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The practice and innovation of compatible marine utilization models in China

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Marine Spatial Planning (MSP) is essential for optimizing marine resources allocation and resolving conflicts in sea use, but it is challenged by the complex and multi-functional nature of maritime resources. This study utilizes participatory methods, inductive reasoning, and overlay analysis to explore both theoretical and practical aspects of compatible marine utilization models. The paper begins by clarifying the logic of compatible sea use through marine functional zoning and identifying its core characteristics: quantity, spatial conflict, and impacts on natural attributes. Building on China's national territorial spatial planning reforms and practical experiences, the paper introduces three major categories of compatible marine use models: development sequencing compatibility, spatial coexistence compatibility, and functional synergy compatibility. A compatibility discrimination matrix is developed to assess these models across different marine functional areas. Combined with the compatibility discrimination results, taking the marine and coastal spatial planning of Yantai City in China as a case study, the paper analyzes the compatibility demands and planning strategies within various marine functional areas. Finally, it evaluates the risks associated with each compatibility model and proposes targeted control strategies tailored to the specific features of each model and characteristics of sea use activities. The research findings highlight the positive role of compatible sea use models in promoting marine economic development, enhancing spatial efficiency, and mitigating sea use conflicts. However, these models also present varying potential risks, necessitating differentiated control strategies aligned with legal frameworks and specific sea use activities. The study offers valuable insights for MSP and contributes to the efficient utilization of marine resources and the advancement of marine spatial governance.

KEYWORDS

compatible marine use, marine spatial planning, marine functional zoning, development sequencing, spatial coexistence, functional synergy, compatibility discrimination

1 Introduction

Since the 21st century, the development and utilization of marine resources have significantly bolstered the economic and social progress of coastal regions, with the marine economy emerging as one of the most dynamic and promising areas for economic growth. With the expansion of the large-scale marine development and utilization, Marine Spatial Planning (MSP) has become essential in regulating development order and optimizing resource allocation. It has increasingly established itself as a foundational tool for comprehensive marine management. The global initiative for MSP originated from the establishment of national marine protected areas, aimed at resolving conflicts between human marine activities and marine environmental protection (Xu, 2015). In 1976, marine nations and international organizations proposed the concept of MSP, initially aimed at establishing marine protected areas to address ecological and environmental degradation caused by human activities, such as the zoning plan for the Great Barrier Reef in Australia during the 1980s, although this differs significantly from the current multi-objective MSP. In 1992, the United Nations Conference on Environment and Development released Agenda 21, introducing the concept of Integrated Coastal Zone Management and offering related recommendations and measures for addressing challenges in marine spatial management. At the World Summit on Sustainable Development in 2002, governments' commitments to effective utilization of marine resources, optimization of marine spatial resource allocation, and establishment of marine protected areas promoted the development of MSP. In 2006, UNESCO hosted the first MSP workshop, formally proposing an ecosystem-based approach to MSP. In 2009, UNESCO's Intergovernmental Oceanographic Commission (IOC) published "Marine Spatial Planning: A Step-by-Step Approach toward Ecosystem-based Management," outlining ten steps for global reference and providing a robust foundation for advancing MSP worldwide. Under the initiative of the United Nations and the European Union, several important marine nations formulated relevant laws for MSP (Zhang, 2022). In 2017, UNESCO held the second MSP workshop, which, upon reviewing the current status and future trends of MSP worldwide, identified five MSP priority areas, viewing MSP as an important means to achieve Sustainable Development Goals (Ma and Yu, 2022). The same year, the IOC-UNESCO adopted a "Joint Roadmap to accelerate Marine Spatial Planning processes worldwide." To accelerate the implementation of MSP globally, the IOC-UNESCO and the European Commission launched the MSP Global 2030 initiative in February 2019. In 2022, the IOC-UNESCO and the European Commission co-hosted the third International Conference on MSP. The conference evaluated recent MSP implementations and discussed the challenges and opportunities in achieving the priorities and goals outlined in the MSP roadmap, with the aim of covering at least one-third of the global marine areas under national jurisdiction through MSP by 2030. According to *State of the Ocean Report 2024*, by 2023, 126 countries and regions had implemented region-based marine management policies, and 45 countries or regions had approved national, sub-national, and/or local-level MSP (Ahern et al., 2024). MSP is increasingly being used as a tool for multi-sectoral participation and coordination of diverse interests, especially in the context of developing a sustainable ocean economy. This trend not only underscores the global recognition of the importance of sustainable ocean development but also highlights the international community's efforts to achieve Sustainable Development Goal 14 (SDG 14), which aims to conserve and sustainably use the oceans and marine resources. The core objective of MSP is to scientifically allocate marine resources and orderly conduct marine activities to alleviate the pressure of human activities on marine ecosystems. Current MSP advocates for the sustainable use and management of marine resources by balancing ecological, social, and economic objectives, namely multi-objective MSP. In this framework, the ocean is treated as a multi-use environment, where activities such as fisheries, shipping, tourism, and energy development occur, often competing with or conflicting with one another (Lombard et al., 2019). The success of MSP hinges on several key factors. (i) Participation of multiple stakeholders (Wilke, 2023; Borja et al., 2024). Involving multiple stakeholders in the planning process is crucial for MSP success. Effective stakeholder participation reduces transaction costs and mitigates conflicts through knowledge sharing, ultimately enhancing the efficiency of planning efforts (Zaucha and Kreiner, 2021). (ii) Ecosystem Service Assessment (Lester et al., 2020; Lonsdale et al., 2020; Basirati et al., 2021; Lippi et al., 2024). Evaluating the capacity of different marine areas to provide specific ecosystem services is essential. This assessment supports planners in the efficient allocation of spatial resources, ensuring the protection and rational use of areas with high-value services (Lombard et al., 2019). (iii) Application of Decision Support Tools (DSTs). MSP relies on an evidence-based decision-making process (Pınarbaşı et al., 2019) to achieve sustainable marine resource use and ecosystem service management. DSTs serve as technical platforms for mapping marine geographic data, exploring various marine use scenarios, and analyzing interactions among different marine activities and the environment. These tools are instrumental in conducting trade-off analyses and making informed decisions that balance competing uses of marine space (Bonnevie et al., 2019). Despite significant progress in MSP implementation globally, there remain disparities across different regions. This suggests the need for further research and understanding of the specific demands and challenges of MSP implementation in various regions.

China's earliest practices in MSP began in the late 1980s with the implementation of small-scale marine functional zoning. This was followed by the "National Marine Functional Zoning (2001-2010)" and "National Marine Functional Zoning (2011-2020)" in the 21st century. During this period, provincial and municipal governments in China, based on the national-level marine functional zoning, synchronized the compilation and implementation of provincial and municipal marine functional zoning, thus establishing a three-tiered "national-provincial-county" marine functional zoning system. In 2012, the Chinese government issued and implemented the "National Island Protection Plan," with coastal provinces and cities simultaneously developing their own island protection plans. In 2015, the "National Marine Primary Function Zone Planning" was introduced, and coastal provincial governments also initiated provincial marine primary function zone plans. This established a MSP system in China, which includes marine functional zoning, island protection planning, and marine main functional area planning. By 2018, the establishment of the Ministry of Natural Resources led to the reform of territorial spatial planning starting in 2019, integrating marine spatial plans with land spatial planning into a unified territorial spatial planning system, thereby achieving "integration of multiple regulations." Despite this, the marine component of territorial spatial planning is still commonly referred to as MSP. Currently, national, provincial, and county territorial spatial plans have been successively approved and implemented, serving as a crucial framework for regulating marine development and utilization activities and implementing comprehensive marine management.

Within China's territorial spatial planning system, the use of sea areas often has a uniqueness, lacking consideration for the compatibility of marine functions. In recent years, with the emergence of more new marine industries, the methods of marine development and utilization have become more diverse, and some marine activities cannot be implemented because they do not comply with MSP. For example, if a sea area is designated for aquaculture use, but in recent years, the aquaculture industry and tourism have become deeply integrated, with aquaculture entities hoping to develop seawater aquaculture and marine tourism activities simultaneously through the construction of aquaculture platforms. However, due to the unique functions of marine areas, the implementation of other activities is restricted, making it challenging to apply the "aquaculture + tourism" model effectively. Therefore, the key to solving the above problems lies in emphasizing the need for compatible functions in MSP. With decades of development, management departments have increasingly recognized the importance of marine function compatibility in marine spatial management. Hence, the new technical guidelines for territorial spatial planning require "the establishment of a spatial use access evaluation system for natural resource development and utilization areas, clarification of the access requirements for regional development and utilization, and identification of permissible and compatible types of sea use." Additionally, various coastal provinces in China have also issued documents encouraging the compatible use of marine functional areas. It can be anticipated that with the continuous emergence of new marine industries and models, marine development and utilization will increasingly transition from a single-industry focus to a multi-industry integration model. This shift will further emphasize the spatial complexity of marine areas. Consequently, there is an urgent need for management departments to refine MSP concepts and systems to support high-quality marine development.

However, due to insufficient attention from the academic community and management departments on compatible marine use, existing research in European countries mainly focuses on the coordination of marine activities at the project implementation level, without addressing the broader relationship between marine activities and planning. In contrast, research in China tends to concentrate on the degree of compatibility (typically categorized as compatible, conditionally compatible, or incompatible), lacking a comprehensive approach to compatible marine use, and many management needs remain underexplored. For this reason, this paper adopts methods such as participatory approach, inductive reasoning, and overlay analysis to conduct theoretical research on compatible marine use. By examining research and practices on spatial compatibility both domestically and internationally, this study aims to elucidate the concept and fundamental principles of compatible marine use from the perspective of MSP. Based on practical needs, the paper classifies and identifies compatible marine use models, proposing specific models comprising three major categories and six subcategories. Additionally, the study analyzes the basic demands and characteristics of compatible marine use in the context of marine and coastal spatial planning practice in Yantai, China. Finally, taking into account China's legal framework and marine management practices, the paper assesses the potential risks associated with various compatible models and provides suggestions for spatial control (Shown as Figure 1). The findings of this study may have practical significance for optimizing MSP concepts and systems and promoting high-quality marine development. Through further research and practice, we hope to provide more comprehensive and in-depth theoretical support for sea area management and spatial planning implementation.

2 Research and practice progress

2.1 Research and practice of compatible marine use in China

In land use management, compatibility encompasses two aspects: first, the feasibility of different land use types coexisting on the same parcel of land, known as "land use compatibility"; and second, the ability to select and modify land use types, which is reflected in the "flexibility," "adaptability," and "suitability" of land use (Zheng and Hu, 2019). As urban land demand evolves towards diversification and complexity, the management challenges faced by classification standards based solely on single-use function have led some scholars in recent years to explore key methods for promoting efficient and intensive land use — mixed land use (Jiang et al., 2022). The theory of mixed land use from a compatibility perspective underscores the coordinative characteristics among various land uses, highlighting the relational attributes between different land types (Jiang et al., 2014; Wang, 2018). Most related studies are qualitative analyses focusing on the compatibility of functions within a single land use, based on planning management policies, standards (Wu, 2005; He, 2006; Zhao and Tang, 2008), or urban residents' behavioral characteristics to determine compatibility (Zhong, 2009). To reduce subjectivity in the determination process, some scholars have attempted to quantify descriptions by calculating compatibility, including constructing land use compatibility judgment matrix to perform multi-scale measurements of mixed land use (Zheng, 2018), and measuring

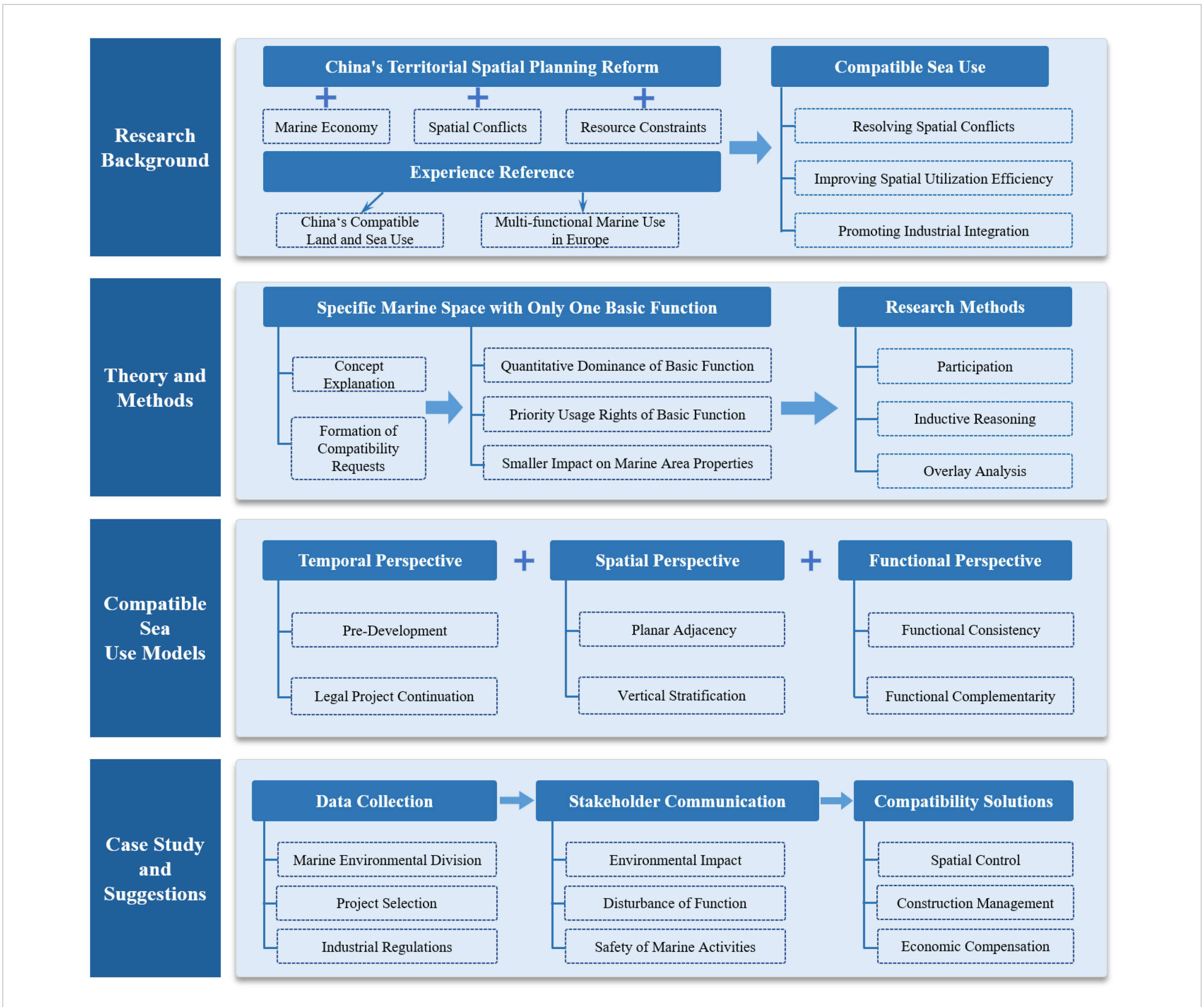

FIGURE 1
Research framework.

compatibility between plots at the dual scale of plots and blocks (Shi et al., 2021).

With the implementation of marine functional zoning systems, Chinese government has introduced the concept of compatible marine use in the 1990s, initially integrating it into provincial marine functional zoning frameworks (Wang and Liu, 2011). In the management of marine area use, the conformity analysis of marine functional zoning has emerged as a critical component of the demonstration and approval processes for marine area utilization. This topic has garnered extensive discussion within the academic community. Scholars have explored the intrinsic characteristics of conformity in marine functional areas and have developed criteria for assessing marine function compatibility (Xu et al., 2010; Ding et al., 2019; Ma et al., 2022). Moreover, researches on marine spatial use regulation has consistently emphasized the importance of functional compatibility (Zhao et al., 2020; Zhou et al., 2021).

2.2 Research and practice on the multi-use in European Seas

Globally, the rapid expansion of the developing marine economy has heightened demand for marine space, making the scarcity of marine resources increasingly evident. Spatial conflicts among different marine activities are intensifying, leading coastal nations to focus more on the coordination and efficiency of marine development and utilization. In this context, the "multi-use" model has emerged as a leading international approach for compatible marine use. This model allows single or multiple marine entities to share marine space resources in geographically adjacent areas, making the use of specific marine zones less exclusive. By enabling multiple entities to share spatial rights (Lukic et al., 2018a; Schultz-Zehden et al., 2018), the model aims to maximize economic and social benefits while reducing conflicts over marine use (Schupp et al., 2019). Practically, this often involves combining different marine activities in the same location or integrated them on multi-use platforms.

Early multi-use of seas focused on developing multi-functional marine facilities or directly connecting marine facilities to expand aquaculture production (Buck, 2001; Buck, 2002). Since then, the industry has begun extensive research on various marine multi-use combinations (Buck et al., 2008), including multi-use combinations of wind and wave energy generation (Perez-Collazo et al., 2015), coexistence of offshore wind farms with marine conservation (Lacroix and Pioch, 2011; Kyriazi et al., 2015; Kyriazi et al., 2016), and the integration of fisheries with tourism (Piasecki et al., 2016), achieving an organic integration of nature and culture (Kyvelou, 2019). In 2016, the Multi-Use in European Seas (MUSES) project, funded by the EU Horizon 2020 program and coordinated by the Scottish Marine Alliance and project partners across Europe, aimed to deeply investigate and assess multi-use sea activities in European sea basins by establishing an analytical framework. The MUSES project identified and analyzed high-feasibility multi-use sea combinations, including offshore wind energy, aquaculture, and environmental protection (Lukic et al., 2018). For example, incorporating environmental protection measures within offshore wind farms, such as the establishment of artificial reefs and marine protected areas, can enhance biodiversity and provide valuable ecosystem services (Przedrzymirska et al., 2018). The project examined the drivers behind multi-use sea activities, including policy support, technological innovation, market demand, and environmental protection needs. It also highlighted the challenges facing multi-use sea activities, such as uncertainties in legal and regulatory frameworks, technical complexity, economic feasibility issues, and the need for effective stakeholder coordination. The project emphasizes exploring highly technical, innovative, and industrialized solutions, including multi-use platforms and other "soft" ways of marine space-sharing models. Examples include coastal and maritime tourism, small-scale fisheries, and governance work, etc. Multi-use platforms, such as those developed by the TROPOS project, aim to integrate modules for various compatible marine activities, like floating power plants that combine different marine renewable energies such as wind, tidal, and wave energy (Quevedo et al., 2013). Fully integrated multi-component and multi-use platforms can serve as the main infrastructure shared by multiple uses, for example, the H2Ocean project designed a platform that combines renewable energy collection, hydrogen generation, aquaculture, and environmental monitoring (Stuiver et al., 2016). According to related research, the main driving factors for multi-use of seas include the increasing demand from citizens for sustainable tourism, green energy, high-quality food, etc. Its main constraints include the lack of coordination mechanisms, licensing procedures and risks, lack of sufficient incentives, technical and financial support, fragmented sector management, stakeholder coordination, and the general public's lack of awareness (Lukic et al., 2018b).

Multi-use of seas encompasses both the use of multi-use platforms and the shared utilization of marine space. Multi-use platforms are physical structures designed to support a variety of marine activities simultaneously. On the other hand, the shared utilization of marine space involves different marine activities coexisting within the same area, aiming to achieve complementarities and mutual benefits through the joint use of space or infrastructure. Schupp et al (Zhao et al., 2020), based on the connectivity in spatial, temporal, provisioning, and functional dimensions, classified "multi-use of seas" into four types: (i) Multi-functional, where diverse marine activities occur simultaneously in the same area with shared services and core infrastructure; (ii) Symbiotic use, where activities co-occur in the same marine space and share common peripheral infrastructure or services; (iii) Coexistence, where marine activities take place simultaneously in the same location; (iv) Repurposing, where activities occur sequentially over time within the same marine space. Furthermore, distinctions can be made between multiple uses achieved by a single marine entity and those involving several entities, such as offshore wind farms combined with mariculture (Di Tullio et al., 2018), aquaculture and wave energy generation (Quevedo et al., 2013), the combination of fisheries, tourism, and environmental protection (Calado et al., 2019), and multi-use combination cases driven by the tourism, renewable energy, and oil and gas industries in several Mediterranean countries (Depellegrin et al., 2019). Combining activities can streamline marine operations, reduce costs, and address spatial needs (European Commission, 2019). For example, aquaculture near offshore wind farms can achieve synergistic effects by lowing operational and maintenance costs (Buck et al., 2010; Lagerveld et al., 2014; Röckmann et al., 2017). Van den Burg et al (Van den Burg et al., 2019), identified that the greatest potential for integrated use lies within 16 nautical miles offshore and at depths of 100 meters or less.

In practice, the multi-use of seas generally falls into two main types: hard multi-use and soft multi-use. Hard multi-use involves long-term installation of significant industrial and engineering infrastructure, such as offshore wind energy production platforms or oil and gas extraction platforms, and is predominantly observed in Nordic countries. In contrast, soft multi-use encompasses activities like small-scale fisheries and tourism that do not require extensive infrastructure and are more prevalent in southern European countries where tourism is a major economic driver (Bocci et al., 2019).. The former focuses on technological advancements and innovations, while the latter emphasizes the sustainability of the practical process (Bocci et al., 2018).

3 Theory and method

3.1 The concept and the fundamental logic of compatible marine use

The term "compatibility" originally originates from computer science, describing the degree of coordination between hardware, software, or their combinations. Over time, this concept has broadened to other fields, where it signifies the ability of different elements, components, or systems to coexist harmoniously, adapt to one another, and support or complement each other. In the early stages of MSP implementation in China, the principle that "a specific sea area has only one basic function" was established to regulate marine development. As practice evolved, the concept of "compatible functions" emerged. Unlike "basic functions," which are prioritized for marine space development, "compatible functions" refer to other permissible uses that can only be implemented after thorough assessment, provided they do not impact the basic functions. Therefore, in marine spatial planning and management, compatibility is generally regarded as the coordination between marine activities and the fundamental functions of marine areas, specifically indicating scenarios where marine activities may not align directly with basic functions but do not impede their performance.

After years of practice, management departments and marine planners widely agree that developing marine spatial plans, categorizing marine areas into various functional types, and establishing regulatory rules are essential prerequisites for effective marine spatial management. The purpose of MSP is to allocate different marine activities in a scientific and rational manner, thereby regulating the order of marine use. The primary approach is to allocate similar types of marine activities to designated areas, creating distinct zones with varying functions (i.e., marine functional areas). This strategy enables the implementation of differentiated regulations tailored to the specific functions of each area. Marine functional areas are objectively influenced by the natural characteristics of the sea area, including factors such as natural resource conditions, environmental status, and geographical location. Since sea areas often contain multiple types of natural resources such as marine biological, chemical, landscape, and mineral resources, they can serve multiple functions, including marine aquaculture, coastal tourism, and mineral extraction. Therefore, planners need to further consider factors such as socio-economic development needs, national policies, or regional marine industry development advantages. They should exclude other functions and select the most suitable, efficient, and advantageous development direction and content as the basic function of the sea area. For example, some coastal areas may serve multiple functions, such as port operations, coastal tourism, and aquaculture. If there is a pressing need to enhance foreign trade competitiveness for local economic and social development, planners may prioritize port functions as the primary focus. Conversely, if the local ports sufficiently meet transportation needs and the government aims to develop tourism, planners might designate coastal tourism as the basic function, potentially excluding port and aquaculture activities.

As socio-economic development advances, new demands for sea use may emerge over time. These demands might include changes in sea use requirements, the need for the integrated development of different industries, the necessity for submarine cables and pipelines to cross marine functional areas, or the presence of some legitimate sea use activities within these areas that do not align with the basic function of the sea area. This situation necessitates compatible sea use, typically aligning with functions that were excluded during the process. Since MSP has already established the basic function of a sea area, sea use activities that match this basic function generally encounter fewer restrictions and lower entry barriers. Moreover, the area proportion of such activities within the functional area is generally larger. Conversely, compatible functions occupy a smaller scale within the functional area, often scattered and more fragmented. More importantly, to utilize the sea area, the users often need to provide more comprehensive justifications to ensure that their development and utilization activities will not affect the basic function (Shown as Figure 2).

If we consider marine functional areas (including marine spaces and all types of marine activities) as a system, then different marine activities are components of the system. According to the systems theory, structure represents the internal rationale of the system, while function reflects the external expression of its elements and structure. A particular structure always manifests a specific function, and a certain function is always realized by a system with a corresponding structure. Consequently, the basic function of marine functional areas is intrinsically linked to the types of marine activities conducted. Therefore, this paper defines compatibility according to the following characteristics based on system coordination theory.

Firstly, in terms of quantity, marine activities consistent with the basic function are in a dominant position, while compatible marine activities are in a subordinate position. If the area designated for compatible marine activities is extensive and densely concentrated, the intended use of the sea can be directly achieved by modifying the marine functional areas, thereby eliminating the need for compatibility adjustments. This feature is well-reflected in the implementation of MSP in China. For example, most activities in aquaculture zones are related to aquaculture, while fishing ports are often scattered. The numerical advantage of basic functions indicates that the development direction of marine functional areas generally aligns with the expectations of MSP. This also ensures that most sea use activities within the marine functional area are similar, thereby avoiding mutual interference between different sea use activities and reducing the efficiency of marine spatial development and utilization, achieving the goal of regulating marine development order.

Secondly, from the perspective of internal coordination of the system, compatible marine activities influence the basic functions of the system, both positively and negatively. Certain marine activities can support the achievement of basic functions and should be encouraged to some extent. Conversely, if marine activities directly hinder the realization of basic functions, such as through environmental pollution or landscape impacts, then these activities should either be deemed incompatible or subjected to additional restrictions. This feature is often reflected in the integrated development of marine industries in recent years, such as the integration of marine aquaculture with coastal tourism or marine renewable energy. The mutual coordination between basic functions and compatible functions can further leverage the potential of marine spatial resources, achieving the goal of high-tech industries leading the transformation and upgrading of traditional industries.

Thirdly, generally, the alteration in natural attributes of marine areas due to compatible functions should not surpass the changes imposed by the basic function, ensuring that compatible marine activities do not impair the basic functions when they cease. This is crucial because preserving the basic function of marine functional

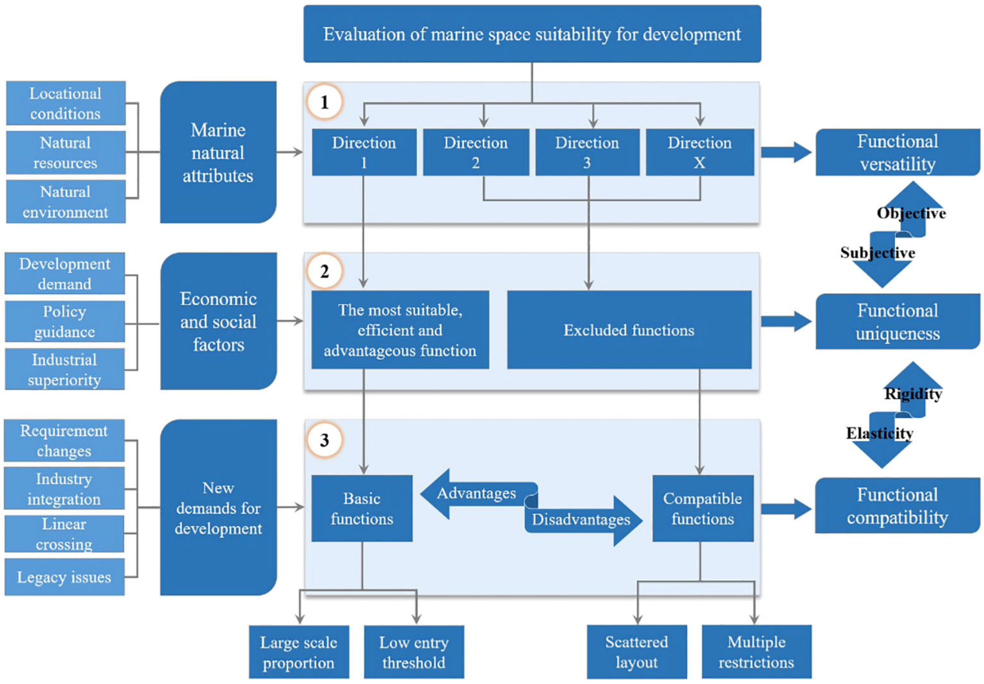

FIGURE 2
Basic logic of compatible marine utilization.

areas is a key aspect of MSP implementation and oversight. If compatible functions alter the natural attributes of the sea area more than the basic function, the area may lose its basic function. For instance, port construction in an aquaculture zone, involving land reclamation, could directly damage the marine environment and make future aquaculture activities unfeasible.

3.2 Research methods

The exploration of compatible sea use is mainly theoretical, employing methods such as participatory approaches, inductive reasoning, and overlay analysis. Specifically:

1. Participatory Method. During the analysis of compatible sea use, government departments, potential and existing marine users, and other stakeholders were encouraged to participate in discussions, expressing their interests and objectives regarding marine development and utilization. Based on this, planners conducted a comprehensive assessment, considering ecological protection and the sea use needs of different interest groups as much as possible, thereby enhancing the scientific rigor and practicality of the compatible sea use plans.
2. Inductive Reasoning. Based on the understanding of the needs, characteristics, and spatial conflicts of marine spatial compatibility during the process of MSP, the general characteristics, classification, and risks of compatible sea use models were summarized. This method requires planners to have rich experience in MSP, which can be obtained through communication with stakeholders.
3. Overlay Analysis. This method involves overlaying marine spatial zoning maps with potential sea use activities, industry plans (such as offshore wind power, marine photovoltaic systems, marine ranching, etc.). The goal is to assess which activities may have compatible sea use needs. Further analysis is then conducted to evaluate these activities' compliance with designated marine functional areas, leading to the formulation of marine spatial management rules. Overlay analysis provides a clear visual representation of both existing and potential sea use activities within each marine functional area, facilitating discussions among planners and stakeholders about the needs and feasibility of compatible sea use.

4 Classification and discrimination of compatible marine use models: the case of China

4.1 Functional classification of China's new round of MSP

China's current territorial spatial planning includes a marine functional zoning system with 3 primary zones, 6 secondary zones, and 21 tertiary zones (Shown as Table 1). Since ecological protection zones and ecological control zones are primarily for

TABLE 1 Marine functional zoning system.

Primary zone	Secondary zone	Tertiary zone
Ecological protection zone	Ecological protection zone	Ecological protection zone
Ecological control zone	Ecological control zone	Ecological control zone
Marine development zone	Fisheries zone	Fisheries infrastructure zone
		Aquaculture zone
		Fishing zone
	Transportation zone	Port zone
		Shipping zone
		Road, bridge, and tunnel zone
	Industrial, mining and communication zone	Industrial zone
		Salt field zone
		Solid mineral zone
		Oil and gas zone
		Renewable energy zone
		Submarine cable and pipeline zone
	Recreational zone	Scenic tourism zone
		Entertainment zone
	Special zone	Military zone
		Underwater cultural heritage protection zone
		Dumping zone
		Other special zone
	Reserve zone	Reserve zone

ecological protection and generally prohibit or strictly limit development, and special use marine zones and reserved marine zones have strong exclusivity, these four types of marine functional areas are not considered in the analysis of compatible sea use in this paper.

4.2 Classification of compatible marine use models

In long-term practice, management departments often determine the compatibility of marine functional areas based on the impact on natural attributes—specifically, sea use activities with a significant impact on natural attributes can be compatible with those with a lesser impact. However, as the means of marine development and utilization have evolved and marine spatial use control systems have improved, this understanding no longer fully meets the current needs of marine spatial planning and management, necessitating a clear definition of the types and specific circumstances involved. This paper argues that the key to compatible use lies in whether marine activities entering a specific marine functional area will cause orderly implementation within the zone. In reality, the negative impacts of marine activities on basic functions manifest in several ways. Firstly, the impact of marine activities on the marine natural attributes exceeds the permissible extent of the zone, and even after the activities are ceased, the natural attributes of the marine area cannot be restored to their original state. For example, if reef-based aquaculture is conducted in a port zone, it could lead to a decrease in water depth, severely threatening the navigation safety of ships. Similarly, conducting pile-based offshore photovoltaic(PV) projects in aquaculture zones could alter the marine dynamic environment, weakening the seawater exchange capacity of the local sea area, leading to increased pollution, and threatening the quality and safety of aquaculture products. Secondly, during the implementation of marine activities, they directly affect the implementation of activities consistent with the basic function from environmental, safety, and landscape perspectives. For instance, constructing offshore wind farms or ports in marine tourism zones would directly affect the marine landscape, environment, and safety, resulting in the loss of the tourism function of the sea area.

Therefore, the focus of compatible marine use is on how marine activities can minimize their impact on the basic functions. Since MSP is essentially a means of optimizing the spatial and temporal configuration of marine development activities, and compatible sea use aims to manage the relationships between two or more marine functions, this paper suggests addressing this from the dimensions of time, space, and function. By optimizing and regulating these factors, multiple marine development activities can meet the control requirements of marine functional areas while avoiding or reducing conflicts between sea use activities. This can be achieved through three specific approaches: avoidance through development sequencing, spatially circumvented and alignment with the goals of the basic function (Shown as Figure 3).

4.2.1 Development sequencing compatibility

Development sequencing compatibility involves the strategic scheduling of different marine activities to enable sequential utilization within the same area. This approach enhances spatial utilization efficiency over time and avoids the impact of compatible marine activities on basic functions. It primarily encompasses two scenarios: pre-development planning and the continuation of existing legal projects.

Pre-development involves initiating marine activities with minimal impacts on marine natural attributes before the core functions of a marine functional area are established. This typically implies that the area has not yet been developed or utilized. In practice, due to careful and rational advance planning, some marine functional areas are not designated for development or utilization in the short term. These areas are usually reserved for large-scale projects in port, industrial, and energy sectors, which require extensive sea use demonstration periods. Conversely, mariculture, which provides short-term benefits with easily

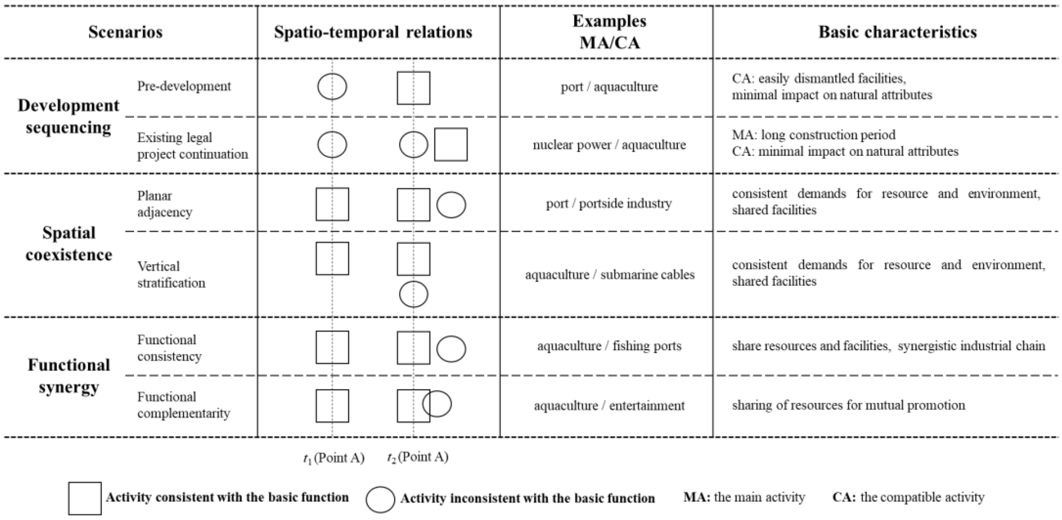

FIGURE 3
Three basic cases of compatibility.

removable facilities, results in minimal alterations to the area's natural attributes and does not hinder the future utilization of the sea space for port, industrial, or energy-related activities.

The continuation of existing legal projects occurs when existing legal marine activities no longer conform to the basic function of the adjusted functional area on account of adjustments in marine functional areas. Nonetheless, these activities do not affect the performance of the adjusted basic functions, or related construction projects have not been implemented, thus allowing the continuation of existing legal marine activities. This phenomenon is especially noticeable in current planning processes, particularly concerning mariculture activities. In practice, due to the requirements of major projects such as nuclear power plants and ports, existing fishery marine areas are being reallocated for industrial or port use. As a result, the existing legal aquaculture operations no longer align with the new functional area requirements. Since the construction or planning period of nuclear power and port projects is long, and there is no immediate need for compensation and eviction of aquaculture activities, existing legal activities are still allowed to continue until the projects commence to construct.

4.2.2 Spatial coexistence compatibility

Spatial coexistence compatibility refers to a mode of sea use in which different marine activities harmoniously coexist through the rational allocation and arrangement of spatial resources. It mainly includes two scenarios: planar adjacency and vertical stratification.

1. Planar Adjacency Compatibility. It means the adjacent distribution of different types of marine activities in the horizontal direction. For historical reasons, certain marine activities, such as fishing ports within port areas, have existed prior to the implementation of MSP. Given the vast spatial scale of designated marine functional areas compared to the relatively small areas utilized for these marine activities, it is challenging to allocate specific functional areas for these existing activities separately. Additionally, marine activities often meet the resource and environmental conditions and utilization control requirements of the functional area and can share infrastructure (such as waterways). With proper coordination, the mutual impact between different types of marine activities can be negligible.
2. Vertical Stratification Compatibility. It means the three-dimensional development of marine areas, including the water surface, water body, seabed, and subsoil, which is an emerging marine use model in China. Vertical stratification not only solves the challenges of linear infrastructure crossing other activities but also enhances spatial utilization efficiency and facilitates integrated industrial development. Examples include vertically stratified use of marine areas for submarine cable pipelines with mariculture, nuclear power cooling water with cross-sea bridges. However, practical experience has shown that vertical stratification can lead to new spatial conflicts, particularly during the construction phase of projects, which may significantly disrupt existing operations. Legal, planning, and economic measures are required to enhance spatial utilization control and improve stakeholder coordination.

4.2.3 Functionally synergistic compatibility

Functionally synergistic compatibility focuses on the strategic arrangement of different marine activities to reduce construction and production costs, enhance resource utilization efficiency and economic benefits, while promoting the synergistic development among activities. It is mainly categorized into functional consistency and functional complementarity.

1. When different marine activities share the same development goals (Shown as Figure 4), they are considered functionally consistent. For example, seawater aquaculture and fishing ports both aim to enhance fisheries' economic growth through the development and utilization of fishery resources. While aquaculture directly utilizes these resources, fishing ports serve as complementary facilities. Rationally integrating the construction of fishing ports within aquaculture areas can reduce transportation costs and minimize seafood product loss.
2. Functional complementarity occurs when two or more marine activities have a complementary and supplementary relationship, sharing facilities, platforms, and part of the sea space. Taking marine ranching and tourism as examples, these two activities promote each other to some extent, achieving resource sharing and mutual advantages. Marine ranches can provide a stable supply of seafood to meet the tourism industry's demand for food products, while tourism can provide an additional stream for marine ranches, improving their economic benefits. Furthermore, these activities can share facilities and platforms, such as using tourist wharves for marine operations and leveraging sea-sightseeing platforms and fish-watching windows created by marine ranches to enrich the tourist experience.

4.3 Compatibility discrimination matrix

In accordance with the aforementioned classification, a "Functional area-Sea Use Classification" compatibility discrimination matrix has been developed. Drawing from the author's team's recent experiences in regional and multi-level MSP projects, extensive research, discussions, and planning feedback, the following sea use models with significant demand in current marine utilization and management practices have been identified (Shown as Table 2).

1. The Development Sequencing Compatibility Model primarily applies to fishery infrastructure areas, port areas, shipping areas, and industrial marine areas that are compatible with aquaculture. This is mainly due to aquaculture being a key component of the primary industry within the entire marine economy, which involves traditional fishermen's livelihoods and often exerts significant pressure on marine and planning departments in the context of integrated marine management. Additionally, open aquaculture activities such as raft, cage, and seabed cultivation have a minimal impact on the marine natural attributes and feature easily removable facilities. Consequently, management practices typically prioritize the rights of aquaculture entities,

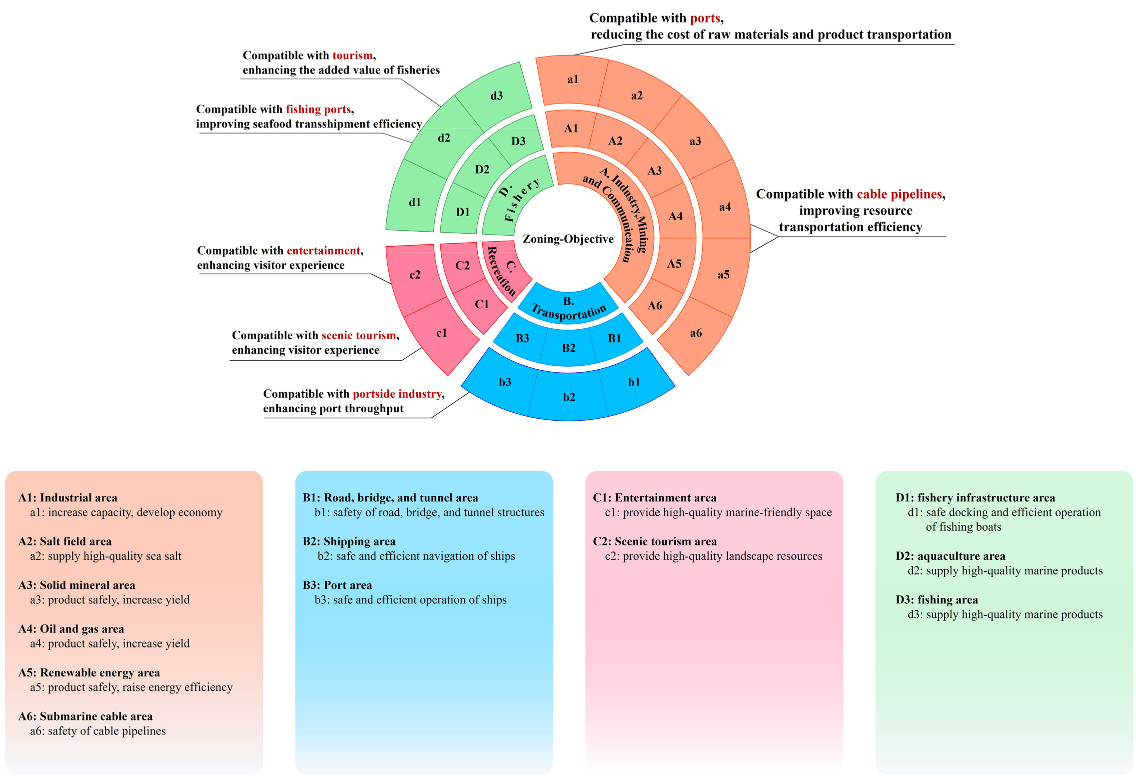

FIGURE 4
Spatial development objectives for different marine functional areas.

TABLE 2 Compatibility discrimination matrix.

Functional Area Type	Marine Use Classification													
	Fishery infrastructure	Aquaculture	Fishing ground	Port	Shipping	Road, bridge and tunnel	Industrial	Salt field	Solid mineral	Oil and gas	Renewable energy	Submarine cable	Scenic tourism	Recreation
Fishery infrastructure	√	●	×	■[1]	×	×	■[1]	×	×	×	×	■[2]	×	×
Aquaculture	▲[1]	√	●	×	×	■[2]	×	×	×	×	▲[2]	▲[2]	×	▲[2]
Fishing	×	×	√	×	×	×	×	×	×	×	×	■[2]	×	×
Port	■[1]	●	×	√	▲[1]	×	▲[2]	×	×	×	×	■[2]	×	×
Shipping	×	●	×	×	√	×	×	×	×	×	×	■[2]	×	×
Road bridge and tunnel	×	×	×	×	■[2]	√	×	×	×	×	×	■[2]	×	×
Industrial	■[1]	●	×	▲[2]	×	×	√	×	×	×	×	×	×	×
Salt field	×	×	×	×	×	×	×	√	×	×	■[2]	×	×	×
Solid mineral	×	×	×	×	×	×	×	×	√	×	×	×	×	×
Oil and gas	×	×	×	×	×	×	×	×	×	√	×	▲[1]	×	×
Renewable energy	×	■[2]	×	×	×	×	×	×	×	×	√	▲[1]	×	×
Submarine cable	×	×	×	×	×	■[2]	■[2]	×	×	×	×	√	×	×
Scenic tourism	×	×	×	×	×	×	×	×	×	×	×	■[2]	√	▲[1]
Recreational	×	×	×	×	×	×	×	×	×	×	×	■[2]	▲[1]	√

√ Compatible; ●[1] Pre-development; ●[2] Continuation of existing legal project; ■[1] Planar Adjacency; ■[2] Vertical Stratification; ▲[1] Functional consistency; ▲[2] Functional complementarity; × Incompatible.

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permitting short-term development and use in these areas prior to the activation of their core functions.

2. The Spatial Coexistence (Planar) Compatibility Model mainly distributes in fishery infrastructure marine areas compatible with port and industrial uses, as well as in port areas and industrial marine areas compatible with fishery infrastructure uses. Port, industrial, and fishery infrastructure activities have similar methods of marine use and impacts on the marine natural attributes. Due to historical factors such as pre-existing sea use before relevant regulations were implemented and unregulated marine area management, these types of marine activities are often intermixed without significant spatial conflicts over time. Several Spatial Coexistence (Vertical) compatibility models illustrate this, such as the compatibility of fishery infrastructure areas and port areas with submarine cable uses, and renewable energy areas with aquaculture. Thanks to the Chinese government's recent encouragement of vertical stratification of marine use rights, the above marine use models are widely recognized in practice.
3. The Functionally Consistent Compatibility Model is mostly found in aquaculture areas compatible with fishery infrastructure uses, port areas compatible with shipping uses, oil and gas marine areas, renewable energy areas compatible with submarine cable uses, entertainment areas compatible with scenic tourism uses, and scenic tourism areas compatible with entertainment uses. Although the above compatibility models may have striking differences in their development and utilization methods, they all belong to different segments of the same industrial chain with consistent spatial development goals. Functionally Complementary Compatibility Model mainly applies to scenarios such as port areas being compatible with industrial uses, industrial marine areas being compatible with port activities, and aquaculture areas being compatible with recreational uses. These activities complement the fundamental functions of their respective zones and can enhance each other to increase overall output value.

However, it is important to note that these compatibility results are theoretical explorations. Their practical applicability requires a thorough analysis based on local laws, regulations, and specific conditions.

4.4 Practice of compatible marine utilization models in China

4.4.1 Overview of MSP in Yantai

Yantai, located in the central part of the Shandong Peninsula in China, covers a total sea area of 11,600 square kilometers and has a mainland coastline of 798.65 kilometers. The city features diverse marine ecosystems, including estuarine wetlands, bay wetlands, island groups, and seagrass beds, and is rich in marine life and fishery resources. This makes Yantai a prominent fishing area and a major producer of aquatic products in China. The region also boasts numerous natural sandy beaches, unique coastal and island erosion landforms, and abundant marine cultural tourism resources, positioning it as an ideal destination for comprehensive marine sightseeing and leisure tourism. Additionally, Yantai is endowed with substantial mineral resources such as coal, brine, and gold, which are abundant and easily extractable. The city also holds significant potential for marine renewable energy development, particularly wind energy, due to its favorable conditions. Consequently, Yantai has a strong foundation for advancing industries like marine aquaculture, coastal tourism, port shipping, and marine renewable energy, all of which have considerable demand for marine space and potential conflicts among various marine activities.

Since 2021, Yantai has embarked on the development of its marine and coastal spatial planning. A central objective of this plan is to delineate marine functional areas, as depicted in Table 1, and establish spatial control requirements. These functional areas and control measures are crucial for marine spatial management. Following the steps outlined in Figure 2, the plan initially conducted a scientific evaluation of the natural attributes of the marine areas and then considered socio-economic factors to delineate 135 marine functional areas. These zones include ecological protection areas, ecological control areas, aquaculture zones, fishery infrastructure zones, port zones, shipping zones, road-bridge-tunnel zones, industrial zones, salt field zones, scenic tourism zones, entertainment zones, other special marine zones, and dumping zones.

4.4.2 Workflow

As shown in Figure 5 the first step involves preparing the data materials, including marine functional zoning, marine ranching plans, offshore wind power planning, offshore PV planning, and sea area usage rights data, all of which should be in vector format. Marine ranching, offshore wind power, and offshore PVs are key directions for future marine development and utilization in the study area, with industry plans reflecting the main demands for sea use. Sea area usage rights data reflect the current state of marine development and utilization in the study area.

The second step is to communicate with potential sea users, such as enterprises (e.g., wind power, photovoltaic, aquaculture, shipbuilding, tourism enterprises), fishermen, and government management departments (e.g., marine, fisheries, transportation, tourism management departments), through methods like holding discussion meetings, publicly soliciting opinions on websites, or sending emails. This step aims to comprehensively understand the demands for compatible sea use. For potential sea users who propose demands for compatible sea use, they are required to provide proof documents to substantiate the necessity and feasibility of the compatible sea use, and to explain the extent of impact of the proposed compatible sea use activities on the basic functions.

The third step involves overlaying the sea use layouts from various industry plans and project locations provided by

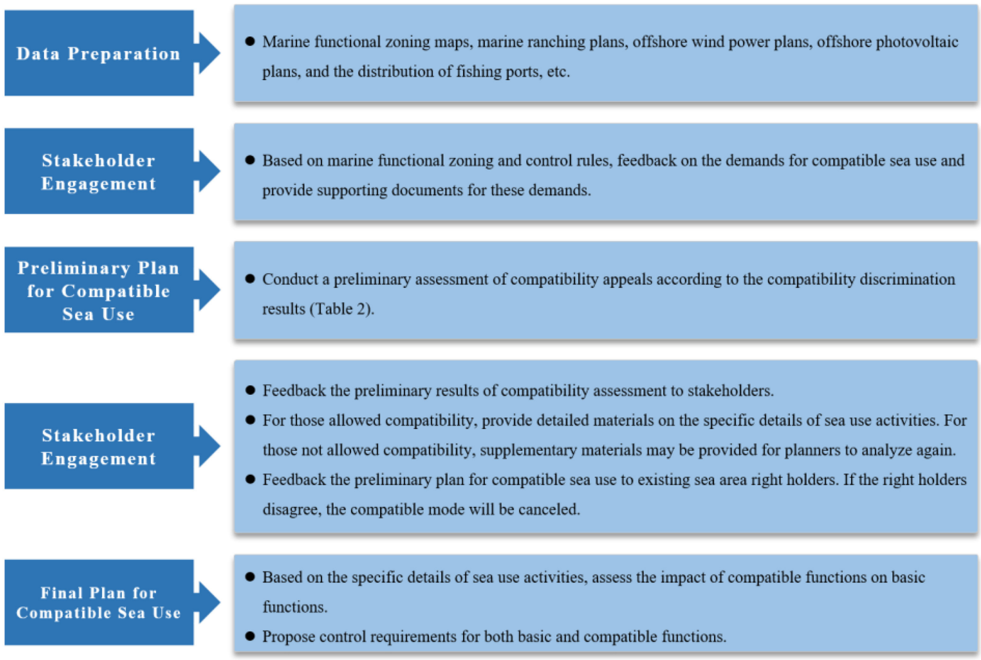

FIGURE 5
Process of the plan for compatible sea use.

stakeholders onto the marine functional zoning map to analyze the marine functional types and control rules of the sea areas where these plans and projects are located. Based on Table 2, a preliminary analysis of the city's compatible sea use demands is conducted, forming a preliminary plan for compatible sea use.

The fourth step is to feedback the preliminary plan for compatible sea use to potential sea users, informing them of the reasons for allowing or disallowing compatibility. For those allowed compatibility, they are required to provide more details on sea use activities, such as the sea use methods and construction techniques of the project. More importantly, opinions are solicited from other sea users in the marine functional area where the project is located (whose projects comply with the marine functional zoning and have obtained sea area usage rights). If other sea users disagree, the compatible sea use model will not be adopted.

The fifth step is to conduct further analysis on the ultimately permitted models of compatible sea use, assessing the mutual impact of compatible sea use activities with existing sea use activities. On this basis, control requirements are proposed for both the basic and compatible functions.

4.4.3 Demand for compatible marine use and planning solutions

In the process of formulating use control rules for marine functional areas, opinions from stakeholders, including government and enterprises, were extensively sought. The planning process reviewed the needs of industries such as aquaculture and offshore wind power, and overlaid related marine use projects onto the marine functional zoning map to identify the stakeholders' demands for compatible marine use in specific zones, as follows (Shown as Table 3):

1. Aquaculture. As a major center for aquaculture, Yantai's marine fishery sector is pivotal to the city's marine economy, with significant spatial demands for aquaculture activities. After decades of development, the coastal areas have been almost fully utilized. Therefore, the future development of marine aquaculture must either expand into deeper waters, which presents challenges in terms of funding, technology, and marine hazards, or adopt compatible marine use models to conduct aquaculture activities in non-aquaculture zones. For traditional fishers, who may lack sufficient financial and technical support, coastal waters remain preferable for aquaculture, making compatible marine use an effective solution. Research indicates that various marine functional areas, including port zones, shipping zones, industrial zones, renewable energy zones, scenic tourism zones, and entertainment zones, generally have a demand for compatible aquaculture use. However, these compatibility models differ: port zones, shipping zones, industrial zones, scenic tourism zones, and entertainment zones involve compatibility through sequential development, whereas renewable energy marine zones involve functional compatibility.
2. Marine Renewable Energy. With China's commitment to achieving carbon peaking by 2030 and carbon neutrality by

TABLE 3 Main requirements and planning schemes for marine spatial compatibility in Yantai City.

Type of Marine Functional Area		Compatibility Requests	Reason	Planning Scheme
Fisheries area	Aquaculture area	Recreational use	A comprehensive recreational fishery tourism complex is planned, integrating fishing, underwater sightseeing, dining, and more.	**Adopted.** It is required that the construction of aquaculture platforms should minimize impacts on the marine environment, and strictly control the disposal of household waste and sewage.
		Renewable energy use (offshore wind power)	Plans to develop offshore wind power or a fusion development model with aquaculture, conducting cage farming under the turbines.	**Adopted.** Offshore wind farms are far from the shore, which can promote the transformation and upgrading of aquaculture. Wind power enterprises are required to compensate aquaculture entities; when conducting aquaculture, fishing boats should not threaten the safety of wind power foundations.
		Renewable energy use (offshore PV)	Plans to develop offshore PVs or a fusion development model with aquaculture, conducting open aquaculture under photovoltaic panels.	**Not adopted.** The construction of photovoltaic foundations would significantly impact the marine environment in the intertidal zone and severely damage aquaculture activities, which is detrimental to the development of the aquaculture industry.
		Fisheries infrastructure use	There are scattered fishing ports within the functional area.	**Adopted.** It is required to control pollution and household waste disposal from fishing ports to protect the marine environment.
		Submarine cable pipeline use	Submarine cable pipelines cross this functional area.	**Adopted.** The construction of submarine cable pipelines must minimize impacts on aquaculture, and reasonable compensation should be provided if necessary. Furthermore, it is crucial that aquaculture activities must not use reef throwing methods to avoid threatening the safety of submarine cable pipelines.
Transportation area	Port area	Aquaculture use	This functional area was originally designated for aquaculture use and contains legitimate aquaculture activities.	**Adopted**. Aquaculture activities must not interfere with the safety of port operations. Otherwise, it is recommended to proceed with the orderly exit of aquaculture activities through relocation compensation.
		Industrial use	There are shipbuilding enterprises within the port zone.	**Adopted.** It is required that shipbuilding enterprises do not affect port operations and navigational safety during their use of the sea.
		Fisheries infrastructure use	Due to historical reasons, there are some fishing ports within this functional area.	**Adopted.** It is required that the main users of fishing ports and port zones communicate fully to maintain navigational safety.
	Shipping area	Aquaculture use	This functional area was originally designated for fisheries use and contains legitimate aquaculture activities.	**Adopted.** Aquaculture activities must not interfere with navigational safety. Otherwise, it is recommended to proceed with the orderly exit of aquaculture activities through relocation compensation.
		Submarine cable pipeline use	Submarine cable pipelines cross this functional area.	**Adopted.** Dredging is prohibited in the crossing area to avoid threatening the safety of submarine cable pipelines.
Industrial, mining, and communication area	Industrial area	Aquaculture use	This functional area has not yet been developed, and nearby fishermen have the need for aquaculture.	**Adopted.** Aquaculture activities must refrain from using reef-throwing methods to avoid causing irreversible damage to the marine environment. When the industrial use function is activated, aquaculture activities should promptly exit.
		Road, bridge, and tunnel use	Supporting road facilities for the port industrial zone.	**Adopted.** It is required to control the scale of sea use as much as possible.
		Renewable energy use	Construction of offshore PV projects in the power drainage area is encouraged by national policy.	**Adopted.** The offshore PV sea use entity must communicate with the power sea use entity and obtain permission from the latter.
	Renewable energy area	Aquaculture use	This functional area plans to develop a fusion model of offshore wind power and aquaculture.	**Adopted.** It is required that when conducting aquaculture, fishing boats should not threaten the safety of wind power foundations.
Recreational area	Scenic tourism Area	Aquaculture use	This functional area has not yet been developed, and nearby fishermen have the need for aquaculture.	**Adopted.** Aquaculture activities should exit before the scenic tourism function is activated.

(Continued)

TABLE 3 Continued

Type of Marine Functional Area		Compatibility Requests	Reason	Planning Scheme
		Submarine cable pipeline use	Submarine cable pipelines cross this functional area.	**Adopted.** It is required that scenic tourism activities protect the safety of submarine cable pipelines.
		Aquaculture use	This functional area has not yet been developed, and nearby fishermen have the need for aquaculture.	**Adopted.** Aquaculture activities should exit before the sports and leisure function is activated.
	Entertainment area	Submarine cable pipeline use	Submarine cable pipelines cross this functional area.	**Adopted.** It is required that sports and leisure activities protect the safety of submarine cable pipelines.
		Solid mineral use	There are solid minerals in the nearshore seabed, which can be directly mined by constructing a subsea tunnel from the shore (three-dimensional layered sea use), without disturbing the seabed, water column, or surface.	**Adopted.** It is required to conduct scientific construction design to avoid affecting the space above the seabed.

2060, the scale of offshore wind power and PV construction has grown significantly. However, the large-scale marine use required for marine renewable energy projects poses significant challenges for site selection. Consequently, sharing marine space with aquaculture has become a key strategy for the development of marine renewable energy. According to offshore wind power policies, such projects must be situated at least 30 kilometers from the coast or in waters with a minimum depth of 30 meters. This requirement aligns with the practices of offshore deep-water marine aquaculture. Offshore PV energy, a newly emerging form of marine renewable energy in China, typically utilizes pile-based structures and is predominantly located in intertidal zones. During consultations with stakeholders, most PV projects were planned within these intertidal aquaculture areas. However, the construction of PV piles could disrupt the marine dynamics of these zones, potentially impacting aquaculture activities. Therefore, this study recommends the prohibition of offshore PV construction in aquaculture zones to prevent ecological disturbances.

3. Submarine Cables and Pipelines. Yantai has 15 inhabited islands, often located close to the mainland, with freshwater, gas, electricity, and communications often supplied via submarine cables and pipelines from the mainland. The development of offshore wind power, offshore PV, and other renewable energy projects necessitates the installation of submarine cables to transmit electricity from sea to land. These cables and pipelines frequently must cross through various zones, including aquaculture areas, port zones, and shipping lanes. To support the livelihoods of island residents and the implementation of clean energy projects, it is essential to ensure that aquaculture zones, port zones, and shipping zones are compatible with submarine cable and pipeline use. Simultaneously, it is essential to ensure that marine activities within these functional areas do not jeopardize the integrity and safety of the submarine cables and pipelines, which are safeguarded under regulations such as the *Regulations on the Protection of Submarine Cables and Pipelines*.
4. Marine Ranching and Recreational Activities. propelled by China's robust endorsement of marine ranching, the convergence of marine aquaculture with recreational activities has gained popularity. As a result, there is a growing demand to utilize marine ranching platforms for recreational purposes. However, when incorporating recreational activities into aquaculture zones, it is crucial to address potential environmental pollutants, such as trash and sewage, which could adversely affect the aquaculture environment.
5. Fisheries Ports and Aquaculture Zones. Due to historical reasons, some fishing ports are mixed with commercial ports or located within aquaculture zones. These fishing ports are vital infrastructure for fishers to conduct aquaculture and fishing activities. When fishing ports are located within port zones, effective scientific management can ensure that they do not compromise navigational safety. However, fishing ports located within aquaculture zones necessitate enhanced environmental management to any adverse impacts on aquaculture activities.
6. Solid Mineral Extraction and Cultural-Sports-Recreational Marine Zones. By utilizing advanced underwater construction techniques, solid mineral extraction can be compatible with entertainment zones. Typically, this type of extraction involves large ships and heavy equipment, which can significantly alter the natural characteristics of a marine area and potentially disrupt other marine activities. However, in this proposed plan, the extraction zone is strategically located near the coastline. This proximity allows for the construction of an underwater tunnel extending from the shore, facilitating solid mineral extraction without impacting recreational activities in the vicinity. This approach exemplifies a model of three-dimensional, layered marine utilization.

5 Risk analysis and countermeasure suggestions for marine use management under MSP

5.1 Risks and suggestions for development sequencing compatibility

Mariculture occupies a precarious position among various marine activities. The expansion of ports, industry, tourism, and other marine activities often encroaches on spaces traditionally used for aquaculture, transforming these areas into ports, industrial zones, or recreational marine zones. Moreover, mariculture is entangled with complex and sensitive socio-economic issues that impact the basic livelihoods of traditional fishermen. Therefore, introducing development sequencing compatibility into planning, implementation, and management can effectively resolve conflicts and contradictions in aquaculture management, safeguarding the vital interests of coastal aquaculture communities. However, development sequencing compatibility, as a short-term model, still presents certain risks in its implementation and management. This model fundamentally differs essentially from the other two compatibility models. Upon activation of the basic function of a marine functional area is activated (e.g., the commencement of port construction), compatible activities (aquaculture activities) should yield to marine activities that align with the basic function, such as ports.

During the planning process, it is essential to strengthen stakeholder coordination to ensure that the aquaculture community is well-informed about the relevant background, especially the timeframe allocated for aquaculture activities. Additionally, planners should also define the basic functions, compatible functions, and usage control requirements of marine functional areas. Under pre-development scenarios, marine use applications and approvals should reasonably specify the duration of marine use, enhance the control of development and utilization methods, and ensure these do not interfere with the implementation of subsequent activities. Since compatible marine activities are beneficiaries, compensation is generally not warranted. However, for existing legal projects, if compatible marine activities incur losses due to planning adjustments, reasonable compensation should be provided during the exit phase.

5.2 Risks and suggestions for spatial coexistence compatibility

5.2.1 Planar spatial coexistence compatibility

The characteristic of planar spatial coexistence compatibility is that both the basic and compatible functions often have the same or similar development and utilization methods. This similarity typically results in fewer spatial conflicts between different activities. However, since these functions have distinct spatial development goals belong to different industry types, it is crucial to ensure that the implementation of one function does not inconvenience other activities and facilitates the operations of other marine entities. In practice, fishing ports, shipbuilding, and ports may share harbor pools or waterways. Therefore, control rules should be developed based on comprehensive research on the waterway usage requirements of each marine entity to avoid disruptions to waterway traffic.

5.2.2 Vertical spatial coexistence compatibility

The vertical stratification use of marine areas can solve conflicts arising from linear infrastructure, such as submarine tunnels and cables, that traverse various functional areas. This approach promotes industrial integration and enhances spatial utilization efficiency. Meanwhile, it is undeniable that vertical spatial coexistence compatibility brings more spatial conflicts by making the marine use range of two or more entities adjacent. Construction, operation, and maintenance phases of marine activities, in particular, are often not synchronized, with projects initiated earlier being highly susceptible to interference from later projects. Accordingly, planning should clearly outline project construction control requirements. It is essential for construction units to strategically plan their construction timing and location, manage the intensity of construction activities, and minimize disturbances to other marine operations. If interference is unavoidable, it is imperative to enhance coordination among stakeholders. The compatibility model should only be integrated into the planning process after securing consent from all relevant parties, and a compensation plan should be established to address any potential impacts.

5.3 Risk analysis and suggestions for functionally synergistic compatibility

5.3.1 Functionally consistent compatibility

The feature of functionally consistent compatibility is that two types of marine activities have the same spatial development goals. Although there are differences in specific utilization methods, there is often a close cooperative relationship between marine activities. Consequently, models of functionally consistent compatibility enhance the efficiency of marine resource utilization. The potential risk lies in the difference between the development and utilization methods of compatible marine activities and the overall requirements of the functional area. For example, in regions where aquaculture and fishery infrastructure uses are compatible, the construction of fishery infrastructure often entails land reclamation and the installation of impermeable structures to develop dock shorelines, which significantly alters the marine natural attributes. Moreover, spills from fishing vessels can lead to marine environmental pollution, adversely affecting local aquaculture activities. Therefore, it is crucial in planning and establishing usage control regulations to thoroughly assess the impacts of compatible marine activities on natural marine attributes and to carefully demonstrate their coordination with fundamental functions.

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5.3.2 Functionally complementary compatibility

The concept of functionally complementary compatibility has emerged as a vital requirement in the development of China's marine ranches in recent years. In practical terms, users and management authorities frequently encounter uncertainties regarding the permissibility of conducting recreational activities on marine ranch platforms within aquaculture zones. Clarifying this model is conducive to the integrated development of marine fisheries and tourism, enhancing the benefits of marine ranches, and enriching tourist experiences. The main risk of this model lies in the different impacts of the two types of activities on marine natural attributes. Although tourists are generally on boats or platforms and do not come into direct contact with seawater, the process of touring or participating in activities can still produce significant amounts of domestic waste, which poses increased environmental risks to aquaculture areas. Consequently, the regulation of compatible marine activities should be intensified to prevent impacts on fundamental functions when establishing usage control rules.

6 Conclusion and discussion

Compatible marine use not only exemplifies the feasibility and practicality of planning but also significantly influences the spatial configuration and developmental order of marine environments. Existing research has mostly focused on assessing levels of compatibility, yet they often overlook the fundamental principles, categorization, and governance of marine use compatibility. Based on it, this paper employs theories of systemic coordination to elucidate the underlying logic of compatible marine use, particularly in terms of preserving the essential functions of designated marine functional areas. The study proposes the basic characteristics of compatible sea use. In terms of quantity, basic functions should always dominate, while compatible functions should remain secondary. In terms of spatial conflict, compatible functions should either bolster the basic functions or at least not interfere with their realization. Regarding the impact on the natural attributes of the sea area, the influence exerted by compatible functions should not surpass that of the basic functions. This discussion introduce specific types of compatible marine use models for the first time, categorizing them into three main categories and six specific scenarios: development sequencing compatibility, spatial coexistence compatibility, and functionally synergistic compatibility. Development sequencing compatibility, viewed through a temporal lens, encompasses two specific scenarios: pre-development and the continuation of existing legal projects. Spatial coexistence compatibility, analyzed from the perspective of spatial resource allocation, includes planar adjacency compatibility and vertical stratification compatibility. Functional synergy compatibility, examined from the dimension of functional matching, comprises functional consistency and functional complementarity. Combining the practice of China's marine spatial planning compilation, using participatory methods, the paper discriminates the compatibility situations of various marine activities in different functional areas, identifying 33 practically feasible compatible models. On this basis, taking Yantai City of China as an example, During the planning process, the compatibility requirements of different marine functional areas were thoroughly analyzed. The study found: (i) Due to the relevance of aquaculture to the livelihoods of traditional fishermen, there is a strong demand for other marine functional areas to be compatible with aquaculture use. (ii) Influenced by China's 'dual carbon' policy, there is substantial policy support for the integrated development of renewable energy and aquaculture. Consequently, there is a significant demand for renewable energy zones to be compatible with aquaculture, and vice versa. However, this compatibility is not feasible for intertidal zones, as their ecological environment is highly susceptible to threats from development. (iii) To support the livelihood of island residents and the implementation of clean energy projects, there is a strong demand for submarine cables and pipelines to traverse other marine functional areas, necessitating compatibility with cable and pipeline use and ensuring their safety. (iv) With the integrated development of marine ranching and coastal tourism, there is a high demand for aquaculture zones to support recreational activities. However, these recreational activities must not compromise the aquaculture environment. (v) Due to historical reasons, some fishing ports are located in port zones or aquaculture zones. Considering that fishing ports are similar to ports in terms of development and use and are important support facilities for aquaculture, ports and aquaculture zones can be compatible with fisheries infrastructure use. (vi) Additionally, the extraction of solid minerals via submarine construction, without impacting the marine space above the seabed, enables compatibility between entertainment zones and this specialized form of mineral utilization. Finally, based on the unique features of each compatibility model and the nature of sea use activities, the paper offers management recommendations for harmonious maritime utilization. For development sequencing compatibility scenarios, it is important to address the issues of the withdrawal and compensation of development activities. For spatial coexistence compatibility scenarios, it is crucial to manage the interference of compatible functions with basic functions. For functional synergy compatibility scenarios, it is necessary to manage the impact of sea use activities on the marine natural attributes, avoiding any detrimental effects of compatible functions on basic functions.

The compatible sea use models proposed in this paper comprehensively address the spatial use demands of different types of sea use activities in the compilation and implementation of MSP in China. These models ensure adherence to pertinent laws and regulations concerning spatial planning and marine area management, while also accommodating the imperatives of economic and social development. This helps to resolve spatial conflicts in marine development and utilization. However, the compatible sea use models presented in this paper are primarily theoretical discussions and do not include quantitative assessments of the interactions between different sea use activities. This lack of empirical data poses challenges for the effective implementation and management of MSP. Therefore, the next step requires planners to conduct quantitative analyses of typical compatible sea use models. Additionally, it is essential for management departments and marine users to scientifically assess the compatibility of two sea use activities before adopting a compatible sea use model, thereby reducing the risk of new spatial conflicts arising from such models. Once the relevant research is further developed, it is advisable for management authorities to issue policy documents or technical guidelines regarding compatible sea use. These guidelines should detail specific scenarios and define applicable ranges, thus standardizing the formulation and management of planning implementation.

Data availability statement

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

Author contributions

YL: Writing – original draft, Writing – review & editing. YY: Writing – original draft, Writing – review & editing. YH: Writing – review & editing. XL: Investigation, Writing – review & editing. DL: Funding acquisition, Resources, Writing – review & editing.

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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.

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