Promoting the Modernization of Concept, Equipment, Technology, and Management in Marine Ranching Development Postprint

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Abstract

The construction of modern marine ranches represents a key strategy for ecological environmental protection in China' s coastal waters and the healthy development of marine fisheries. The construction philosophy of China's marine ranches has continuously evolved, transitioning from artificial reef deployment and stock enhancement to sea area environmental improvement and fishery resources conservation. Presently, the construction scale of marine ranches continues to expand, with 64 national-level marine ranch demonstration zones completed to date. However, numerous issues regarding the realization of modern marine ranch construction remain to be urgently addressed. This article elaborates on the construction philosophy of modern marine ranches from four perspectives: philosophical modernization, equipment modernization, technological modernization, and management modernization. Based on the characteristics of China' s temperate and tropical sea areas and the requirements of coordinated land-sea blue granary construction, a new integrated development model is proposed that combines marine ranches with intensive precision aquaculture farms, coastal zone ecological agriculture-aquaculture farms, and offshore deep-water smart fisheries, aiming to provide references for upgrading existing marine ranches in temperate sea areas and the modern construction of marine ranches in tropical sea areas.

Full Text

Preamble

Modern marine ranching development is a critical component of nearshore ecological protection and the healthy growth of marine fisheries in China. The conceptual approach to marine ranching construction has continuously evolved,

transitioning from merely deploying artificial reefs and releasing aquatic species to a more comprehensive focus on marine environment improvement and fishery resource conservation. To date, China has established 64 national-level marine ranching demonstration zones, with construction scale expanding steadily. However, numerous challenges remain in achieving true modernization of marine ranching development. This paper examines the construction framework for modern marine ranching across four dimensions: conceptual modernization, equipment modernization, technological modernization, and management modernization. Based on the distinct characteristics of China' s temperate and tropical sea areas and the strategic demand for integrated land-sea blue granary development, we propose an innovative integration model combining marine ranching with intensive precision aquaculture, coastal ecological farms, and offshore deep-water smart fishing grounds. This model aims to provide guidance for upgrading existing temperate marine ranches and developing modern marine ranching in tropical waters.

Modern marine ranching represents a new marine industry paradigm that integrates environmental protection, resource conservation, efficient production, and recreational fisheries. The development of modern marine ranching has received significant attention from the Chinese government. The 2017 Central No. 1 Document first emphasized support for intensive healthy mariculture, modern marine ranching development, strengthened regional collaborative protection, and rational control of nearshore fishing. The 2018 Central No. 1 Document reiterated the need to coordinate marine fishery resource development, scientifically plan nearshore and offshore aquaculture and distant-water fisheries, and construct modern marine ranches. President Xi Jinping stressed at the 30th anniversary celebration of Hainan' s establishment as a special economic zone that China must firmly pursue a development path featuring harmony between humans and the sea and win-win cooperation, enhance marine resource development capabilities, accelerate the cultivation of emerging marine industries, and support Hainan' s construction of modern marine ranches.

Modern marine ranching development serves as a crucial driver for transforming and upgrading marine fisheries and shifting to new growth models. With strong support from innovation-driven policies and strategic guidance, 64 national marine ranching demonstration zones have been established to date. However, alongside this vigorous development, China' s marine ranching sector has revealed a series of issues including inconsistent concepts, disordered development, and technological deficiencies. Urgent modernization is needed in technological innovation, standardized construction, scientific layout, and standardized management.

Development History of the Marine Ranching Concept

Since its inception, the marine ranching concept has received widespread attention from coastal nations worldwide. The definition has gradually evolved from singular to pluralistic, from abstract to concrete, and from production-focused

to ecology-focused. The approach no longer equates "stock enhancement" or "artificial reef deployment" with marine ranching construction. Instead, it integrates multiple practical technical measures including seedling cultivation, habitat modification, and dynamic monitoring to create healthy ecosystems within designated sea areas.

Through more than half a century of research and practice, the connotation of marine ranching in China has been further developed [1,2]. The industry standard "Marine Ranching Classification" (SC/T 9111-2017) defines marine ranching as a fishery model based on marine ecosystem principles, implemented in specific sea areas through artificial reefs, stock enhancement, and other measures to construct or restore habitats for marine organisms'reproduction, growth, feeding, and predator avoidance, thereby conserving fishery resources, improving marine environments, and achieving sustainable utilization of fishery resources. Similarly, the Shandong Provincial Standard "Marine Ranching Construction Specification" (DB37/T 2982.1-2017) defines marine ranching as an artificial fishery created based on marine ecological principles, utilizing modern engineering technologies, maximizing natural productivity, fostering healthy ecosystems within specific sea areas, and implementing scientific conservation and management of biological resources. These definitions clarify the core elements of marine ranching "modernization" [3-6].

Modern Marine Ranching Construction Concepts

Modern marine ranching construction encompasses critical components including habitat restoration, seedling breeding, primary productivity enhancement, whole-process management, high-value product utilization, clean energy utilization, and recreational fisheries. Its distinctive features are prominently reflected in four aspects: conceptual modernization, equipment modernization, technological modernization, and management modernization.

Conceptual Modernization (1) Ecological Priority. Against the backdrop of numerous challenges facing existing capture fisheries and aquaculture, marine ranching emerges as a new industrial paradigm whose development depends fundamentally on healthy marine ecosystems. Therefore, habitat restoration and resource recovery must be prioritized, with construction scale determined based on carrying capacity—this constitutes the prerequisite for sustainable marine ranching development. Currently, aside from a few marine ranches that incorporate restoration of mangroves, seagrass beds, macroalgal fields, oyster reefs, and coral reefs, most still focus primarily on enhancing high-value aquatic products without adequately considering environmental and ecosystem function recovery. Insufficient attention has been paid to population structure and genetic diversity restoration of fishery resources. If yield maximization remains the primary objective, it will not only lead to decreased product prices and quality but also adversely affect ecosystem stability, contradicting sustainable development principles. Consequently, the "ecological priority" concept

must be prioritized as the foremost principle in future modern marine ranching practices.

(2) Land-Sea Coordination. Marine ranching can be divided into terrestrial and marine components based on natural environment, each bearing different functions. Loss of land-sea connectivity compromises the comprehensive benefits of marine ranching. Coastal ecosystems represent typical ecological transition zones with high ecological vitality, and marine ranching development will inevitably drive coastal zone protection and development. Forage grasses and salt-tolerant plants from saline-alkali ecological farms can serve as high-quality feed for intertidal ecological farms, which in turn provide large quantities of healthy seedlings for marine ranching stock enhancement. Shallow marine ranches further promote saline-alkali farm development through seawater fertilizer production, while cultural industries and eco-tourism strengthen internal connections within coastal ecological farms. Ultimately, this creates a "three-field connectivity" system of saline-alkali ecological farms—intertidal ecological farms—shallow marine ranches, and a "three-industry integration" framework spanning aquatic production—deep processing—recreational fisheries. This model will facilitate rational utilization of coastal biological resources, establish new models for coastal ecosystem protection and sustainable use spanning land and sea, and promote ecological civilization and sustainable social development along China' s coastlines.

(3) Human-Sea Harmony. The ocean has become an essential natural condition for human survival and development, with large populations concentrated in coastal areas. While driving economic development and social progress, this concentration has triggered a series of ecological crises. Human-sea harmony requires humanity to reconsider the relationship between humans and the sea, and among people themselves, treating the ocean with equality, friendliness, and comprehensiveness to form a cultural foundation for harmonious human-sea coexistence. At the economic value level, exploitative development of marine resources must be eliminated, and ecological civilization must be integrated throughout the entire process of marine economic development, achieving sustainable marine economic growth through marine science and technology advancement. At the social value level, equitable distribution of marine benefits must be advocated, coordinating development between marine and terrestrial regions and between coastal and inland nations, as well as interpersonal and intergenerational development. At the ecological value level, a new relationship featuring harmony, equality, and coordinated development between humans and nature must be established, achieving a transformation in thinking patterns. This involves treating the environment upon which we depend with care, giving equal importance to ecological protection and economic development, protecting while developing and developing while protecting, enabling society to actively adapt to the environment, and ultimately achieving harmonious development among humans, land, and sea.

(4) Functional Diversification. Obtaining high-quality aquatic protein rep-

resents only one of marine ranching' s many functions. Modern marine ranching construction places greater emphasis on functional diversification. Marine ranching constitutes an integrated system comprising natural environment, social environment, and human interactions, with diverse ecosystem composition and structure determining its multifunctional nature. The primary prerequisite for marine ranching construction is creating a healthy ecosystem within a designated sea area, with macroalgae transplantation and reef deployment serving as important means to improve marine environments. Macroalgae rapidly proliferate in waters shallower than 6 meters to form artificial kelp forests, providing ecological functions including water purification, food source supplementation, and habitat provision. Small fish and shrimp that feed on natural bait aggregate, attracting other economically valuable wild marine organisms, thereby achieving fishery resource recovery and improved product quality. Integrating clean renewable energy development, seawater comprehensive utilization, and saline-alkali land salt-tolerant plant cultivation can maximize utilization of coastal environmental and spatial resources, enhancing marine productivity. Upon maturation, marine ranches can fully leverage ecological environments and biological resources to develop marine tourism, recreational fishing, scuba diving, convalescence, and other marine tertiary industries, attracting surrounding communities to participate in ranch operations and creating new coastal green 田园综合体 (integrated rural complexes), enabling full sharing of marine ranching' s scientific, ecological, economic, and social values.

Equipment Modernization (1) Engineering Integration. Marine ranching construction is a comprehensive engineering endeavor spanning marine ecology, fisheries management, civil engineering, electronic communications, and multiple other disciplines. The "engineering integration" concept must be emphasized in practical implementation. Using artificial reef deployment as an example, the processes of fabrication, planning, and management should form a systematic engineering project. Full consideration must be given to the reliability and safety of reef materials and structures, preventing negative environmental impacts from material or design issues. Reef deployment processes should follow relevant engineering standards and specifications to achieve rational reef layout and maximize ecological functions for resource conservation. Reef management is equally critical and should incorporate real-time monitoring methods to conduct comprehensive assessments based on environmental factors and fish behavior characteristics, providing references for subsequent operational adjustments.

(2) Automation. To achieve full-chain marine ranching layout, a comprehensive support system must be established encompassing monitoring, assessment, early warning, forecasting, traceability, and management. Information monitoring centers should be established with scientific deployment of underwater cameras, water quality monitoring probes, and other monitoring equipment to measure environmental parameters including temperature, salinity, and pH, while dynamically recording physicochemical indicators and marine organisms

within ranch waters. Through scientific modeling, marine ranching construction effectiveness evaluation technologies should be developed and refined to enable scientific assessment of operational status and timely prediction and forecasting before abnormal conditions occur. Simultaneously, a comprehensive product quality safety traceability and management system throughout the entire production process should be constructed to ensure stable ranch operations.

Technological Modernization (1) Focus on Germplasm Conservation. "Agriculture is the foundation of the nation, and seeds are the foundation of agriculture." High-quality marine biological germplasm resources constitute the important foundation for marine ranching development. Systematic research on germplasm conservation principles and key technologies should be conducted to establish a complete system for collection, organization, identification, protection, preservation, and rational utilization. Original seed farm construction technology should be improved, with equal emphasis on original seed farms and improved variety farms being key to achieving species resource diversification and specialization in marine ranching. Germplasm resource conservation areas should be established, local species artificial breeding and release should be carried out, excessive inbreeding and genetic pollution must be avoided, population carrying capacity in relevant original seed farms should be scientifically assessed, and scientific fishing moratoriums and harvesting plans should be formulated based on population structure to eliminate risks of overfishing.

(2) Focus on Habitat Restoration. Innovative technologies for macroalgal field and seagrass bed restoration should be developed, establishing material and energy flow models for these habitats and analyzing their biological conservation mechanisms. Hydrodynamic field creation technology should be advanced to reveal relationships between flow fields and biological distribution and feeding environments. Engineering improvement technologies based on water exchange should be innovatively developed utilizing circulation ecological characteristics, establishing biological and microbial improvement technology systems and forming a series of methods for substrate environment improvement. Restoration site selection technologies should be advanced, and technical equipment for improving released juvenile survival rates and live juvenile transportation should be developed.

(3) Utilization of Information Technology. Acquisition of comprehensive environmental element information remains in its infancy in China' s marine ranching information network establishment, preventing real-time monitoring and information-based management. An online monitoring system for water environment based on Internet of Things technology should be constructed to achieve three-dimensional real-time online monitoring of key seawater environmental factors including temperature, salinity, dissolved oxygen, and chlorophyll. There is an urgent need to breakthrough biological remote visual monitoring, domestication, and tracking technologies, with high priority placed on

developing biological resource acoustic detection and assessment, and acoustic behavior control and domestication for specific fish species. Marine ranching ecological environment and biological information databases should be integrated, forecasting and early warning systems and expert decision-making systems should be established, environmental disaster early warning mechanisms targeting species-specific biological tolerance limits should be formed, and disaster early warning management platforms should be constructed.

(4) Development of Clean Energy. Marine energy represents a renewable energy source with enormous development potential that is clean and pollution-free, though regionally specific and low in energy density. Currently, offshore wind energy is the most widely utilizable form. Several coastal provinces have already conducted forward-looking layout for offshore wind power construction. Based on mature experiences from developed countries such as Germany and the Netherlands and practices from other Chinese provinces, effective integration of marine ranching and offshore wind power can generate tremendous spatial intensification effects, effectively promoting integrated development of environmental protection, resource conservation, and new energy development, while driving development and utilization of solar energy, tidal energy, and other clean energy sources, thereby generating greater ecological, social, and economic benefits.

Management Modernization Traditional marine ranching management has typically prioritized economic needs and production experience, lacking systematic and scientific approaches. Modern marine ranching management should incorporate "standardization, informatization, intelligence, and systematization" to achieve harmonious human-sea coexistence.

(1) Standardization. From the perspectives of clarifying sea area use rights and protecting investor interests, there is an urgent need to strengthen construction and implementation of relevant legal provisions. Based on sea area environments and resource conditions in various coastal provinces and cities, and according to marine ranching construction and operational management characteristics, relevant laws and regulations should be established and improved. In response to China' s actual needs for marine ranching development, national ecological protection and other relevant policies should be fully and effectively implemented. Through formulation of relevant policies and regulations, active promotion of supporting fiscal and tax system reforms should guide rational marine ranching construction and development. Meanwhile, marine ecological civilization concepts should be vigorously promoted to ensure relevant laws and regulations are deeply understood, guaranteeing smooth advancement of marine ranching construction.

(2) Informatization. Exploring information-based marine ranching construction represents an inevitable choice to adapt to development trends. Modern marine ranching operations require coordination among multiple operational units, including ranch site selection, geological, physical, and biological marine data acquisition, biological carrying capacity assessment, ranch layout, reef

research and development and deployment, biological field observation, ecological safety and environmental security, product resource quantity prediction and harvesting strategies, and benefit evaluation. With scientific and technological advancement, informatization has demonstrated enormous development potential across industries. Informatization, digitalization, and intelligence are gradually permeating marine ranching construction and management processes. Introducing information-based management can effectively improve production efficiency, reduce environmental impacts, and enhance food quality and safety.

(3) Intelligence. The emergence and gradual maturation of computer big data mining technologies provide technical support for intelligent marine ranching construction and management [9]. Relying on long-term accumulated marine ranching operational data and scientific algorithm modeling, not only can the current operational status of marine ranches be scientifically and effectively evaluated, but future trends can also be predicted, thereby helping operators better control cost inputs, avoid risks and losses, and improve product quality. Thus, marine ranching intelligence can better balance economic, social, and environmental benefits, optimize production factor composition, production processes, and final product quality, promote sustainable self-expansion and reproduction of marine ranches, and generate better benefits for operators and the marine environments upon which ranches depend.

(4) Systematization. Marine ranching construction is an undertaking that benefits contemporary society and future generations, requiring high-level attention in terms of policy guidance and financial support. Marine ranching construction, including site selection, layout, facility construction and deployment, as well as sea area resource development and operational management, must be planned and verified in advance, and promoted in an organized manner according to established plans. The most critical aspect is systematic organizational management. Government functional departments and operating enterprises should jointly formulate marine ranching development goals, implement work responsibilities, clarify safeguard measures, improve assessment mechanisms, and enforce strict evaluation and rewards/penalties. Meanwhile, an expert consultation system should be established, employing experts to review and evaluate key projects, promoting scientific and democratic decision-making to ensure land-sea coordination, comprehensive consideration, and rational layout, thereby guaranteeing successful completion of marine ranching construction tasks.

Approaches to Modern Marine Ranching Construction

Developing Upgraded Marine Ranching in Temperate Waters The blue granary represents a redefinition of traditional fisheries in national economic development, forming a land-sea coordinated national food security guarantee system alongside agriculture, forestry, and animal husbandry. The blue granary aims to expand the depth and breadth of China' s food security strategy, utilizing marine and inland water spaces and resources from a land-sea coordination perspective. Following the construction approach of "advancing

both land and sea + moving toward deep blue waters," it seeks to establish an ecologically prioritized, high-quality, efficient, and sustainably supplied aquatic product production system.

Actively promoting the construction of intensive precision aquaculture + coastal ecological farms. Under the premise of ecological priority and green development, innovation in factory-based and pond intensive precision aquaculture technical systems and models should be advanced, accelerating coastal ecological farm construction. Based on ecological principles and utilizing modern engineering technologies, this approach integrates land-sea coordination to construct saline-alkali ecological farms, intertidal ecological farms, and shallow marine ranches, fostering healthy coastal ecosystems and forming new models for coastal ecosystem protection and sustainable utilization featuring "three-field connectivity" and "three-industry integration" [10].

Steadily advancing marine ranching + offshore deep-water smart fishing ground construction. While developing modern marine ranching in nearshore areas, new models for offshore deep-water smart fishing grounds should be actively developed. Using large-scale aquaculture vessels as base stations, deep-sea cage facilities should be deployed to construct deep-water industrial aquaculture models, develop safe and efficient fishing vessel equipment, establish major fisheries logistics channels, and form a new "culture-capture-processing" integrated fisheries model combining marine ranching + smart fishing grounds, thereby strengthening military-civilian integration and "fisheries-based border defense."

Creating New Prospects for Tropical Marine Ranching Construction
Currently, China' s 64 national marine ranching demonstration zones are concentrated primarily in the Bohai Sea-Yellow Sea region, including Shandong, Liaoning, and Hebei provinces, while the South China Sea has only 9 zones, all located in subtropical waters. National-level marine ranching demonstration zone construction in China' s vast tropical sea areas remains nearly blank. The South China Sea tropical waters are rich in fishery resources and have numerous fishing harbors with a strong base of fishery practitioners and well-developed recreational fisheries, providing unique advantages for marine ranching construction.

Tropical marine ranching construction faces a series of scientific and technical challenges. First, the lack of high-value seafood aquaculture industries necessitates seeking alternative drivers such as diving tourism and recreational travel. Second, complex sea conditions including high temperature, high salinity, high humidity, and typhoons, combined with insufficient geological and hydrological data, pose significant challenges.

Tropical marine ranching construction should rely on innovation and research in principles and technologies, including coral reef ecosystem conservation and restoration, corrosion-resistant material development and application, in-situ reef construction techniques, resource species screening and efficient stock en-

hancement, long-term seafood preservation or rapid processing, intelligent resource environment monitoring and evaluation, and eco-tourism development models.

Based on systematic analysis of South China Sea resources, environment, industrial characteristics, and development trends, we recommend developing island-reef resource conservation and enhancement marine ranches, island-reef recreational tourism marine ranches, and tropical coastal ecological farms, using these point developments to drive tropical marine ranching modernization.

Island-reef resource conservation and enhancement marine ranches. These target high-quality seafood resource acquisition in tropical coral reef areas, focusing on conserving and restoring original coral reef ecosystems, appropriately deploying artificial reefs and storm-resistant net cages, screening suitable economic species, and conducting resource enhancement activities.

Island-reef recreational tourism marine ranches. These aim to develop marine recreational tourism, selecting island-reefs with good infrastructure conditions for coral reef ecosystem conservation, fish-aggregating artificial reef zone construction, and landscape artificial reef deployment to conserve and restore fish resources. High-value economic fish stock enhancement should be conducted with supporting land-based or vessel-based tourism support units and marine tourism facilities to develop recreational fishing, diving, and other tourism industries.

Tropical coastal ecological farms. Based on the industrial layout of Hainan' s state farm system, these integrate key technologies for saline-alkali ecological farms, intertidal ecological farms, and shallow marine ranches to achieve "three-field connectivity" and "three-industry integration," improving coastal spatial development efficiency and comprehensive benefits. Major types may include bay-type, mangrove-type, and coral reef-type (including artificial island-reefs), simultaneously developing salt-tolerant plant cultivation, livestock and aquaculture enhancement, resource conservation, deep processing, eco-tourism, and cultural industries.

Marine ranching construction is a process of ecosystem restoration and reconstruction— "building the field before ranching" —with comprehensive benefits prominently reflected in ecosystem protection, resource conservation, and economic returns. Modern marine ranching construction must be based on systematic investigation and assessment, with scientific planning, layout, rational harvesting, and integrated management to achieve effectiveness. Development space and industrial layout must be expanded to fully realize integrated development of intensive precision aquaculture, coastal ecological farms, and offshore deep-water smart fishing grounds. Modern marine ranching must strive to develop representative characteristics of conceptual, equipment, technological, and management modernization. The construction and operation process urgently requires original innovation-driven development, technology leadership, and engineering implementation to break through a series of major scientific questions

and technical bottlenecks, thereby achieving modern marine ranching construction.

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Note: Figure translations are in progress. See original paper for figures.