such significant advances, the levels of funding, staff, and stakeholders' engagement remain relatively low for such a vast system (Maretti et al., 2019). Therefore, marine ecological safety management needs to pay great attention to the role of participating subjects and their mutual interrelations.

2.2 The building of an MESB in the Bohai Sea

Due to differences in resources endowment, ecological conditions, economic foundation, and social evolution, the economic development of the "three provinces and one city" in the Bohai Sea Economic Cluster varies greatly. Therefore, to build the MESB in the Bohai Sea, it is first necessary to solve the problem of the division of roles and functions. Current research on the construction of the MESB in the Bohai Sea still focuses on its connotation, meaning, and specific ecological restoration; as such, it does not include a focus on the precise positioning of the participating subjects in this process, and ignore the subjectivity of the marine ecological safety problems in the Bohai Sea. The industrial development of the Bohai Sea economic zone has caused serious ecological and environmental problems, while driving the rapid rise of the "three provinces and one city" urban agglomeration. In view of the complexity, difficulty, investment, long period, and risk of marine governance, reflected in marine pollution and other marine ecological problems (Cheng et al., 2019; Pinillos et al., 2023), the construction of the MESB requires gathering the interests and strengths of different stakeholders such as government, Non-governmental Organizations, and enterprises (Cunha and Magalhaes, 2019; Gao J. et al., 2022).

As a trans-regional public resource, the non-exclusive nature of the ocean makes local governments reluctant to actively bear any costs, assuming considerably less responsibility for the ecological management and restoration of the ocean (Wang et al., 2020) "except in a coercive or other special way to make individuals act in their common interest" (Yu et al., 2021). Therefore, the building of the MESB in the Bohai Sea requires the development of policy, legal, and institutional development influences (Liu et al., 2021; Zhang et al., 2021) to focus on the state, market, and public society in the maintenance of marine ecological security at multiple levels, adopting a co-evolutionary hierarchical governance theory perspective (Jiang and Li, 2021). From the perspective of ecological modernization theory, the further integration of economic and social development and ecological conservation requires the central role of technological innovation and mature market mechanisms in ecosystem development (Mol and Spaargaren, 2000). Therefore, in the process of construction of the MESB in the Bohai Sea, the local government should not actively invest in the early stages, due to the cost of management and other factors, but rather when the marine ecological safety problems in the Bohai Sea will gradually become prominent and affect the local economic development level, financial income, and even the survival of residents. At this moment, the local government should actively guide enterprises and the public to participate in the construction of the MESB through the formulation of policies, laws, and regulations.

As a higher quality tool for marine ecological civilization, the construction of a good market mechanism for the MESB requires giving full play to the main position of enterprises in the marine economy. Although pre-investment costs are high and risky, and the government needs to assume the role of guidance and supervision, the adoption of a single-government governance model will lead to a significant increase in endogenous transaction costs (Du et al., 2022). Compared to the market-oriented governance model, the single-government governance model consists mainly in an ex-post control using administrative policies in response to problems (Murphy et al., 2021). However, the lag effect of policies and behavioral constraints compensation (Xia et al., 2022) can hardly meet the public value of the whole society (Jiang et al., 2019), which in turn affects the process of ensuring a good ocean state. It is difficult for marine enterprises, which are the main driver of land-based pollution, to actively participate in the process of building the MESB, when the cost paid is greater than the benefits obtained. Moreover, only when the active participation of enterprises in the MESB has become an important source of income, its construction will become

consciously incorporated in the enterprise behavior. Therefore, through their active behavior, sea-related enterprises can provide the key resources, such as capital and technology, which will directly determine the speed and quality of the construction of the MESB in the Bohai Sea.

From a behavioral choice perspective, ocean issues are rooted in individual behavioral choices, and citizens can change their public values and decision-making behaviors to achieve the state-driven goal of establishing a good marine ecosystem (Bakker, 2022). Small community marine education practices in Indonesia (Zhang et al., 2022) and Scotland (Gacutan et al., 2022) have also demonstrated that increased levels of public understanding of marine knowledge improve marine ecology and result in more "ocean-aware" communities (Bai and Cheng, 2016). Theoretical studies have found that public awareness, recognition, participation, and support are important to achieve regional marine environmental governance goals, and that a combination of the precautionary principle and adaptive management is considered as an effective tool to achieve the sustainable use of marine resources (Li et al., 2021). Previous studies of specific environmental governance behaviors found that the level of public participation plays an important role in enhancing the effectiveness of pollution control (Xue et al., 2022). Public participation, as a kind of civil rights application and redistribution, is an effective mechanism for the government and the public to negotiate and coordinate services on administrative external behaviors through a reasonable and legal way; moreover, improving the quality of public participation can entail a favorable supervision for local governments (Millette et al., 2020). Therefore, the incorporation of public participation into the construction of MESBs can help form a balanced marine management system, and is conducive to expanding the breadth of the MESB.

In summary, the construction of the Bohai MESB is a comprehensive, long-term and complex project, and special attention should be paid to the positioning of functions and roles as well as the distribution of benefits among the main parties involved in the construction, so as to form a comprehensive and long-term synergistic governance system. However, few scholars have explored the construction of MESB in the Bohai Sea from the perspective of participating subjects. In the process of construction of the MESB in the Bohai Sea, regarding the assumption of the research subject, we referred to role-setting in previous studies on marine ecological security governance. In the end, we determined the three main strategic players: local government, marine enterprises, and the general public. Through this, we aim to achieve the integration of government governance, market utilization, and social governance. This approach can address the dynamic and governance mechanism issues of the MESB in the Bohai Sea from the source. Although some scholars are currently aware of the importance of the participation of multiple subjects (Song et al., 2017; García-Ayllón, 2019), there are still problems such as a lack of top-level design, insufficient participation of multiple subjects, and insufficient governance investment in regional marine ecological environment governance. To this respect, the evolutionary game theory is based on the biological evolutionary theory, with the assumption that the game subjects are finite rational people, and that the game parties finally achieve a static equilibrium through the process of continuous mutual learning and adaptation (Smith and Price, 1973; Maynard Smith, 1974). In this study, we created an evolutionary game model for the construction of the MESB in the Bohai Sea, and analyzed the core influencing factors that affect the proposed participation or non-participation of sea-related enterprises in the decision.

Based on previous studies, the contributions of this study are as follows. The first contribution relates to the selection of research objects and subjects. As a special marine area characterized by closed waters, long self-cleaning cycle, and fragile ecology, and because it is an inland sea, it is difficult to ensure marine ecological security governance of the Bohai Sea, which is directly related to the success or failure of global marine ecological security governance. This study from the selection of a new proposition for multi-party checks and balances and optimal decision-making research correspondence, to provide constructive advice for China's marine ecological security governance. Marine enterprises, local governments and the public are all limited rationality, information asymmetry and strategic choice interaction, there are no clear legal provisions between the three parties to force constraints, and there is a game relationship driven by interests. By constructing the MESB in the Bohai Sea, it reveals the interaction mechanism between the game subjects, makes all the participants benefit as much as possible, and at the same time, helps each participant to choose the correct use of decision-making (Xu et al., 2023).

Second, this study was the first to explore the dynamics and governance mechanism in the construction of the MESB in the Bohai Sea from the perspective of participating subjects, and to provide a scientific reference for the construction of MESBs in China by using Matlab numerical simulation.

3 Model hypotheses and analysis

Marine Protected Areas represent a complex area, where the relationship between different stakeholders must be balanced. The construction of the MESB in the Bohai Sea provides a coordination mechanism and management framework for the integrated management of the Bohai Sea ecological environment. A high-level coordination and governance committee is established in the construction of the MESB, in order to actively support marine enterprises in assuming ecological and environmental responsibilities, while reducing industrial pollution from land-based sources. In addition, the construction of the MESB in the Bohai Sea requires strengthening special legislation and comprehensive laws and regulations in the Bohai Sea Rim, as well as an accountability and supervision system (Scott and Thomas, 2017). In this way, it is possible to create an ecological protection system based on the general public, ultimately truly integrating sea and land to achieve coordinated and sustainable economic, ecological, and social development (Song et al., 2017).

Therefore, this study assumed that in the construction of the MESB in the Bohai Sea, local governments, marine enterprises, and the public are the three main stakeholders involved, which are finite rational economic subjects. More in detail, local governments mainly include the provinces of Shandong, Liaoning, and Hebei, and the city

of Tianjin. On this basis, the tripartite relationship was identified as shown in Figure 1, and the following assumptions were made.

3.1 Hypothesis 1

In the construction of the MESB in the Bohai Sea, there are two strategic choices for local governments, i.e., strict regulation and lax regulation. If the local governments adopt a strict regulatory strategy, they will have a certain amount of regulatory costs (C_1) and good government credibility (R_1), while if they adopt a lax regulatory strategy, they will have higher regulatory costs C_2 ($C_2 < C_1$). When marine enterprises actively participate in the construction of the MESB in the Bohai Sea, the local government will impose a lower ecological and environmental tax rate (t_1). At the same time, if the local governments implement a strict regulatory strategy, they will provide a certain amount of subsidies (S) to marine enterprises, while if they adopt a lax regulatory strategy, they will not provide any incentives or subsidies. If marine enterprises do not participate in the construction of the MESB, local governments will impose a higher ecological tax rate t_2 ($t_1 < t_2$). When the local governments adopt a strict regulatory strategy, they will impose a fine on the marine enterprises (F) for inaction, while when they adopt a lax regulatory strategy, the public will report violations by marine companies. If local governments choose to remain silent at this point, they will entail a certain loss of government credibility (D_1).

3.2 Hypothesis 2

In the construction of the MESB in the Bohai Sea, marine enterprises have two possible strategies: active participation and non-participation. When they actively participate in the construction of the MESB in the Bohai Sea, their product output is Q_1 and the unit price of product is P. Moreover, marine enterprises pay a cost of construction of the MESB, C_3. At this point, they provide ecological benefits to the public (R_2), and pay ecological taxes to the government (Q_1t_1). If marine enterprises provide ecological and environmental benefits that meet public expectations, as a result of their active participation in the construction of the MESB in the Bohai Sea, they will establish a good corporate image and obtain intangible benefits (R_3). Conversely, if the public believes that the products offered by marine enterprises do not meet their expectations, the public will report them to the government, resulting in a loss of corporate social image of the marine enterprise (D_3). When marine enterprises do not participate in the construction of the MESB in the Bohai Sea, their product output is Q_2 ($Q_2 > Q_1$), while the unit price of product is still P. In this case, the ecological loss caused by their non-participation in the construction of the MESB in the Bohai Sea is D_4. If the local governments implement a strict regulatory strategy, marine enterprises need to pay taxes to the government (t_2Q_2) and fines (F). At the same time, they will also need to pay ecological compensation to the public, in strict accordance with the relevant regulations (C_4). If the public reports on marine enterprises, the latter will incur in a loss of social image caused by their inaction (D_2). If local governments implement a lax regulatory strategy, marine enterprises will often pay ecological taxes to the government at a lower rate (Q_2t_1), while expanding production to balance the cost of regulation, in accordance with the principle of maximizing benefits and minimizing costs (Guo et al., 2021). In this case, if the public reports the violation of the MESB in the Bohai Sea, marine enterprises will incur in a loss of social image (D_2) and of government credibility (D_1).

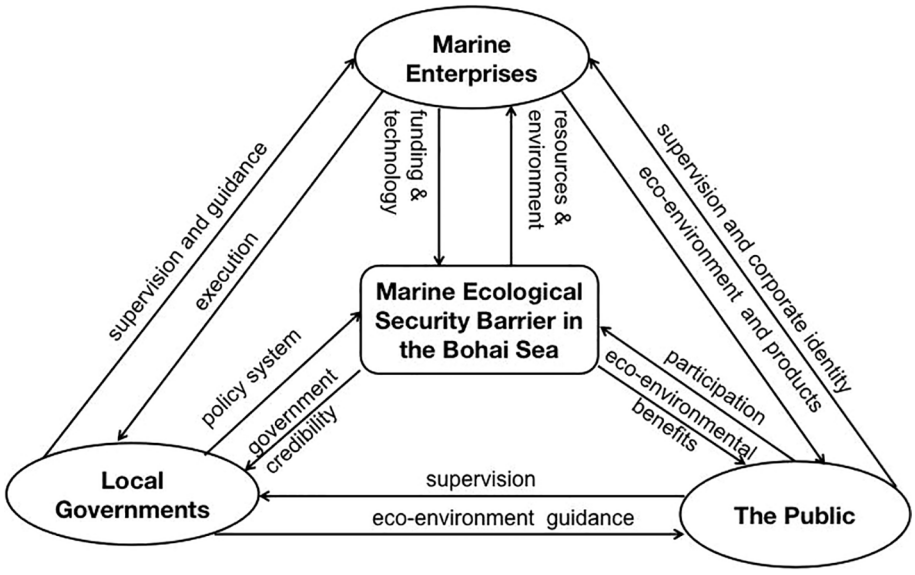


FIGURE 1
The relationship between the three parties in building the MESB in the Bohai Sea.

3.3 Hypothesis 3

The public is the most direct stakeholder of the marine ecosystem. It has two strategy options: supervisory reporting and non-supervisory reporting. If the ecological and environmental benefits R_1 produced by marine enterprises thanks to their active participation in the construction of the MESB in the Bohai Sea meet public expectations, and then the public will choose to accept and adopt the non-supervisory reporting strategy. Otherwise, the public will adopt the supervisory reporting strategy, and the cost of supervisory reporting will be C_5. If marine enterprises do not participate in the construction of the MESB in the Bohai Sea, the resulting loss of marine ecological environment will be D_4. In this case, if the local governments will implement a strict regulatory strategy, and the public will monitor and report the inaction of marine enterprises, receiving an eco-compensation from marine enterprises (C_4) and an incentive from the government (W).

3.4 Hypothesis 4

Marine enterprises will choose the strategy to participate in the construction of the MESB in the Bohai Sea in the proportion of x, and will choose the strategy of non-participation in the proportion of $1 - x$. Similarly, the local governments will choose the strict regulatory strategy in the proportion of y, and the lax regulatory strategy in the proportion of $1 - y$; and the public will choose the strategy of supervisory reporting in the proportion of z, and that of non-supervisory reporting in the proportion of $1 - z$.

Because the construction of the MESB in the Bohai Sea is still in the conceptual stage, no specific data can be provided to support it. To enhance the scientificity of this study, we referred to the Action Plan on the comprehensive management of the Bohai Sea, issued by the Department of Marine Ecology and Environment of the Ministry of Ecology and Environment of China in 2019. This Plan states that by October 2019, funding support for Bohai Sea governance exceeded 7 billion yuan. The three provinces and one city investigated 565 enterprises, investigated and rectified nearly 2,000 environmental risk hazards, issued 187 rectification instruments, and filed environmental emergency plans for more than 5,400 enterprises.

Table 1 provides a description of the main parameters employed in this study.

TABLE 1 Description of the main parameters employed in this study.

Symbol	Description	Symbol	Description
C_1	Local governments' regulatory costs in adopting the strict regulatory strategy	P	Unit product price of marine enterprises
C_2	Local governments' regulatory costs in adopting the lax regulatory strategy	D_1	Loss of government image as a result of lax regulatory measures implemented by the Government
C_3	Marine enterprises' costs of active participation	D_2	Loss of corporate image of marine enterprises not involved in being reported by the public
C_4	Ecological compensation in case of non-participation of marine enterprises	D_3	Loss of corporate image caused by monitoring and reporting despite active participation by marine enterprises
C_5	Cost of supervisory reporting by the public	D_4	Ecological losses caused by those marine enterprises that do not participate in the construction of the MESB in the Bohai Sea
R_1	Government credibility in adopting the strict regulatory strategy	t_1	Lower environmental tax rates
R_2	Ecological benefits arising from the active participation of marine enterprises	t_2	Higher environmental tax rates
R_3	Eco-benefits of marine enterprises activism Intangible benefits from meeting public expectations	S	Government subsidies for the proactive behavior of marine enterprises
Q_1	Total production with active participation of marine enterprises	F	Government fines for the inaction of marine enterprises
Q_2	Total production without participation of marine enterprises	W	Government rewards for effective public supervisory reporting

Based on these assumptions, an evolutionary game model of the three subjects, i.e., local governments, marine enterprises, and the public, was constructed; the benefits of the combination of the different strategies, adopted by the three types of subjects, are shown in Table 2.

4 Model development and solution

4.1 Development of the evolutionary game model

The replication dynamics analysis is a dynamic differential analysis method that allows to analyze the degree of fitness of a strategy within a population in the evolutionary game theory. Based on the data illustrated in Table 2, the replicator dynamic equations for the marine enterprises, local governments, and the public were derived, as follows.

4.1.1 Replicator dynamic equation for the marine enterprises

The expected utility for marine enterprises, when they choose to actively participate in the construction of the MESB in the Bohai

TABLE 2 Equilibrium outcome of the three-party game.

Strategy combination	Marine enterprises	Local government	Public
Active participation, strict regulation, supervisory reporting	$PQ_1 - t_1Q_1 - C_3 + R_2 - D_3 + S$	$t_1Q_1 - C_1 + R_1 - S$	$R_2 - C_5$
Active participation, strict regulation, non-supervisory reporting	$PQ_1 - t_1Q_1 - C_3 + R_2 + R_3 + S$	$t_1Q_1 - C_1 + R_1 - S$	R_2
Active participation, lax regulation, supervisory reporting	$PQ_1 - t_1Q_1 - C_3 + R_2 - D_3$	$t_1Q_1 - C_2 - D_1$	$R_2 - C_5$
Active participation, lax regulation, non-supervisory reporting	$PQ_1 - t_1Q_1 - C_3 + R_2 + R_3$	$t_1Q_1 - C_2$	R_2
Non-participation, strict regulation, supervisory reporting	$PQ_2 - t_2Q_2 - D_4 - C_4 - D_2 - F$	$t_2Q_2 - C_1 + F + R_1 - W$	$C_4 - D_4 - C_5 + W$
Non-participation, strict regulation, non-supervisory reporting	$PQ_2 - t_2Q_2 - D_4 - C_4 - F$	$t_2Q_2 - C_1 + F + R_1$	$C_4 - D_4$
Non-participation, lax regulation,supervisory reporting	$PQ_2 - t_1Q_2 - D_4 - D_2$	$t_1Q_2 - C_2 - D_1$	$- D_4 - C_5$
Non-participation, lax regulation, non-supervisory reporting	$PQ_2 - t_1Q_2 - D_4$	$t_1Q_2 - C_2$	$- D_4$

Sea, is U_{SRE1}, and the expected utility when they choose not to participate is U_{SRE2}. The average expected utility for marine enterprises is $\overline{U_{SRE}}$, where:

$$U_{SRE1} = PQ_1 - t_1Q_1 - C_3 + R_2 + yS - zD_3 \quad (1)$$

$$U_{SRE2} = PQ_2 - yt_2Q_2 - (1-y)t_1Q_2 - yC_4 - D_4 - zD_2 - yF \quad (2)$$

$$\overline{U_{SRE}} = xU_{SRE1} + (1-x)U_{SRE2} \quad (3)$$

The replication dynamics equation for the marine enterprises participating in the construction of the MESB in the Bohai Sea is as follows:

$$\begin{aligned} F(x) = \frac{dx}{dt} &= x(1-x)(U_{SRE1} - U_{SRE2}) \\ &= x(1-x)[PQ_1 - t_1Q_1 - C_3 + R_2 + yS - zD_3 - PQ_2 \\ &\quad + yt_2Q_2 + (1-y)t_1Q_2 + yC_4 + D_4 + zD_2 + yF] \end{aligned} \quad (4)$$

The derivative of F(x)is as follows:

$$\begin{aligned} F(\acute{x}) = &(1-2x)[PQ_1 - t_1Q_1 - C_3 + R_2 + yS - zD_3 - PQ_2 \\ &+ yt_2Q_2 + (1-y)t_1Q_2 + yC_4 + D_4 + zD_2 + zF] \end{aligned} \quad (5)$$

4.1.2 Replicator dynamic equation for local governments

The expected utility for local governments when adopting the strict regulatory strategy is U_{G1}, and the expected utility when adopting the lax regulatory strategy is U_{G2}. The average expected utility of local governments is $\overline{U_G}$, where:

$$U_{G1} = -C_1 + R_1 - xS + xt_1Q_1 + (1-x)F + (1-x)t_2Q_2 - (1-x)zW \quad (6)$$

$$U_{G2} = -C_2 + xt_1Q_1 + (1-x)t_1Q_2 - zD_1 \quad (7)$$

$$\overline{U_G} = yU_{G1} + (1-y)U_{G2} \quad (8)$$

The replication dynamics equation for the adoption of the strict regulatory strategy by local governments is as follows:

$$\begin{aligned} F(y) = \frac{dy}{dt} &= y(1-y)[U_{G1} - U_{G2}] \\ &= y(1-y)([C_2 - C_1 + R_1 - xS + (1-x)t_2Q_2 - (1 \\ &\quad - x)t_1Q_2 - (1-x)zW + zD_1] \end{aligned} \quad (9)$$

The derivative of F(y) is as follows:

$$\begin{aligned} F(\acute{y}) = &(1-2y)[C_2 - C_1 + R_1 - xS + (1-x)F + (1-x)t_2Q_2 \\ &- (1-x)t_1Q_2 - (1-x)zW + zD_1] \end{aligned} \quad (10)$$

4.1.3 Replicator dynamic equation for the public

Setting the expected utility of the public to U_{P1} when the public adopt supervisory reporting strategies, and to U_{P2} when the public adopt non-supervisory reporting strategies, the average expected utility of the public is $\overline{U_P}$, where:

$$U_{P1} = -C_5 + xR_2 - (1-x)D_4 + (1-x)yC_4 + (1-x)yW \quad (11)$$

$$U_{P2} = xR_2 - (1-x)D_4 + (1-x)yC_4 \quad (12)$$

$$\overline{U_P} = zU_{P1} + (1-z)U_{P2} \quad (13)$$

The replication dynamics equation for the adoption of the supervisory reporting strategy by the public is as follows:

$$F(z) = \frac{dz}{dt} = z(1-z)(U_{P1} - U_{P2}) = z(1-z)[-C_5 + (1-x)yW] \quad (14)$$

The derivative of F(z) is as follows:

$$F(z') = (1 - 2z)[-C_5 + (1 - x)yW] \quad (15)$$

4.2 Analysis of the three-party evolutionarily stable strategy

The replication dynamics analysis is a dynamic differential analysis method to analyze the degree of fitness of a particular strategy within a population in the evolutionary game theory. If the net gain of a strategy during the game is higher than the average gain of other strategies in a certain population group, then this strategy is considered to be the most suitable for expansion in the population group, i.e., the strategy is considered to be stable against the invasion of variant strategies.

4.2.1 Asymptotic stability analysis of marine enterprises

The replication dynamics equation of marine enterprises participating in the construction of the MESB in the Bohai Sea is as follows:

$$\begin{aligned} F(x) = \frac{dx}{dt} &= x(1 - x)(U_{SRE1} - U_{SRE2}) \\ &= x(1 - x)[PQ_1 - t_1Q_1 - C_3 + R_2 + yS - zD_3 - PQ_2 \\ &\quad + yt_2Q_2 + (1 - y)t_1Q_2 + yC_4 + D_4 + zD_2 + yF] \end{aligned} \quad (16)$$

When $F(x) = 0, F(x)' < 0$, x is the evolutionary stabilization strategy of marine enterprises. Moreover, there are three possible cases:

1) When $y = \frac{PQ_1 - PQ_2 + t_1Q_2 - t_1Q_1 - C_3 + R_2 + D_4 + zD_2 - zD_3}{t_1Q_2 - t_2Q_2 - S - C_4 - F}$, $F(x) = 0$ is always satisfied, independently from its value, x is in a stable state, and marine enterprises' strategy will not change.

2) When $y > \frac{PQ_1 - PQ_2 + t_1Q_2 - t_1Q_1 - C_3 + R_2 + D_4 + zD_2 - zD_3}{t_1Q_2 - t_2Q_2 - S - C_4 - F}$, then we have $F'(x)|_{x=0} > 0, F'(x)|_{x=1} < 0$.

That is, $x = 1$ is the stability point. This indicates that the strategies of marine enterprises to participate in the construction of the MESB in the Bohai Sea are closely related to the behavior of both local governments and the public. When the proportion of local governments adopting a strict regulatory strategy is higher than $\frac{PQ_1 - PQ_2 + t_1Q_2 - t_1Q_1 - C_3 + R_2 + D_4 + zD_2 - zD_3}{t_1Q_2 - t_2Q_2 - S - C_4 - F}$, marine enterprises will actively participate in the construction of the MESB in the Bohai Sea, due to a combination of factors such as tax rates and corporate social image.

3) When $y < \frac{PQ_1 - PQ_2 + t_1Q_2 - t_1Q_1 - C_3 + R_2 + D_4 + zD_2 - zD_3}{t_1Q_2 - t_2Q_2 - S - C_4 - F}$, then we have $F'(x)|x=1 > 0, F'(x)|_{x=0} < 0$.

That is, $x = 0$ is the stability point. When the proportion of local governments choosing a strict regulatory strategy is lower than $\frac{PQ_1 - PQ_2 + t_1Q_2 - t_1Q_1 - C_3 + R_2 + D_4 + zD_2 - zD_3}{t_1Q_2 - t_2Q_2 - S - C_4 - F}$, marine enterprises will choose the strategy of not participating in the construction of the MESB in the Bohai Sea in the next stage of the game.

4.2.2 Analysis of the replication dynamics of local governments' adoption of the strict regulatory strategy

The replication dynamics equation for the adoption of the strict regulatory strategy by local governments is as follows:

$$\begin{aligned} F(y) = \frac{dy}{dt} &= y(1 - y)[U_{G1} - U_{G2}] \\ &= y(1 - y)([C_2 - C_1 + R_1 - xS + (1 - x)t_2Q_2 - \\ &\quad (1 - x)t_1Q_2 - (1 - x)zW + zD_1] \end{aligned} \quad (17)$$

When $F(y) = 0, F(y)' < 0$, y is the evolutionary stabilization strategy of local governments. Moreover, there are three possible cases:

1) When $x = \frac{C_2 - C_1 + R_1 + F + t_2Q_2 - t_1Q_2 - zW + zD_1}{S + F + t_2Q_2 - t_1Q_2 - zW}$, $F(y) = 0$ is always satisfied, independently from its value, y is in a stable state, and local governments' strategy will not change.

2) When $x > \frac{C_2 - C_1 + R_1 + F + t_2Q_2 - t_1Q_2 - zW + zD_1}{S + F + t_2Q_2 - t_1Q_2 - zW}$, then we have $F'(y)|y=0 > 0, F'(y)|_{y=1} < 0$. That is, $y = 1$ is the stability point. This indicates that the decision of local governments is closely related to the proportion of positive behaviors of marine enterprises and the proportion of the public's adoption of the monitoring strategy. When the proportion of marine enterprises actively participating in the construction of the MESB in the Bohai Sea is higher than $\frac{C_2 - C_1 + R_1 + F + t_2Q_2 - t_1Q_2 - zW + zD_1}{S + F + t_2Q_2 - t_1Q_2 - zW}$, the local governments will choose the strict regulatory strategy, due to a combination of factors such as credibility.

3) When $x < \frac{C_2 - C_1 + R_1 + F + t_2Q_2 - t_1Q_2 - zW + zD_1}{S + F + t_2Q_2 - t_1Q_2 - zW}$, then we have $F'(y)|y=0 < 0, F'(y)|_{y=1} > 0$. That is, $y = 0$ is the stability point. This indicates that when the proportion of marine enterprises actively participating in the construction of the MESB in the Bohai Sea is lower than $\frac{C_2 - C_1 + R_1 + F + t_2Q_2 - t_1Q_2 - zW + zD_1}{S + F + t_2Q_2 - t_1Q_2 - zW}$, the local governments will tend to choose the lax regulatory strategy.

4.2.3 Analysis of the replication dynamics of the public's adoption of the supervisory reporting strategy

The replication dynamics equation for the adoption of the supervisory reporting strategy by the public is as follows:

$$F(z) = \frac{dz}{dt} = z(1 - z)(U_{P1} - U_{P2}) = z(1 - z)[-C_5 + (1 - x)yW] \quad (18)$$

When $F(z) = 0, F'(z) < 0$, z is the evolutionary stabilization strategy of the public. Moreover, there are three possible cases:

1) When $y = \frac{C_5}{(1-x)W}$, $F(z) = 0$ is always satisfied, independently from its value, z is in a stable state, and the public strategy will not change.

2) When $y > \frac{C_5}{(1-x)W}$, then we have $F'(x)|z=0 > 0, F'(x)|_{z=1} < 0$. That is, $z = 1$ is the stability point. This indicates that the public's supervisory reporting strategy is closely related to the proportion of marine enterprises not participating in the construction of the MESB in the Bohai Sea, and to the proportion of local governments adopting the strict regulatory strategy. When the

10.3389/fmars.2023.1226665

latter is higher than $\frac{C_5}{(1-x)W}$, the public will adopt the supervisory reporting strategy in the construction of the MESB in the Bohai Sea, due to the influence of the cost of supervisory reporting and government incentives.

3) When $y < \frac{C_5}{(1-x)W}$, then we have $F'(x)|_{x=0} > 0$, $F'(x)|_{x=1} < 0$. That is, $z = 0$ is the stability point. When the proportion of local governments adopting the strict regulatory strategy is lower than $\frac{C_5}{(1-x)W}$, the public will choose the non-supervisory reporting strategy in the next stage of the game.

5 Equilibrium points of the evolutionary game and stability analysis

In the replicated dynamic system of the tripartite game of marine enterprises, local governments, and the public, on the basis of the Liapunov stability theory, the system of combination of the strategies of the three subjects of the game is stable when all the real parts of the eigenvalues of the system Jacobi matrix are lower than 0. Based on the replicated dynamic equation of each game subject, the Jacobi matrix of the replicated dynamic system was obtained as follows:

$$J = \begin{pmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{pmatrix}$$

As shown in Table 3, the equilibrium points that may satisfy the condition that all the real parts of the eigenvalues of the system Jacobi matrix are negative, are (0, 0, 0), (0, 1, 0), (0, 1, 1), (1, 1, 0), and (1, 0, 0). This shows the process, from the stage where marine enterprises, local governments, and the public do not pay attention and do not actively participate in the construction of the MESB in the Bohai Sea, to the stage where local governments and the public are aware of the importance of the construction of the MESB, and finally to the stage where marine enterprises can actively and consciously promote the MESB without the supervision of local governments and the public. According to the range of values of each parameter in the expression, the stability of each equilibrium point can be discussed in the following five cases.

Case 1: When $PQ_1 - PQ_2 + t_1Q_2 - t_1Q_1 - C_3 + D_4 + R_2 < 0$, $C_2 - C_1 + R_1 + t_2Q_2 - t_1Q_2 + F < 0$, $-C_5 < 0$, then (0, 0, 0) is the ESS point of the system. After transformation, we can obtain: $Q_2 - t_1Q_2 - D_4 > PQ_1 - t_1Q_1 - C_3 + R_2$, $-C_1 + R_1 + t_2Q_2 + F < -C_2 + t_1Q_1$, $-C_5 < 0$. This means that the after-tax product revenue minus the environmental loss caused when marine enterprises do not participate in the construction of the MESB in the Bohai Sea is higher than the after-tax revenue minus the cost paid for it when marine enterprises actively participate in it, plus the resulting ecological benefits. For local governments, the cost of adopting a lax strategy plus the tax levied is higher than the sum of the cost of implementing a strict regulatory strategy, the tax, the fines imposed on enterprises, and the resulting credibility. According to the equilibrium condition, at this time, the benefits of marine enterprises adopting the strategy of not participating in the construction of the MESB in Bohai Sea are higher

TABLE 3 Stability analysis of the equilibrium solution to the three-party evolutionary games.

Equilibrium point	Eigenvalues λ_1, λ_2, λ_3	Positive and negative signs
(1, 1, 1)	$PQ_2 - PQ_1 + t_1Q_1 - t_2Q_2 + C_3 - C_4 - D_2 + D_3 - D_4 - R_2 - S - F$, $C_1 - C_2 - D_1 - R_1 + S$, C_5	(U, U, +)
(1, 0, 1)	$PQ_2 - PQ_1 + t_1Q_1 - t_1Q_2 + C_3 - D_2 + D_3 - D_4 - R_2$, $C_2 - C_1 + D_1 + R_1 - S$, C_5	(U, U, +)
(1, 1, 0)	$PQ_2 - PQ_1 + t_1Q_1 - t_2Q_2 + C_3 - C_4 - D_4 - R_2 - S - F$, $C_1 - C_2 - R_1 + S$, $-C_5$	(U, U, -)
(1, 0, 0)	$PQ_2 - PQ_1 + t_1Q_1 - t_1Q_2 + C_3 - D_4 - R_2$, $C_2 - C_1 + R_1 - S$, $-C_5$	(U, U, -)
(0, 1, 1)	$PQ_1 - PQ_2 + t_2Q_2 - t_1Q_1 - C_3 + C_4 + D_2 - D_3 + D_4 + R_2 + S + F$, $C_1 - C_2 - D_1 + t_1Q_2 - t_2Q_2 - R_1 - F + W$, $C_5 - W$	(U, U, U)
(0, 0, 1)	$PQ_1 - PQ_2 + t_1Q_2 - t_1Q_1 - C_3 + D_2 - D_3 + D_4 + R_2$, $C_2 - C_1 + D_1 + t_2Q_2 - t_1Q_2 + R_1 + F - W$, C_5	(U, U, +)
(0, 1, 0)	$PQ_1 - PQ_2 + t_2Q_2 - t_1Q_1 - C_3 + C_4 + D_4 + R_2 + S + F$, $C_1 - C_2 - R_1 + t_1Q_2 - t_2Q_2 - F$, $-C_5 + W$	(U, U, U)
(0, 0, 0)	$PQ_1 - PQ_2 + t_1Q_2 - t_1Q_1 - C_3 + D_4 + R_2$, $C_2 - C_1 + R_1 + t_2Q_2 - t_1Q_2 + F$, $-C_5$	(U, U, -)

U indicates that the positive and negative signs are uncertain and require further discussion.

than those of actively participating in it; the benefits of local government choosing the lax strategy are higher than those adopting the strict regulation strategy; and the benefits of the public adopting the non-reporting strategy are higher than those of choosing the reporting strategy. Hence, the evolutionary stabilization strategies of marine enterprises, local governments, and the public are non-participation, lax regulation, and non-reporting, respectively.

This often happens in the early stage of the construction of the MESB, when the central government has just issued related promotion policies, local governments are still in the stage of waiting and watching, and marine enterprises and the public do not have a clear understanding of the MESB. In this case, marine enterprises, local governments, and the public prefer to wait and see what happens. Under such circumstances, the construction of the MESB needs to analyze the behavior tendency and the influencing factors of these subjects, so as to lay the foundation for the construction of the MESB. The local governments of Shandong Province, Hebei Province and Tianjin Municipality in the Bohai Sea region are in a wait-and-see mode for the government to make a comprehensive management program for the Bohai Sea region due to the distribution of interests and the differences in the level of economic development. Under these circumstances, businesses and the public in the region will not take action either.

Case 2: When $PQ_1 - PQ_2 + t_2Q_2 - t_1Q_1 - C_3 + C_4 + D_4 + R_2 + S + F < 0, C_1 - C_2 - R_1 + t_1Q_2 - t_2Q_2 - F < 0, -C_5 + W < 0$, then (0, 1, 0) is the ESS point of the system. After transformation, we can obtain: $PQ_1 - t_1Q_1 - C_3 + R_2 + S < PQ_2 - t_2Q_2 - C_4 - D_4 - F$, $-C_2 + t_1Q_2 < -C_1 + R_1 + t_2Q_2 + F$, $C_5 > W$. This means that the income of marine enterprises when they do not participate in the construction of the MESB in the Bohai Sea minus the ecological environmental taxes, marine ecological environmental losses, fines, and marine ecological compensation paid to the public is higher than the after-tax income of marine enterprises when they actively participate in the construction of MESB in the Bohai, Sea minus the costs paid for participating in the construction of MESB in the Bohai Sea, plus ecological benefits and government subsidies. For local governments, the cost of adopting a strict regulatory strategy plus government credibility gains, tax revenue, and fines levied on marine enterprises is higher than the cost of adopting a lax strategy plus tax revenue. For the public, the cost of supervisory reporting is higher than the government incentives. According to the equilibrium condition, at this time, the benefits of marine enterprises not participating in the construction of the MESB in the Bohai Sea are higher than the benefits of those that participate. The benefits of local governments adopting a strict regulation strategy are higher than those adopting a lax strategy, and the benefits of the public adopting the strategy of not reporting are higher than those for the strategy of supervisory reporting. Hence, the evolutionary stabilization strategies of marine enterprises, local governments, and the public are non-participation, strict regulation, and non-supervisory reporting, respectively.

This situation generally occurs at the stage when the MESB policy is formulated and implemented from the central to the local level. Local governments are forced to strictly supervise the implementation due to the pressure from the central government; however, marine enterprises and the public still do not recognize the importance of building the MESB, and they will choose the strategy of not participating and not supervising the reporting, respectively. The positive behavior of the local governments has broken the rigid pattern of inaction of the three participating subjects in the early stage, and has made a solid, first step to promote the construction of the MESB. Due to the political and policy pressure from the central government, the provinces in the Bohai Sea region are forced to take the first step in the construction of the Bohai Sea Marine Ecological Safety Barrier.

Case 3: When $PQ_1 - PQ_2 + t_2Q_2 - t_1Q_1 - C_3 + C_4 + D_2 - D_3 + D_4 + R_2 + S + F < 0$, $C_1 - C_2 - D_1 + t_1Q_2 - t_2Q_2 - R_1 - F + W < 0$, $C_5 - W < 0$, then (0, 1, 1) is the ESS point of the system. After transformation, we can obtain: $PQ_1 - t_1Q_1 - C_3 - D_3 + R_2 + S < PQ_2 - t_2Q_2 - C_4 - D_2 - D_4 - F$, $-C_2 - D_1 + t_1Q_2 < -C_1 + t_2Q_2 + R_1 + F - W$, $C_5 < W$.This means that the after-tax income of marine enterprises when they do not participate in the construction of the MESB in the Bohai Sea, minus the ecological loss, corporate image loss, ecological compensation to the public, and fines, is higher than the after-tax income of marine enterprises when they actively participate in the construction, minus the cost of participation and the loss of image when they are reported to meet public expectations, plus the resulting good ecological benefits and government subsidies. For local governments, the cost of adopting a lax regulatory strategy plus the ecological taxes and fines levied, and their credibility, minus the rewards for effective public reporting, is higher than the cost of adopting a lax regulatory strategy, plus the tax revenue and minus the loss of government image, when reported by the public. For the public, the rewards from the government are higher than the costs of supervisory reporting. According to the equilibrium conditions, the benefits of marine enterprises not participating in the construction of the MESB in the Bohai Sea are higher than those for participation; the benefits of the local governments adopting a strict regulatory strategy are higher than those for adopting a lax regulatory strategy; and the benefits of the public adopting the reporting strategy are higher than those for adopting the not reporting strategy. Hence, the evolutionary stabilization strategies of marine enterprises, local governments, and the public are non-participation, strict regulation, and supervisory reporting, respectively.

This generally happens when, after fully interpreting the central government's policy on the MESB, the local government publicizes and educates about it, achieving good results. At this point, the public's awareness and the level of marine ecology and environmental protection have been significantly improved, and the public can fully participate in the process of building the MESB. However, marine enterprises will still adopt a conservative non-participation strategy, due to risk and interest considerations.

A good marine ecological protection context is a key link to build the MESB in the Bohai Sea. The public is both the direct and indirect subject of this construction. Its indirectness is mainly reflected in the fact that it exerts pressure on marine pollution subjects through public opinion, prompting them to actively participate in the construction of the MESB. The active participation of the public is a catalyst for the comprehensive construction ofthe MESB.

Case 4: When $PQ_2 - PQ_1 + t_1Q_1 - t_2Q_2 + C_3 - C_4 - D_4 - R_2 - S - F < 0$, $C_1 - C_2 - R_1 + S < 0$, $-C_5 < 0$, then (1, 1, 0) is the ESS point of the

system. After transformation, we can obtain: $PQ_2 - t_2Q_2 - C_4 - D_4 - F < PQ_1 - t_1Q_1 - C_3 + R_2 + S, -C_2 < -C_1 + R_1 - S, -C_5 < 0$. This means that the after-tax income minus the cost of participation, plus the benefit of good image and government subsidies, when marine enterprises actively participate in the construction of MESB in the Bohai Sea, is higher than the after-tax income minus the ecological compensation, ecological losses, and fines paid to the public when marine enterprises do not participate. For local governments, the cost of adoption of a strict regulatory strategy, plus government credibility and minus government subsidies to enterprises, is higher than the cost of adoption of a lax regulatory strategy. For the public, in this case, supervision and reporting imply only high expenses. According to the equilibrium conditions, at this time, the benefits of marine enterprises actively participating in the construction of the MESB in the Bohai Sea are higher than those for not participating; the benefits of the local governments adopting a strict regulatory strategy are higher than those for adopting a lax regulatory strategy; and the benefits of the public adopting a non-supervisory reporting strategy are higher than those for adopting a supervisory reporting strategy. Hence, the evolutionary stabilization strategies of marine enterprises, local governments, and the public are active participation, strict regulation, and non-supervisory reporting, respectively.

This generally happens in the context of the strengthening of marine ecological protection awareness and public opinion across the whole society. Marine enterprises are forced to participate in the construction of the MESB in the Bohai Sea due to tax rates, fines, and other coercive factors. The active participation of the marine enterprises is an important element in this process. Marine enterprises provide technology and other important resources for the construction of the MESB in the Bohai Sea, and even become the main driver for marine pollution prevention and treatment, which will directly determine the quality and speed of the construction of the MESB in the Bohai Sea.

Case 5: When $PQ_2 - PQ_1 + t_1Q_1 - t_1Q_2 + C_3 - D_4 - R_2 < 0$, $C_2 - C_1 + R_1 - S < 0$, $-C_5 < 0$, then (1, 0, 0) is the ESS point of the system. After transformation, we can obtain: $PQ_2 - t_1Q_2 - D_4 < PQ_1 - t_1Q_1 - C_3 + R_2, -C_1 + R_1 - S < -C_2, -C_5 < 0$. The after-tax income of marine enterprises, minus the costs paid for participation, plus the resulting ecological benefits, when they actively participate in the construction of MESB in the Bohai Sea, is higher than the after-tax income minus the resulting ecological losses under the non-participation strategy. For local governments, the credibility of the government minus the cost of government subsidies and payments is lower than the cost of regulation under the lax strategy. At this point, for the public, there will only be cost expenditures for supervisory reporting. According to the equilibrium conditions, at this time, the benefits of marine enterprises adopting the strategy of actively participating in the construction of the MESB in the Bohai Sea are higher than those for not participating; the benefits of local governments adopting the lax regulation strategy are higher than those for adopting the strict regulation strategy; and the benefits of the public for non-supervisory reporting are higher than those for supervisory reporting. Hence, the evolutionary stabilization strategies of marine enterprises, local governments, and the public are active participation, lax regulation, and non-supervisory reporting, respectively.

This situation generally occurs in the late stage of the construction of the MESB. At this time, the role of the market in this process is fully played, and the enthusiasm of marine enterprises, as the main actor of the market, is mobilized. Marine enterprises are fully aware of the importance of marine ecological security and, at the same time, can realize the unification of marine ecological and enterprise benefits through technical improvement and other measures, so that they can actively and consciously participate in the construction of the MESB without any supervision. Local governments and the public fully recognize the role of marine enterprises as the "defender" and "implementer" of marine ecological security and, therefore, it will no longer adopt any supervision and reporting decisions. This is the advanced stage of construction of the MESB.

In summary, based on these assumptions, the stabilization points of Case 1, Case 2, Case 3, Case 4, and Case 5 are (0, 0, 0), (0, 1, 0), (0, 1, 1), (1, 1, 0), and (1, 0, 0), respectively. Among these points, (1, 0, 0) is the ideal state in which marine enterprises can consciously and actively implement the construction of the MESB in the Bohai Sea in the absence of government supervision and public reporting. In other three scenarios, namely (0, 0, 0), (0, 1, 0), and (0, 1, 1) marine enterprises may not have the main role in the construction of the MESB in the Bohai Sea. Finally, in the case of (1, 1, 0), marine enterprises are already actively participating in the construction of the MESB in the Bohai Sea, and a further increase in cost investment will not lead to an improvement in the marginal effect.

6 Simulation analysis

In order to identify the different constraints and the strength of the influencing factors, this study adopted a numerical simulation method to analyze the influence of different strategy values of marine enterprises, local governments, and the public on the equilibrium strategy of the system for the abovementioned three scenarios of system dynamic evolution path and stability. Then, for the ideal case 5, the main parameters were changed with the aim of analyzing how the system tends to evolve and stabilize under different intensities of the relevant factors. The system parameters were assigned according to the basic assumptions and the correlation action relations between the parameters in the constraints of case 5. This study employed MATLAB R2020a, setting the simulation step size to 0.15, the simulation initial time at 0, and the end time at 30.

6.1 The impact of regulatory cost C_1 of the strict regulatory strategy implemented by local governments on the evolutionary steady state

The impact of the cost paid by local governments to implement the strict regulatory strategy on the steady state of the evolutionary

game, holding other parameters constant, is as follows. When C_1 = 40, C_1 = 45, then local governments will implement the strict regulation strategy. Under the strict regulation of local governments, marine enterprises will actively participate in the construction of the MESB in the Bohai Sea, and the three-party game will approach the stability point (1, 1, 0). When C_1 keeps increasing and reaches a certain level (C_1 = 50), local governments, under the pressure of increasing costs, will voluntarily abandon the strict regulatory strategy and shift to the lax regulatory strategy, at which time the three-party game will approach (1, 0, 0) as shown in Figure 2.

This shows that a stronger strict regulation by local governments is more conducive to promoting marine enterprises to actively participate in the construction of the MESB in the Bohai Sea. When marine enterprises have integrated marine ecological security into their own development strategies and have become conscious of their behavior, local governments will be constrained by the regulatory input and the completion of the construction of the MESB in the Bohai Sea, and will adopt regular and lax regulation.

6.2 The impact of government credibility R_1 of the strict regulatory strategy implemented by local governments on the evolutionary steady state

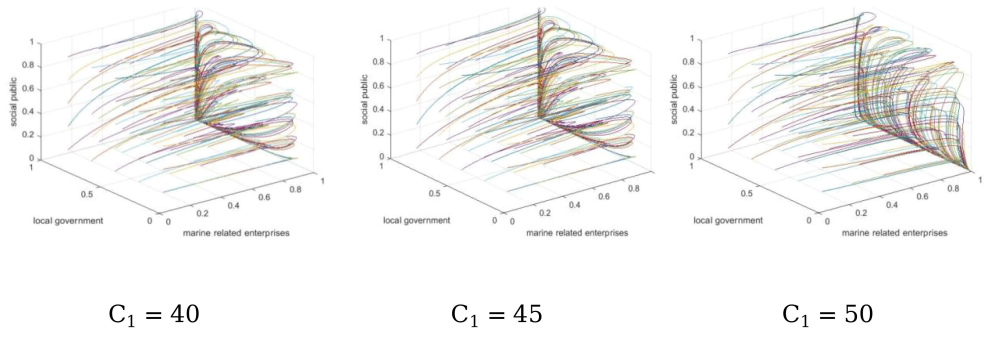
The impact of the government credibility, generated by local governments to implement the strict regulatory strategy, on the steady state of the evolutionary game, holding other parameters constant, is as follows. When R_1 = 50, R_1 = 60, then local governments will implement the strict regulation strategy. Under the strict regulation of local governments, marine enterprises will actively and consciously participate in the construction of the MESB in the Bohai Sea, and the three-party game will approach the stability point (1, 0, 0). When R_1 keeps increasing and reaches a certain level (R_1 = 70), the increase in the credibility of local governments will strengthen their important role in the construction of the MESB in the Bohai Sea; therefore, that they will give up the lax regulatory strategy and turn to the strict regulation strategy, and will continue to promote the steady implementation of the construction of the MESB. At this time, the three-party game will be close to (1, 1, 0), as shown in Figure 3.

This indicates that a higher government credibility, generated by the local governments' participation in the construction of the MESB in the Bohai Sea, will be more favorable to the formation of local government performance. This will not only strengthen the local governments' determination to perform strict regulation, but also be more favorable to promote the evolutionary trend of marine enterprises' participation in the construction of the MESB in the Bohai Sea.

6.3 The impact of government rewards for effective public supervisory reporting W, on the evolutionary steady state

The impact of the government reward for effective public supervisory reporting on the steady state of the evolutionary game, holding other parameters constant, is as follows. When W = 10, W = 20, then local governments will implement the strict regulatory strategy, marine enterprises will consciously and actively participate in the construction of the MESB in the Bohai Sea, and the three-party game will approach the stability point (1, 1, 0). When W keeps increasing and reaches a certain degree (W = 30), local governments, constrained by the increase in regulatory cost, will abandon the strict regulatory strategy and adopt the lax regulatory strategy, at which time the three-party game will be close to (1, 0, 0), as shown in Figure 4.

When the social public's awareness of marine ecological security reaches a certain level, the governments' reward incentives will fail, i.e., a further increase in investment in socially just rewards will not yield marginal benefits. In the higher call of marine ecological environmental protection, marine enterprises will actively participate in the construction of the MESB and incorporate it into their own development strategy, thereby showing the adoption of a regular behavior. At this point, the local governments will also gradually shift to lax regulation.



C_1 = 40 C_1 = 45 C_1 = 50

FIGURE 2
Regulatory cost evolution path of the strict regulatory strategy implemented by local governments.

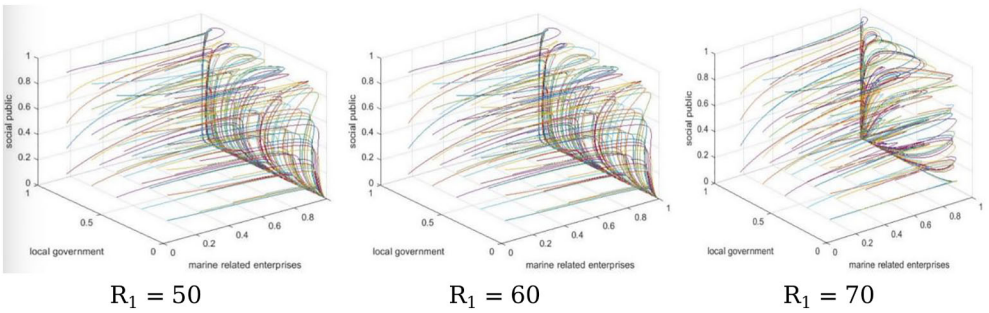


FIGURE 3
Government credibility evolution path of the strict regulatory strategy implemented by local governments.

7 Conclusions and policy implications

7.1 Conclusions

MESBs are the product of combining the concept of "ecological security barrier" with the strategy of "Maritime Power". Moreover, they are also a specific tool for the implementation of a land-sea integration strategy. In fact, they creatively combine the need for protection of the marine ecological environment with the objective of sustainable development of the marine economy, thereby not only ensuring the spatial security of national development, but also entailing economic benefits and ecological services to the region (Jiang and Li, 2021). This has become a strategic, forward-looking, and comprehensive management initiative in the sustainable development of marine ecology and environment. This study took the Bohai Sea, in China, as the research object, and used evolutionary game theory to construct a game model including local governments, marine enterprises, and the public. Through the analysis of the interests of each decision maker, this study investigated the strategies to actively construct the MESB in the Bohai Sea. Due to differences in cognition and interest motivation among decision makers, there will inevitably be certain conflicts and synergies in the decision-making actions. Therefore, the analysis of the conflict and cooperation among decision makers will help them make the right decision in favor of "Marine Ecological Civilization".

In order to contribute to the construction of the MESB in the Bohai Sea and provide a reference to guarantee regional marine ecological security, this study constructed a tripartite game model consisting of marine enterprises, local governments, and the public, and analyzed the evolutionary equilibrium conditions and evolutionary stabilization strategies of the three parties using MATLAB R2020a. The conclusions of the study are as follows.

First, the construction of the MESB in the Bohai Sea is a long-term, systematic and comprehensive project. In terms of the main participants, first, the Bohai Sea region (three provinces and one city) has large differences in the level of economic development and development, as well as in ecological and environmental governance capacity. Therefore, the construction of the MESB in the Bohai Sea needs to pay attention to the distribution of interests among local governments. In addition, the synergistic development of economic development and ecological security in the Bohai Sea region not only involves the behavior of local governments, but also is inseparable from the behavior of marine enterprises and the public. The intricate distribution of interests increases the difficulty of constructing the MESB in the Bohai Sea. Therefore, the construction of the MESB in the Bohai Sea requires top-level design and comprehensive integrated planning.

Secondly, the construction of the MESB in the Bohai Sea requires that the collaborative governance capacity of the local governments of the three provinces and one city be brought into full play. At different stages of the construction of the MESB in the Bohai Sea, local governments have different operational performance and strategic choices, which depend on the sum of

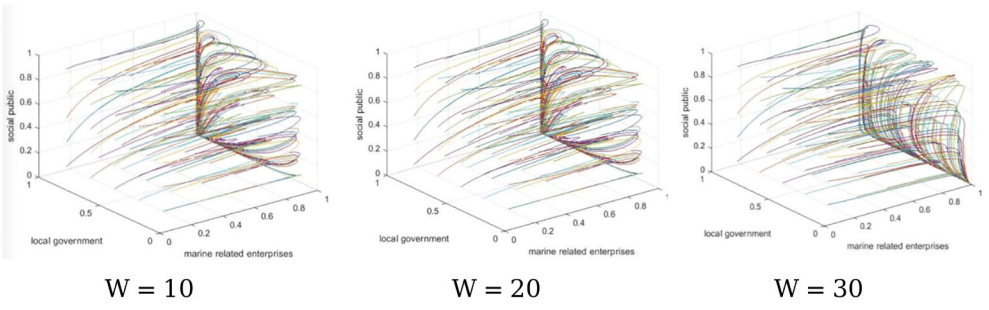


FIGURE 4
Government rewards evolution path of effective public supervisory reporting.

the costs, credibility and other benefits paid by the local governments under different strategic choices.

Thirdly, in the construction of the MESB in the Bohai Sea, the behavioral choices of enterprises involved in the sea are characterized by phases, which are mainly closely related to the costs paid and ecological losses caused by their participation.

Fourthly, whether the public monitors or not depends mainly on the cost it pays for monitoring. Therefore, it is particularly important to smooth the channels of public participation in the key aspects of promoting the construction of the MESB in the Bohai Sea.

In conclusion, in the construction of the MESB in the Bohai Sea, we should not only pay attention to the guiding and supervising role of the government, but also encourage the guiding role of the market economy, stimulate the vitality of the construction body of marine enterprises, and comprehensively promote the implementation of the MESB.

7.2 Policy implications

7.2.1 Improving the reward and punishment appraisal system and mechanism in the construction of the MESB in the Bohai Sea

Firstly, the central government should make an effort to realize the top-level design. Construct a comprehensive and systematic participation system for the Bohai MESB with the core of "Bohai Sea local governments–marine enterprises–the public", and clarify the responsibilities and rules for the distribution of benefits of each subject in the construction of the Bohai MESB. The responsibilities and benefit distribution rules of each subject in the construction of the barrier should be clarified.

Secondly, the central government and the Bohai Rim local governments need to formulate a comprehensive, systematic and long-term plan for the construction of the MESB in the Bohai Sea, taking into account the stage-by-stage characteristics of the construction of the MESB in the Bohai Sea and the distribution of benefits among the main parties at each stage, and to formulate a combination of mid- to long-term and short-term planning programs. In particular, in the early stages of the construction of MESB in the Bohai Sea, given the investment term mismatch in the construction of the MESB in the Bohai Sea, it is difficult for marine enterprises to actively participate from the early stage of construction. Therefore, it is necessary to innovate the operation mechanism of marine resources allocation, encourage the macro-control role of the government, and strengthen the guiding and supporting role of the government in the construction of the MESB. Specifically, first of all, we need to construct an optimized assessment and evaluation index system for the MESB in the Bohai Sea, integrating the internal, vertical "central government-local governments-government staff" assessment index system with the multi-body "local governments-enterprises-public" assessment index system, which is a multi-dimensional and comprehensive assessment and evaluation index system. Secondly, the assessment and evaluation of the MESB of the Bohai Sea will be incorporated into the performance appraisal of local governments and the assessment and selection of cadres. Finally, according to the evaluation index, we need to establish an effective reward and punishment mechanism for marine enterprises, and strengthen their rights and obligations in the construction of the MESB in the Bohai Sea. Preferential tax rates and subsidies can be used to reward active marine enterprises, and economic or legal recourse can be imposed on those enterprises that violate the construction of the MESB in the Bohai Sea, so as to comprehensively promote its construction.

7.2.2 Achieving the process and diversification of construction means and measures, and consciously encouraging the behavior of the construction subject

In the process of construction of the MESB in the Bohai Sea, any action will entail a cost. In order to maximize the benefits, the local governments of the "three provinces and one city" need to adopt targeted measures based on the stage characteristics of the construction of the MESB in the Bohai Sea. In the initial stage of construction, the government should strengthen the use of "hard means", i.e., administrative means. In the middle and late stages of construction, it should take the initiative to decentralize; moreover, it should let the market become the main place for marine resources allocation and ecological protection; and, through various forms of publicity and education, it should improve the ecological and environmental protection awareness of marine enterprises, so that the concept of marine ecological security is internalized into their production and operation behavior, and consciously becomes their main behavior. More in detail, education and propaganda can be combined with industry, academia, and research, so that the public and enterprises can master the knowledge of marine ecological resources and environment, improve their own ability to use them, improve the quality of marine ecological protection and sense of responsibility, and give full play to the enthusiasm for participation of multiple subjects, finally achieving a high degree of autonomy in "doing nothing is better than doing something", as well as the unity of ecological security and economic benefits.

7.2.3 Sound supervision mechanism for public participation in the construction of the MESB in the Bohai Sea

In order to smoothly promote the construction of the MESB in the Bohai Sea, it is necessary to open channels for the active participation of the public, e.g., by adopting a hearing system for major issues, and to enrich the tool for public participation, including through the use of a variety of social media, microblogging, WeChat, and Shake. In his way, it is possible to implement a social public supervision of local governments and marine enterprises, so that the MESB in the Bohai Sea can really be instrumental in coordinating the relationship between sea and land, as well as between human development and marine ecological protection, and in improving the supply of marine ecosystem services.

This study assumed two possible behaviors of marine enterprises, i.e., that they are either actively involved in the

construction of the MESB in the Bohai Sea, or not at all. However, in reality, with the evolution of the concept of "ecological security barrier", the majority of marine enterprises are involved in the construction of the MESB in the Bohai Sea under the supervision of local governments, even if they are passively involved. Therefore, future research should explore more deeply the participation behavior of marine enterprises.

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

DL: Visualization, Writing - Review & Editing, Writing - Original Draft. HC: Formal analysis, Methodology. TQ: Conceptualization, Writing - Review & Editing. All authors contributed to the article and approved the submitted version.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This study was supported by the Shandong Provincial Natural Science Foundation (Grant No. ZR2021MD073).

Conflict of interest

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

Publisher's note

References

Alongi, D. M. (2002). Present state and future of the world's mangrove forests. *Environ. Conserv.* 29 (3), 331–349. doi: 10.1017/S0376892902000231

Armstrong, J. M., and Ryner, P. C. (1980). *Ocean management: seeking a new perspective* (Washington, D.C. U.S: Department of Commerce, Office of Ocean, Resource, and Scientific Policy Coordination).

Bai J, Y., and Cheng, J. (2016). The construction of marine ecological security barrier: thoertical origins and system innovation. *J. Ocean Univ. China (Social Sciences)* 6, 19–25. doi: 10.16497/j.cnki.1672-335x.2016.06.003

Bakker, K. (2022). Smart Oceans: Artificial intelligence and marine protected area governance. *Earth System Governance* 13, 100141. doi: 10.1016/j.esg.2022.100141

Bao, J., Wu, D., Anning, C., and Hu, Z (2011). Overall strategy on developing China's land and ocean during the "Twelfth Five-year Plan" period geographic perspective. *China Soft Sci.* 5, 1–11.

Bennett, N. J., Di Franco, A., Calò, A., Nethery, E., Niccolini, F., and Milazzo, M. (2019). Local support for conservation is associated with perceptions of good governance, social impacts, and ecological effectiveness. *Conserv. Lett.* 12, e12640. doi: 10.1111/conl.12640

Cao, H. J., and Han, G. X. (2020). Research on the construction of interregional collaborative platform in the process of building the Bohai Sea marine ecological security barrier. *Chin. Fisheries Economics* 2, 64–71.

Cao, H. J., and Xie, Y. F. (2021). The research on the construction of marine ecological security barrier in the Bohai Sea. *J. Ocean Univ. China (Social Sciences)* 1, 21–31. doi: 10.16497/j.cnki.1672-335x.202101003

Cheng, Y., Li, Y., and Zhao, M. (2019). Experience and lessons of EU marine spatial planning: The perspective of land and sea territorial integration Urban Plan. *Forum* 5, 59–67. doi: 10.16361/j.upf.201905006

Costanza, R. (1999). The ecological, economic, and social importance of the oceans. *Ecol. economics* 31 (2), 199–213. doi: 10.1016/S0921-8009(99)00079-8

Cunha, N. S., and Magalhaes, M. R. (2019). Methodology for mapping the national ecological network to mainland Portugal: A planning tool towards a green infrastructure. *Ecol. Indic.* 104, 802–818. doi: 10.1016/j.ecolind.2019.04.050

Doherty, E., Murphy, G., and Hynes, S. (2014). Valuing ecosystem services across water bodies: Results from a discrete choice experiment. *Ecosystem Serv.* 7, 89–97. doi: 10.1016/j.ecoser.2013.09.003

Douvere, F., and Maes, F. (2009). *The contribution of marine spatial planning to implementing integrated coastal zone management* (London UK: Coastal zone management), 13–30.

Du, Y. W., and Cao, W. M. (2022). DEPD model for evaluating marine ranching ecological security and its application in Shandong, China. *Ocean Coast. Manage.* 224, 106206. doi: 10.1016/j.ocecoaman.2022.106206

Du, Y. W., and Li, X. X. (2022). Critical factor identification of marine ranching ecological security with hierarchical DEMATEL. *Mar. Policy* 138, 104982. doi: 10.1016/j.marpol.2022.104982

Du, Y. W., and Wang, Y. C. (2021). Evaluation of marine ranching resources and environmental carrying capacity from the pressure-and-support perspective: A case study of Yantai. *Ecol. Indic.* 126, 107688. doi: 10.1016/j.ecolind.2021.107688

Du, Y. W., Wang, Y. C., and Li, W. S. (2022). Emergy ecological footprint method considering uncertainty and its application in evaluating marine ranching resources and environmental carrying capacity. *J. Clean. Prod.* 336, 130363. doi: 10.1016/j.jclepro.2022.130363

Gacutan, J., Galparsoro, I., Pınarbaşı, K., Murillas, A., Adewumi, I. J., Praphotjanaporn, T., et al. (2022). Marine spatial planning and ocean accounting: synergistic tools enhancing integration in ocean governance. *Mar. Policy* 136, 104936. doi: 10.1016/j.marpol.2021.104936

Gao, J., An, T., Shen, J., Zhang, K., Yin, Y., Zhao, R., et al. (2022). Development of a land-sea coordination degree index for coastal regions of China. *Ocean Coast. Manage.* 230, 106370. doi: 10.1016/j.ocecoaman.2022.106370

Gao, L., Ning, J., Bao, W., Yan, A., and Yin, Q. (2022). A study on the marine ecological security assessment of Guangdong-Hong Kong-Macao Great Bay Area. *Mar. pollut. Bull.* 176, 113416. doi: 10.1016/j.marpolbul.2022.113416

García-Ayllón, S. (2019). New strategies to improve co-management in enclosed coastal seas and wetlands subjected to complex environments: Socio-economic analysis applied to an international recovery success case study after an environmental crisis. *Sustainability* 11 (4), 1039. doi: 10.3390/su11041039

Granit, J., Liss Lymer, B., Olsen, S., Tengberg, A., Nõmmann, S., and Clausen, T. J. (2017). A conceptual framework for governing and managing key flows in a source-to-sea continuum. *Water Policy* 19 (4), 673–691. doi: 10.2166/wp.2017.126

Guangnian, X., Qiongwen, L., Anning, N., and Zhang, C. (2023). Research on carbon emissions of public bikes based on the life cycle theory. *Transportation Lett.* 15 (4), 278–295. doi: 10.1080/19427867.2022.2123142

Guo, E. G., Li, X. H., Qi, Y., and Zhang, S. L. (2021). Protection and construction of the national Northern important ecological security barrier. *Chin. J. Environ. Manage.* 2), 80–85. doi: 10.16868/j.cnki.1674-6252.2021.02.080

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., and D'Agrosa, C. (2008). A global map of human impact on marine ecosystems. *Science* 319 (5865), 948–952. doi: 10.1126/science.1157390

Hou, B., Yue, W. Z., Ma, R. F., Wang, T., and Jia, Y. (2022). Research on the challenges and realization path of sea-land coordination in territorial spatial planning. *J. Nat. Resour.* 37, 880–894. doi: 10.31497/zrzyxb.20220404

Hughes, T. P., Baird, A. H., Bellwood, D. R., Card, M., Folke, C., and Grosberg. (2003). Climate change, human impacts, and the resilience of coral reefs. *Science* 301 (5635), 929–933.

Jiake, Q. I. N., Rucan, F. U., Shengqi, N., Yongkui, Z., Maoyuan, Y. U., and Yilin, M. A. (2011). Study on the protection and development of ecological barrier in Guangxi Beibu gulf. *For. Resour. WANAGEMENT* 5, 30.

Jiang, S. S., and Li, J. M. (2021). Exploring the motivation and effect of government-enterprise collusion in the utilization of marine resources: Evidence from China's coastal areas. *Ocean Coast. Manage.* 212, 105822. doi: 10.1016/j.ocecoaman.2021.105822

Jiang, Y., Zhang, J., Chen, K., Xue, X., and Michael, A. U. (2019). Moving towards a systematic marine eco-compensation mechanism in China: Policy, practice and strategy. *Ocean Coast. Manage.* 169, 10–19. doi: 10.1016/j.ocecoaman.2018.12.002

Kaiwen, P., Ning, W., Kaizhong, P., and Qing-Heng, C. (2004). A discussion on the issues of the re-construction of ecological shelter zone on the upper reaches of the Yangtze River. *Acta Ecologica Sin.* 24 (3), 617–629. doi: 10.2116/analsci.20.717

Kirwan, M. L., Guntenspergen, G. R., d'Alpaos, A., and James, T. (2010). Limits on the adaptability of coastal marshes to rising sea level. *Geophys. Res. Lett.* 37 (23), 1–5. doi: 10.1029/2010GL045489

Kong, F., Cui, W., and Xi, H. (2021). Spatial–temporal variation, decoupling effects and prediction of marine fishery based on modified ecological footprint model: Case study of 11 coastal provinces in China. *Ecol. Indic.* 132, 108271. doi: 10.1016/j.ecolind.2021.108271

Lazzari, N., Martin-Lopez, B., Sanabria-Fernandez, J. A., and Becerro, M. (2020). Alpha and beta diversity across coastal marine social-ecological systems: Implications for conservation. *Ecol. Indic.* 109, 105786. doi: 10.1016/j.ecolind.2019.105786

Li, C., Wu, Y., Gao, B., Zheng, K., Wu, Y., and Li, C. (2021). Multi-scenario simulation of ecosystem service value for optimization of land use in the Sichuan-Yunnan ecological barrier, China. *Ecol. Indic.* 132, 108328. doi: 10.1016/j.ecolind.2021.108328

Li, H. M., Tang, H. J., Shi, X. Y., Zhang, C., and Wang, X. (2014). Increased nutrient loads from the Changjiang (Yangtze) River have led to increased harmful algal blooms. *Harmful Algae* 39, 92–101. doi: 10.1016/j.hal.2014.07.002

Limin, H., and Ning, L. (2007). Theoretical reflections on sea-land integration. *J. Pacific* 08), 82–87. doi: 10.14015/j.cnki.1004-8049.2008.03.012

Liu, C. H., Sun, Y., and Han, Y. (2021). Regional environmental governance of the Yellow Sea and Bohai Sea from the perspective of land and sea coordination: Conference report. *Mar. Policy* 127, 104446. doi: 10.1016/j.marpol.2021.104446

Lu, J., Wu, X., and Wu, Y. (2023). The construction and application of dual-objective optimal speed model of liners in a changing climate: taking Yang Ming route as an example. *J. Mar. Sci. Eng.* 11 (1), 157. doi: 10.3390/jmse11010157

Mallory, T. G., Chubb, A., and Lau, S. (2022). China's ocean culture and consciousness: Constructing a maritime great power narrative. *Mar. Policy* 144, 105229. doi: 10.1016/j.marpol.2022.105229

Maretti, C. C., Leão, A. R., Prates, A. P., Simões, E., and Subirá., R. J. (2019). Marine and coastal protected and conserved areas strategy in Brazil: Context, lessons, challenges, finance, participation, new management models, and first results. *Aquat. Conserv: Mar. Freshw. Ecosyst.* 29 (S2), 44–70. doi: 10.1002/aqc.3169

Maynard Smith, J. (1974). The theory of games and the evolution of animal conflicts. *J. Theor. Biol.* 47 (1), 209–221. doi: 10.1016/0022-5193(74)90110-6

Millette, K. L., Gonzalez, A., and Cristescu, M. E. (2020). Breaking ecological barriers: Anthropogenic disturbance leads to habitat transitions, hybridization, and high genetic diversity. *Sci. Total Environ.* 740, 140046. doi: 10.1016/j.scitotenv.2020.140046

Ministry of Infrastructure and Environment (2013). *Summary national policy strategy for infrastructure and spatial planning: making The Netherlands competitive, accessible, liveable and safe*. Available at: https://www.government.nl/binaries/government/documenten/publications/2013.

Mol, A. P. J., and Spaargaren, G. (2000). Ecological modernisation theory in debate: A review[J]. *Environ. Politics* 9 (1), 17–49.

Murphy, E. L., Bernard, M., Gerber, L. R., and Dooley, K. J. (2021). Evaluating the role of market-based instruments in protecting marine ecosystem services in wild-caught fisheries. *Ecosystem Serv.* 51, 101356. doi: 10.1016/j.ecoser.2021.101356

Perry, R. I., Barange, M., and Ommer, R. E. (2010). Global changes in marine systems: A social–ecological approach. *Prog. Oceanogr.* 87 (1-4), 331–337. doi: 10.1016/j.pocean.2010.09.010

Pinillos, F. J. V., Muñoz, J. M. B., and Ríos, F. T. (2023). Delimiting coastal zones for integrated management: The case of the island and the sea of Chiloé (Chile). *Mar. Policy* 150, 105535. doi: 10.1016/j.marpol.2023.105535

Scott, T. A., and Thomas, C. W. (2017). Winners and losers in the ecology of games: Network position, connectivity, and the benefits of collaborative governance regimes. *J. Public Administration Res. Theory* 27 (4), 647–660. doi: 10.1093/jopart/mux009

Singh, A., and Mee, L. (2008). Examination of policies and MEAs commitment by SIDS for sustainable management of the Caribbean Sea. *Mar. Policy* 32 (3), 274–282. doi: 10.1016/j.marpol.2007.06.004

Smith, H. D., Maes, F., Stojanovic, T. A., and Ballinger, R. C. (2011). The integration of land and marine spatial planning. *J. Coast. Conserv.* 15, 291–303. doi: 10.1007/s11852-010-0098-z

Smith, J. M., and Price, G. R. (1973). The logic of animal conflict. *Nature* 246 (11), 5. doi: 10.1038/246015a0

Song, N. Q., Wang, N., Lin, W. N., and Wu, N. (2017). Use of pollution risk and ecosystem service values in marine management strategies in Bohai Sea, China. *Hum. Ecol. Risk Assessment: Int. J.* 23 (5), 1041–1055. doi: 10.1080/10807039.2017.1297675

Turner, J., and Essex, S. (2016). Integrated terrestrial and marine planning in England's coastal inter-tidal zone: Assessing the operational effectiveness of the Coastal Concordat. *Mar. Policy* 72, 166–175. doi: 10.1016/j.marpol.2016.07.014

Walsh, C. (2021). Transcending land–sea dichotomies through strategic spatial planning. *Regional Stud.* 55 (5), 818–830. doi: 10.1080/00343404.2020.1766671

Wang, J., Beusen, A. H. W., Liu, X., Van Dingenen, R., Dentener, F., and Yao, Q. (2020). Spatially explicit inventory of sources of nitrogen inputs to the Yellow Sea, East China Sea, and South China Sea for the period 1970–2010. *Earth's Future* 8 (10), e2020EF001516. doi: 10.1029/2020EF001516

Wang, C., Chen, J., Li, Z., Nasr, E. S. A., and El-Tamimi, A. M. (2019). An indicator system for evaluating the development of land-sea coordination systems: A case study of Lianyungang port. *Ecol. Indic.* 98, 112–120. doi: 10.1016/j.ecolind.2018.10.057

Wang, Y. C., and Du, Y. W. (2023). Evaluation of resources and environmental carrying capacity of marine ranching in China: An integrated life cycle assessment-emergy analysis. *Sci. Total Environ.* 856, 159102. doi: 10.1016/j.scitotenv.2022.159102

Xia, J., Zhu, W., Liu, X., Ren, Y., Huang, J., and Zhu, M. (2022). The effect of two types of grid transplantation on coral growth and the *in-situ* ecological restoration in a fragmented reef of the South China Sea. *Ecol. Eng.* 177, 106558. doi: 10.1016/j.ecoleng.2022.106558

Xin, M., Wang, B., Xie, L., Sun, X., and Chen, K. (2019). Long-term changes in nutrient regimes and their ecological effects in the Bohai Sea, China. *Mar. pollut. Bull.* 146, 562–573. doi: 10.1016/j.marpolbul.2019.07.011

Xu, L., Shi, J., and Chen, J. (2023). Agency encroachment and information sharing: cooperation and competition in freight forwarding market. *Maritime Policy Manage.* 50 (3), 321–334. doi: 10.1080/03088839.2021.1990428

Xue, J., Li, Z., Feng, Q., Gui, J., and Zhang, B. (2022). Spatiotemporal variations of water conservation and its influencing factors in ecological barrier region, Qinghai-Tibet Plateau. *J. Hydrol.: Regional Stud.* 42, 101164. doi: 10.1016/j.ejrh.2022.101164

Yang, Y., Liang, S., Li, K., Li, Y., Li, J., and Wang, X. (2022). Integrated water-quality management indicators from river to sea: A case study of the Bohai Sea, China. *Mar. pollut. Bull.* 185, 114320. doi: 10.1016/j.marpolbul.2022.114320

Yi, X., Sheng, K., Wang, Y., and Wang, S. (2021). Can economic development alleviate storm surge disaster losses in coastal areas of China? *Mar. Policy* 129, 104531. doi: 10.1016/j.marpol.2021.104531

Yu, J., Zhang, W., Tan, Y., Zong, Z., and Zhang, G. (2021). Dual-isotope-based source apportionment of nitrate in 30 rivers draining into the Bohai Sea, north China. *Environ. pollut.* 283, 117112. doi: 10.1016/j.envpol.2021.117112

Yue, W., Hou, B., Ye, G., and Wang, Z. (2023). China's land-sea coordination practice in territorial spatial planning. *Ocean Coast. Manage.* 237, 106545. doi: 10.1016/j.ocecoaman.2023.106545

Zaucha, J., and Gee, K. (2019). *Maritime spatial planning: past, present, future* (Berlin, Germany: Springer Nature).

Zhang, C., Guo, L., Luo, Q., Wang, Y., and Wu, G. (2022). Research on marine plastic garbage governance in Northwest Pacific Region from the perspective of cooperative game. *J. Clean. Prod.* 354, 131636. doi: 10.1016/j.jclepro.2022.131636

Zhang, Y., Wu, T., Arkema, K. K., Han, B., and Ouyang, Z. (2021). Coastal vulnerability to climate change in China's Bohai Economic Rim. *Environ. Int.* 147, 106359. doi: 10.1016/j.envint.2020.106359