Fundamental Concepts, Technical Logic, and Implementation Pathways of Three-dimensional Marine Spatial Planning

LI Yanping, XU Xiaomeng, LIU Dahai, XIN Li, XU Saiya, LIU Yilin

Abstract: As stratified sea-use rights continue to develop, marine management is expected to evolve toward comprehensive three-dimensional marine spatial planning. Existing research remains concentrated at project and micro scales. This paper explains the necessity of three-dimensional planning from the perspectives of high-quality marine development, optimized allocation and overall organization of three-dimensional resources, and intensive use of nearshore space. It constructs a framework spanning functional, temporal, developmental, and rights dimensions, then proposes an overall technical approach. Key relationships concern three-dimensional and two-dimensional planning, stratified use, and planar and vertical functions. Priority tasks include surveying current stratified use, evaluating suitability, organizing three-dimensional functions and space, and formulating use-control rules.

Keywords: three-dimensional marine spatial planning; stratified sea use; marine functional zoning; suitability evaluation; use control

Funding note: National Natural Science Foundation of China project on conflict mechanisms, organizational modes, and spatial optimization of stratified sea use (42306247); key project of the Key Laboratory of Marine Spatial Resource Management Technology; major project of the Hainan Key Laboratory for Building Maritime Strength.

Oceans provide coastal societies with essential resources and development space. Expanding global use has increased scarcity and conflict, encouraging coastal states to adopt marine and coastal spatial planning [1-4], detailed marine planning [5-6], multi-use marine planning [7], and ocean multi-use [8]. China has also developed three-dimensional stratified sea-use rights under the Sea Area Use Management Law [9]. This institution divides and allocates vertical space so that different activities can use different depths within the same sea area [10-15]. It has advanced since 2015, but current practice still needs a planning framework that moves from individual projects to regional organization [16-18].

1 Why Three-dimensional Marine Spatial Planning Is Necessary

1.1 Supporting High-quality Marine Economic Development

Dense combinations of ports, aquaculture, renewable energy, tourism, cables, pipelines, and ecological protection make two-dimensional allocation increasingly inadequate. Three-dimensional planning can reduce spatial conflict, enable compatible activities, and align projects with broader economic and environmental objectives. It turns project-specific stratified rights into a coordinated spatial structure and supports efficient marine development [16-19].

1.2 Optimizing Allocation and Overall Organization of Three-dimensional Resources

Individual stratified-rights projects may solve local conflicts while creating fragmentation at regional scale. Planning is needed to identify cumulative effects, connect infrastructure, reserve corridors, coordinate neighboring projects, and establish an overall arrangement of surface, water-column, seabed, and subsoil uses. A regional perspective also makes rights assignment transparent and helps balance sectoral claims [19-21].

1.3 Promoting Intensive and Efficient Use of Nearshore Space

Nearshore areas are especially congested. Coordinating compatible vertical uses can reduce horizontal expansion, improve utilization, and preserve ecological space. Examples include combining aquaculture with offshore photovoltaics, coordinating wind power with fisheries, and sharing corridors for bridges, cables, and pipelines. Compatibility depends on environmental conditions, construction methods, timing, safety, and rights [18,22-23].

2 Fundamental Understanding

2.1 Functional Dimension: Coordinating Vertical Functions

Conventional planning uses horizontal zoning and buffer separation to reduce interference. Vertical planning has less room for separation and must treat spatial exclusivity as a primary criterion. Each activity requires a defined vertical range, and compatible activities may enter only when they do not undermine the dominant function. Ecological objects often extend from the surface to the seabed, so apparent unused depth is not automatically developable space.

2.2 Temporal Dimension: Coordinating Development Sequence

Construction and maintenance can temporarily conflict even when completed uses are compatible. Planning should distinguish concurrent and sequential compatibility, account for construction windows and operational cycles, and coordinate early and late projects. Wind-power construction may need to precede aquaculture, and cable or pipeline installation may require temporary exclusion. Timing is therefore part of spatial allocation.

2.3 Development Dimension: New Paths for Marine Ecological Space

Nearshore ecological redlines can restrict infrastructure that cannot avoid protected areas. Because many ecological targets occupy a specific vertical range, carefully controlled directional drilling or subsurface passage may satisfy infrastructure needs without weakening protection. Three-dimensional planning can identify such possibilities while maintaining ecological objectives and specifying strict construction conditions.

2.4 Rights Dimension: Coordinating Multiple Stakeholders at a Wider Scale

Planning expands stratified use from a vertical project arrangement to a regional institutional process. Management departments assume greater responsibility for balancing users, sequencing projects, allocating rights, and defining compensation and supervision. Planning must therefore coordinate public and private rights through use control, construction oversight, and compensation mechanisms.

3 Technical Logic and Implementation

3.1 Overall Approach

3.1.1 Linking Three-dimensional Planning, Two-dimensional Planning, and Stratified Use

Three-dimensional planning should be founded on the current two-dimensional marine planning system. Existing functional zones retain their dominant role, while vertical planning introduces compatible layers and project sequencing. It integrates the regional scope and governance logic of two-dimensional planning with the technical experience of stratified-rights projects.

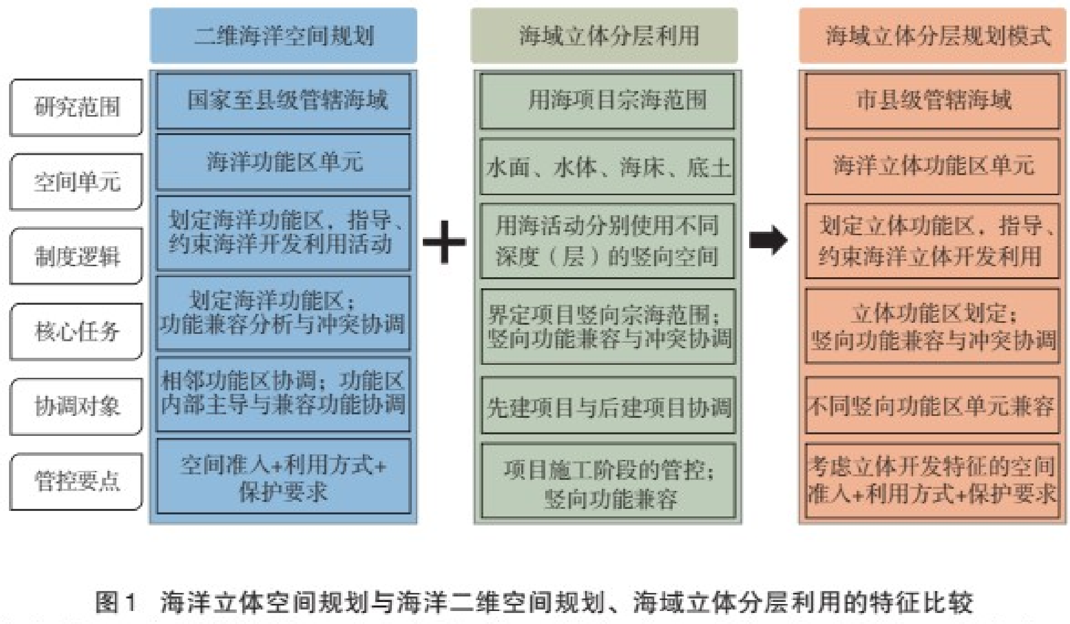

Fig. 1 Comparison of three-dimensional marine spatial planning, two-dimensional marine spatial planning, and stratified use

3.1.2 Linking Planar and Three-dimensional Functions

A three-dimensional functional zone extends from an existing two-dimensional zone. The vertical range required by the dominant planar function becomes the dominant layer; other ranges may be designated as compatible layers. This preserves the established planning system while avoiding functional confusion. Areas without a need or suitable conditions for stratified use may remain under conventional two-dimensional zoning.

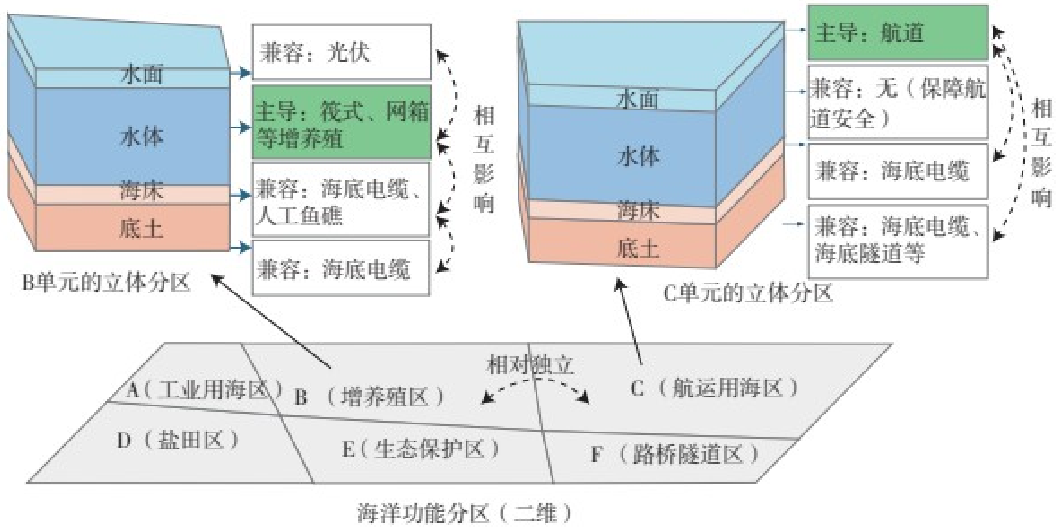

Fig. 2 Transition from two-dimensional to three-dimensional marine functional zoning

3.2 Main Technical Stages

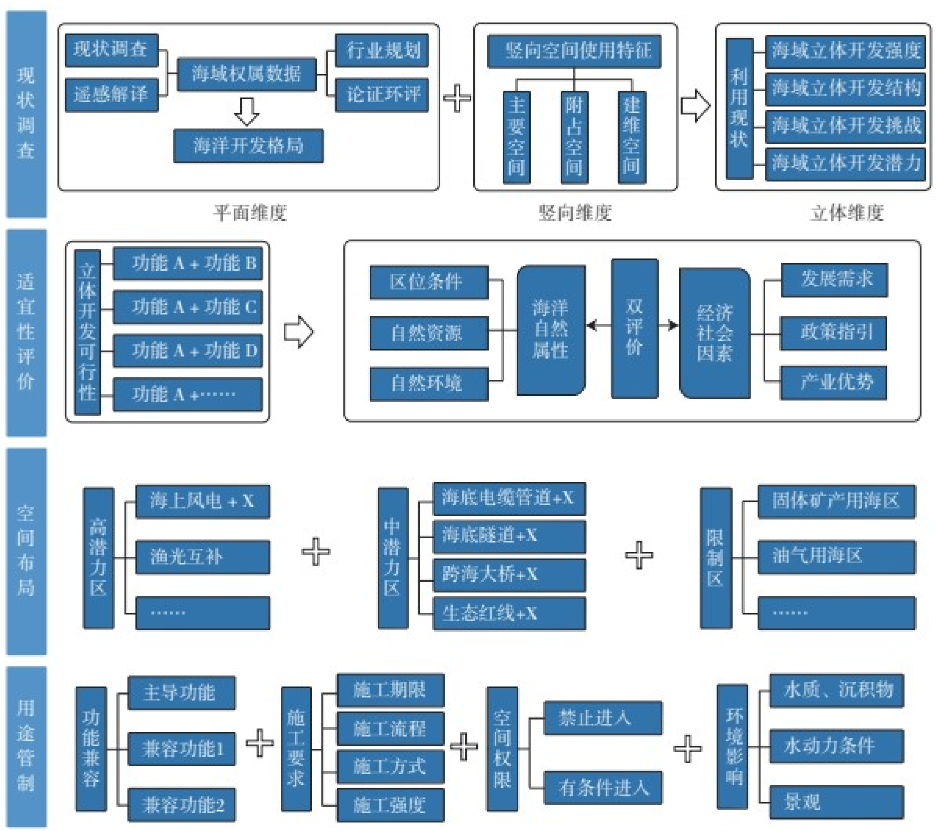

图3 海洋立体空间规划的主要技术环节

Fig.3 Core technical components of three-dimensional marine spatial planning

Fig. 3 Main technical stages of three-dimensional marine spatial planning

3.2.1 Surveying Current Stratified Use

The survey should document how every activity occupies the surface, water column, seabed, and subsoil. Two-dimensional plans often show only horizontal extent and omit vertical use. Marine-rights data, sectoral plans, remote sensing, field investigation, and project documentation should be integrated to determine actual vertical ranges and current conflicts.

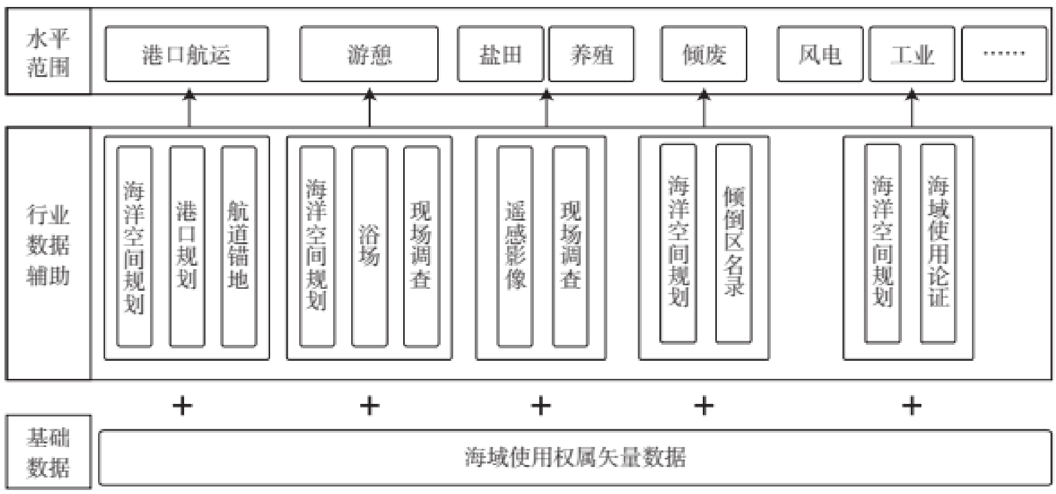

Fig. 4 Evaluation of the planar extent of marine-use activities

表1　用海活动的竖向空间使用特征

Tab.1　Characteristics of vertical ocean utilization activities

用海活动	空间使用特征			具有利用潜力的剩余空间
	主要空间	附占空间	建设维护空间	
围海养殖	水体	海床	水面—水体	底土
筏式和网箱养殖	水体	水面、海床	水面—水体	海床、底土
底播养殖	海床	——	水面—海床	底土
人工鱼礁	海床	——	水面—海床	底土
温(冷)排水	水体	——	水体	水面、海床、底土
海上光伏(桩基式)	水面	水体、海床、底土	水面—底土	水体、海床、底土
海上光伏(漂浮式)	水面	水体、海床、底土	水面—水体	水体、海床、底土
海上风电	底土	水体、海床、底土	水面—底土	水体、海床、底土
跨海桥梁	水面	水体、海床、底土	水面—水体	水体、海床、底土
浴场	水面	水体	——	底土
游乐场	水面	水体	水面—海床	底土
海底电缆管道(海床敷设)	海床	——	水面—海床	水面、水体
海底电缆管道(底土埋设)	底土	——	水面—底土	水面、水体
海底隧道	底土	——	底土	水面、水体、海床
海底场馆	底土	——	底土	水面、水体、海床

Table 1 Vertical-space characteristics of marine-use activities

3.2.2 Suitability Evaluation for Stratified Use

Suitability assessment first identifies the principal, ancillary, and construction space of each activity and then evaluates compatibility between activity pairs. Regional conditions, resources, environment, development demand, policy guidance, industrial advantages, and stakeholder interests are considered together. The result identifies combinations that can share vertical space and those requiring exclusion or sequence control.

表2 用海活动立体分层利用适宜性评价结果

Tab.2 Stratified suitability assessment of ocean space

用海活动	围海养殖	筏式和网箱养殖	底播养殖	人工鱼礁	温(冷)排水	海上光伏	海上风电	跨海桥梁	海水浴场	海上娱乐活动	海底电缆管道(海床)	海底电缆管道(底土)	海底隧道	海底场馆
围海养殖						√		√				√		
筏式和网箱养殖			√	√		√	√	√			√	√	√	√
底播养殖		√				√		√					√	√
人工鱼礁		√				√	√	√					√	√
温(冷)排水						√	√	√					√	√
海上光伏	√	√	√	√	√		√				√	√	√	√
海上风电		√		√	√	√					√			
跨海桥梁	√	√	√	√	√						√	√		
海水浴场											√	√	√	√
海上娱乐活动											√	√	√	√
海底电缆管道（海床敷设）		√				√	√	√	√	√		√	√	√
海底电缆管道（底土埋设）	√	√				√		√	√	√	√			
海底隧道		√	√	√	√	√			√	√	√			
海底场馆		√	√	√	√	√			√	√	√			

Table 2 Suitability assessment of stratified marine-use combinations

3.2.3 Three-dimensional Functional Zoning and Spatial Layout

Planning should define the vertical range of the dominant function, designate compatible layers, and classify areas by development potential. High-potential zones have suitable conditions and strong demand; medium-potential zones contain linear infrastructure or limited combinations; restricted zones are unsuitable for stratified development. Not every layer requires a use, and compatible functions should be designated only when real need and feasibility exist.

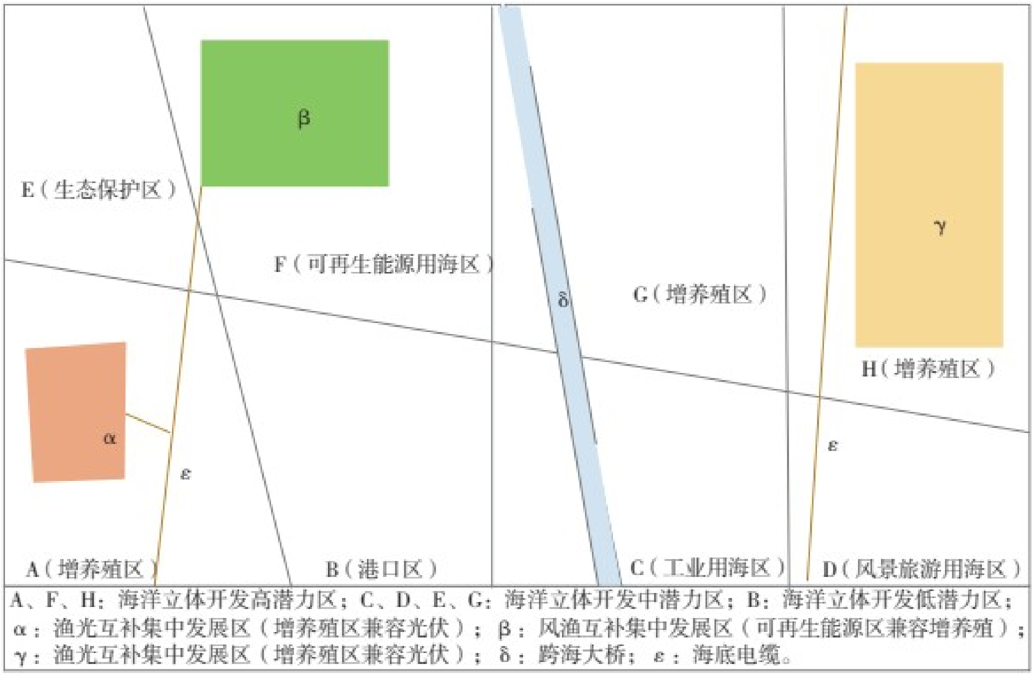

Fig. 5 Schematic three-dimensional spatial layout and zoning

3.2.4 Formulating Use-control Rules

Rules should regulate functional compatibility, construction timing and method, spatial rights, and environmental effects. They should protect cables, bridges, wind foundations, and other facilities; specify seasons and operational windows; control construction intensity and disturbance; prevent impacts on water quality, hydrodynamics, sediment, and landscape; and define compensation where one activity imposes costs on another.

3.3 Implementation Pathways

Two pathways are feasible within the current territorial spatial planning system. First, three-dimensional content can be incorporated into coastal-zone special plans, including survey, suitability evaluation, zoning, layout, and control rules. This approach connects two- and three-dimensional planning and reduces conflicts between systems. Second, it can be incorporated into detailed marine plans now being piloted in Shenzhen, Sanya, Qingdao, and other cities. Detailed planning is well suited to precise local layout and the project-level requirements of three-dimensional use.

4 Conclusions and Discussion

Three-dimensional marine spatial planning is a new form of marine planning and a special mechanism for allocating marine resources. It should coordinate vertical functions, development timing, stakeholder rights, and the relationship between planar and three-dimensional functions. Its principal technical stages are the survey of existing stratified use, suitability evaluation, functional zoning and spatial layout, and use-control formulation. The proposed assessment method, distinction between dominant and compatible layers, and classification of development-potential zones have direct practical value.

The transition from stratified projects to planning moves management from micro to macro scale and from a vertical dimension to fully three-dimensional organization. Because China's marine planning system and relevant legislation are still evolving, theory and methods require further testing. Conditional coastal regions should pilot the approach through coastal-zone special plans or detailed marine plans and use implementation feedback to refine the system.

References

[1] Wen Chaoxiang, Lü Yiping, Lin Xiaoru, et al. Land-sea coordination in coastal spatial planning [J]. Urban Planning Forum, 2020(5): 69-75.

[2] Cheng Yao, Li Yuanwen, Zhao Min. Marine spatial planning from a land-sea coordination perspective: EU experience [J]. Urban Planning Forum, 2019(5): 59-67.

[3] Lin Xiaoru, Wang Liyun, Wen Chaoxiang. Coastal spatial control oriented to land-sea coordination [J]. Urban Planning Forum, 2018(4): 75-80.

[4] Liu Dahai, Xing Wenxiu, Li Yanping, et al. Regulatory framework and rights relationships in coastal planning [J]. Urban Planning Forum, 2022(2): 20-26.

[5] Gu Haibo, Li Xiaojuan, Xing Wenxiu, et al. Detailed marine planning in Shenzhen based on land-sea coordination [J]. Urban Planning Forum, 2023(5): 71-78.

[6] Xing Wenxiu, Lin Yuting, Liu Dahai, et al. Concepts and implementation of detailed marine planning [J]. Urban Planning Forum, 2023(4): 95-103.

[7] Taljaard S, Van Niekerk L. National legal regimes for multi-use marine spatial planning [J]. Marine Policy, 2013, 38: 72-79.

[8] Schupp M F, Bocci M, Depellegrin D, et al. Toward a common understanding of ocean multi-use [J]. Frontiers in Marine Science, 2019, 6: 165.

[9] Cui Wanglai, Li Ruifa, Zhong Haiyue, et al. Property-rights management for stratified sea use [J]. Natural Resource Economics of China, 2022, 35(7): 4-11.

[10] Li Yanping, Chen Yiyang, Liu Dahai, et al. Spatial conflicts and management of stratified sea use [J]. Journal of Natural Resources, 2023, 38(10): 2475-2489.

[11] Zhao Meng, Yue Qi, Xu Wei, et al. Feasibility of three-dimensional sea-use rights [J]. Ocean Development and Management, 2016, 33(7): 70-73.

[12] Ma Xinyu. Legal Issues in Three-dimensional Marine Development in China [D]. Dalian Ocean University, 2024.

[13] Cui Wanglai, Wang Xia, He Yixiong. Definition and management of stratified sea-use rights [J]. Marine Economy, 2024, 14(3): 63-72.

[14] Yang Zhihao, Sun Huaye, Yang Mingming, et al. Supporting institutions for stratified sea-use rights [J]. Ocean Development and Management, 2022, 39(3): 79-83.

[15] Li Yanping, Li Chenyu, Liu Dahai. Institutional difficulties and improvement of stratified sea use [J]. Ocean Development and Management, 2020, 37(9): 3-8.

[16] Li Yanping, Liu Dahai, Chen Yiyang, et al. Three-dimensional marine spatial resources and management [J]. Journal of Natural Resources, 2024, 39(1): 49-61.

[17] Feng Chongjun, Zhong Jinxiang, Zhou Yuan, et al. Three-dimensional cadastral modeling and conflict detection [J]. Science of Surveying and Mapping, 2023, 48(8): 220-228.

[18] Michler-Cieluch T, Krause G, Buck B H. Integrating offshore wind and mariculture operations [J]. Ocean & Coastal Management, 2009, 52: 57-68.

[19] Christie N, Smyth K, Barnes R, et al. Co-location in marine spatial planning [J]. Marine Policy, 2014, 43: 254-261.

[20] Gleason M, McCreary S, Miller-Henson M, et al. Stakeholder-driven marine protected-area network planning [J]. Ocean & Coastal Management, 2010, 53(2): 52-68.

[21] Yates K L, Schoeman D S. Fishers' spatial priorities in conservation planning [J]. ICES Journal of Marine Science, 2014, 72(2): 587-594.

[22] Buck B H, Richard L. Aquaculture Perspective of Multi-use Sites in the Open Ocean [M]. Cham: Springer, 2017.

[23] Li Yanping, Liu Dahai. Marine resource allocation based on three-dimensional development [J]. Marine Environmental Science, 2019, 38(3): 435-440.

AI-assisted translation