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Marine Fisheries 3.0 Postprint

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Abstract

Topics such as maritime power building, marine development strategies, development and utilization of marine resources, marine environmental protection, sustainable development of the marine economy, and marine ecosystem health have become hot topics, with marine resource and environmental issues receiving unprecedented attention in China. Against this backdrop of widespread discussion of initiatives and plans including marine granary, distant-water fisheries, marine ranching, offshore aquaculture, cold water mass fish farming, aquaculture vessels, transparent ocean, smart ocean, transitioning from shallow seas to deep seas, from coastal waters to open oceans, and the construction of marine ecological civilization, this paper proposes a "Marine Fisheries 3.0" development plan. From a global ocean perspective and viewing the ocean as an integrated whole, it examines the development trajectory and future pathways of marine fishery resources through the lens of marine ecosystem structure and function, as well as energy and material flows, with the aim of exploring the establishment of a systematic solution for the sustainable development of China's marine fisheries.

Full Text

Special Topic: Current Status and Prospects of Marine Science Development

Status and Prospect of Marine Science
ChinaXiv Partner Journal: Marine Fishery 3.0
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Abstract

The construction of a maritime power, marine development strategies, exploitation and utilization of marine resources, marine environmental protection, sustainable development of the marine economy, and the health of marine ecosys-

tems have become hot topics, with marine resource and environmental issues receiving unprecedented attention in China. Against the backdrop of widespread discussion about maritime grain warehouses, distant-water fisheries, marine ranching, offshore aquaculture, cold-water mass fish farming, aquaculture vessels, transparent oceans, smart oceans, moving from shallow to deep seas, from coastal to open oceans, and the construction of marine ecological civilization, this paper examines the development history and future pathways of marine fishery resources from a global ocean perspective, treating the ocean as an integrated whole and analyzing it at the level of marine ecosystem structure and function, energy flow, and material flow. We propose the "Marine Fishery 3.0" development plan, aiming to explore and establish a systematic solution for the sustainable development of China' s marine fisheries.

Keywords: marine fishery, marine ecosystem, marine management
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1 Development History of Marine Fisheries

In 2011, the German government proposed the concept of "Industry 4.0,"dividing industrial development into distinct stages based on its characteristics to support research and innovation in a new generation of revolutionary technologies for the industrial sector. Similarly, the development history of marine fisheries exhibits distinct characteristics in different periods and can be divided into various developmental stages (Figure 1 [Figure 1: see original paper]).

1.1 Marine Fishery 1.0

The renowned British naturalist Thomas Henry Huxley (1825–1895) published over 150 scientific papers during his lifetime, including *Man' s Place in Nature*, *An Introduction to the Classification of Animals*, and *Evolution and Ethics*, and was particularly celebrated for his research on marine animals. As a prominent scientific figure and distinguished marine zoologist, Huxley [1] was invited to deliver a speech at the International Fisheries Exhibition in London in 1882, where he declared: "I believe that cod, herring, sardine, mackerel, and probably all fishery resources are inexhaustible; that is to say, nothing we do seriously affects the numbers of fish, and nothing we do can permanently change the state of these fisheries."Huxley's perspective represented the prevailing view of marine fishery resources for a considerable period, and some individuals continue to adhere to this belief even today. Guided by this mindset, the primary direction of marine fishery development focused on expanding fishing capacity—building more, larger, and more powerful fishing vessels—with fishery production directly proportional to fishing capacity. This period can be characterized as the "Marine Fishery 1.0" stage.

As fishing capacity increased rapidly, leading to overcapacity, fishery resources were severely depleted, resulting in declining catches and deteriorating fish quality. Inshore fishery resources dwindled, distant-water fisheries stagnated, and

international fishery disputes became frequent. The proportion of marine aquaculture in the marine economy decreased, constrained by marine environmental conditions, limited farming space, and ecosystem carrying capacity, causing uncertainty about the future development of mariculture. The relationship between fishing capacity and yield was no longer proportional, and correlations between farming area and production, as well as between aquaculture output and economic benefits, became imbalanced. The sustainable development of marine fisheries encountered a bottleneck. This period can be characterized as the "Marine Fishery 2.0" stage.

1.3 Marine Fishery 3.0

In modern times, relying solely on marine capture fisheries can no longer meet our demand for aquatic products. In the 1960s, the renowned Chinese marine scientist Zeng Chengkui proposed the slogan of "farming the sea" and pioneered its practice, leading the development of China' s algae aquaculture industry. In the 1970s, he introduced the concept of "marine agriculture and pastoralism," and in the 1980s, began practicing "farming and pastoralizing the sea." Aquaculture flourished, with marine capture fisheries and inshore aquaculture developing side by side, and eventually aquaculture output surpassed that of capture fisheries. Marine fisheries played a pivotal role in the marine economy, driving coastal economic development. However, as fishing capacity increased rapidly, leading to overcapacity, fishery resources were severely depleted. This resulted in declining catches and deteriorating fish quality, dwindling inshore fishery resources, stagnation of distant-water fisheries, and frequent international fishery disputes. The proportion of marine aquaculture in the marine economy decreased, constrained by marine environmental conditions, limited farming space, and ecosystem carrying capacity, causing uncertainty about the future development of mariculture. The relationship between fishing capacity and yield was no longer proportional, and correlations between farming area and production, as well as between aquaculture output and economic benefits, became imbalanced. The sustainable development of marine fisheries encountered a bottleneck. This period can be characterized as the "Marine Fishery 2.0" stage.

Where does the future of China' s marine fishery development lie? The most widely discussed solutions currently involve vigorously developing maritime grain warehouses, constructing marine ranches, and expanding distant-water fisheries. The maritime grain warehouse concept, based on the idea of comprehensive food security, primarily relies on abundant marine biological resources and utilizes modern technology and advanced production facilities to transform nearshore, shallow sea, deep sea, distant sea, and exploitable international waters into "granaries" that can continuously and efficiently provide marine food through artificial culture, stock enhancement, capture, and subsequent processing and trade. However, how should the maritime grain warehouse plan be implemented? Can distant-water fisheries fundamentally address

China' s growing demand for aquatic products? How should marine ranches be constructed? To break through the bottlenecks in marine fishery development, this paper analyzes the development history and future pathways of China' s marine fisheries from a global ocean perspective, treating the ocean as an integrated whole and examining it at the level of marine ecosystem structure and function, energy flow, and material flow. We propose the "Marine Fishery 3.0" development plan, aiming to explore and establish a systematic solution for the sustainable development of China' s marine fisheries.

Figure 1 [Figure 1: see original paper] The three developmental stages of marine fisheries

2.1 Distant-Water Fisheries

Although distant-water fisheries account for a relatively small proportion of China' s total fisheries and appear to have considerable room for growth, 85% of global fishery resources are currently in a state of "fully exploited or overexploited" according to FAO reports [2], and 90% of large fish in the global ocean have already disappeared [3]. Three-quarters of the world' s fishing grounds have been damaged and are in a state of decline or depletion, with most fishing areas worldwide under strict protection and management. International management of high seas fishery resources is becoming increasingly stringent, costs for distant-water fisheries continue to rise, overseas fishing bases are lacking, profitability is declining, and international disputes are frequent, exposing these operations to multiple risks from natural disasters and political factors. Consequently, distant-water fisheries cannot satisfy China' s growing demand for fishery resources.

2.2 Mariculture

China' s current mariculture is concentrated in narrow zones of bays and coastal areas, facing significant challenges from spatial competition. With the development of the blue economy, the status of mariculture within it has changed, as marine tourism, coastal industries, port construction, and urbanization all demand coastal space. From an economic value perspective, mariculture is gradually being displaced by other sectors. Driven by economic interests, inshore aquaculture is increasingly disadvantaged. Constrained by space and the blind pursuit of high yields, aquaculture density has become excessive, intensifying environmental stress. The most severely eutrophic and polluted areas in China' s coastal waters are concentrated in zones shallower than 15 meters, which coincidentally constitute the primary areas for current mariculture. Coastal water pollution leads to frequent disease outbreaks in cultured organisms, creating numerous problems for aquatic product yield, quality, and food safety, and posing significant challenges to sustainable development. Currently, approximately 70% of China' s mariculture output consists of shellfish, with other components including macroalgae, shrimp, sea cucumber, and jellyfish, while the quantity

of fish culture remains relatively small. In fish culture, industrial systems and large cages are the primary farming methods. Fish feed mainly consists of fishmeal derived from other marine fish, including juveniles of some important economic species, thereby significantly impacting ecosystems and natural fishery resources. Without resolving the protein source for fish feed, the development of fish culture will be severely limited.

2.3 Marine Ranching Construction

Marine ranching construction remains in its infancy. The current concept of marine ranching largely reflects "ecological aquaculture," with expanded farming areas and strengthened integrated management, but without substantive changes to the models and essence of mariculture. Geographically, it remains largely consistent with traditional mariculture, still confined to bays and coastal areas, while offshore aquaculture is only in the exploratory stage. A significant measure in current marine ranching construction is the deployment of artificial reefs. Large-scale deployment of artificial reefs in nearshore areas affects hydrodynamic conditions, sedimentary environments, biogeochemical cycles, and dissolved oxygen levels, necessitating comprehensive assessment of the resource and environmental effects of large-scale ranching construction. Furthermore, current marine ranches largely fail to embody the true meaning of "ranching," as fish constitute too small a proportion. As crucial components of marine ecosystems, the reduction in fish populations creates problems that extend beyond fishery resources to fundamentally alter ecosystem structure and function. Many marine ecological disasters are closely linked to declining fish numbers. In China, fish hold greater cultural significance than other marine organisms, with the long-standing tradition of "no fish, no feast" and the proverb "you cannot have both fish and bear' s paw" underscoring their value—a status other organisms cannot replace. Consequently, the current marine ranching model cannot fundamentally address China' s demand for fishery resources.

3 The Way Forward for China' s Marine Fishery Development

The future of China' s marine fishery development lies in its coastal waters. China possesses the world' s widest continental shelf, with highly productive nearshore waters and abundant biological resources. Against the backdrop of global fishery resource decline, the restoration of nearshore fishery resources represents the fundamental hope for achieving sustainable fishery development.

3.1 Scientific Management of Fishing Activities

The decline of fishery resources is largely attributable to overfishing. Therefore, the key to restoring nearshore fishery resources lies in controlling fishing activities, which also represents an important demonstration of China' s marine management capabilities. Despite numerous fishery management and protection

policies, fundamental resource protection remains elusive. Take the "summer fishing moratorium" (伏季休渔) as an example: since the 1990s, China has implemented a strict summer moratorium aimed at protecting spawning stocks, enhancing recruitment, and increasing fishery yields. However, from a recruitment perspective, the moratorium only protects fish during their growth from juveniles to adults, providing a summer respite for growth, but the fish ultimately disappear after the autumn fishing season opens, being caught within days. Thus, the moratorium policy cannot fundamentally ensure sustainable fishery resource protection. From a recruitment standpoint, implementing a "total catch control" policy is the core of healthy, sustainable fishery resource protection. Fisheries management authorities have proposed reducing fishing effort and protecting resources, establishing specific quotas. However, these quotas are currently determined based on experience or subjective judgment, whereas fishery resource species and abundance vary annually. Determination of allowable catch must be based on scientific assessment, which itself requires extensive systematic research in basic biology, ecosystem carrying capacity surveys, and environmental monitoring.

3.2 Protection and Restoration of Fish Spawning Grounds

Another critical factor affecting marine fishery resource dynamics is the disappearance of fish spawning grounds. Rapid coastal economic development has increased demand for coastal space, with land reclamation destroying coastal wetlands and eliminating spawning and nursery grounds for many important economic fish species. Additionally, land-based pollutant discharge and water quality degradation in nearshore and estuarine areas have had devastating impacts on fish recruitment. While fishery development may generate less economic value than land reclamation, industrial development, or urbanization, this mindset is extremely detrimental in the long term. First, as a populous nation, China cannot rely on fish imports to solve its aquatic product supply problem, as fishery resources worldwide are in decline. From the perspective of fishery resource restoration and sustainable development, we need to establish large-scale protected areas in critical estuarine and nearshore zones, prohibiting industrial and other economic activities to maintain healthy nearshore ecosystems and provide favorable environmental conditions for fish reproduction. Restoration of fish spawning grounds includes habitat rehabilitation and the reduction of intensive aquaculture activities. This effort yields another important benefit: improved nearshore environments and dual benefits from both ecosystem service and production functions.

3.3 Development of Offshore Aquaculture

Mariculture and marine ranching construction remain important pathways to address China' s fishery resource challenges. We must develop offshore aquaculture, utilizing the high productivity of traditional fishing grounds and establishing sea-based ranches on offshore islands, reefs, and artificial islands to

fully exploit natural feed for fish culture, thereby achieving true "farming and pastoralizing the sea." Integrating modern science and technology with traditional fisheries, we can employ wind, wave, and solar power generation to address electricity, freshwater, and energy needs for offshore marine ranch construction, simultaneously solving spatial and environmental constraints while ensuring product quality and green development.

4 Policy Recommendations and Feasibility Analysis for "Marine Fishery 3.0"

4.1 Policy Recommendations for "Marine Fishery 3.0"

(1) Implement a complete fishing ban in China's nearshore waters for 2–3 years to provide opportunities for fish to rest and reproduce, expanding spawning populations and laying a solid foundation for nearshore fishery resource recovery.

(2) In bays and coastal areas, prioritize the service functions of marine ecosystems by establishing marine protected areas to safeguard fish habitats, spawning grounds, nursery areas, and feeding grounds. These zones should shift from ecosystem production functions to service functions, reducing the scale and intensity of mariculture to provide favorable environments for natural fish population reproduction and growth.

(3) In traditional fishing grounds and high-productivity zones on China's nearshore continental shelf, establish modern marine ranches based on islands, artificial islands, and reefs. Leverage the production functions of marine ecosystems to fully utilize abundant natural feed, increase fish populations, and embody the true concept and essence of "marine ranching" and "farming and pastoralizing the sea."

(4) Strengthen comprehensive research targeting sustainable marine fishery resource development. From the perspective of ecosystem energy and material flows, effectively integrate marine observations, basic biology, basic ecology, and biological resource assessment to accurately evaluate annual fishery resource production and allowable catch, implement total catch control, and establish a new fishery rights allocation system.

(5) Shift from fishing abroad to farming abroad, leveraging the Belt and Road Initiative to establish overseas aquatic product bases. Utilize China's nearshore aquaculture technologies and the capital of fishing and farming enterprises to assist developing countries in developing mariculture and establishing ecological ranches, while helping them solve market access issues for their aquatic products, thereby increasing supply sources for China as well.

(6) Implement integrated management of marine fisheries and marine environments, with a single department designated by the state to exercise unified

management, eliminating inter-departmental discord and local fragmentation. The restoration and sustainable development of fishery resources require unified planning and management from a whole-ocean-system perspective, coordinating the development of ecosystem production and service functions, with nearshore fishery resource restoration as a central theme and the goal of establishing healthy nearshore ecosystems and achieving comprehensive marine management.

(7) Establish an energy-efficient, environmentally friendly, and efficient industrial mariculture system. As an important component of fishery resources, industrial aquaculture remains crucial for solving aquatic product supply issues. Continuous integration of new technologies, methods, materials, and processes gives industrial aquaculture significant development prospects.

(8) Maintain a high-quality distant-water fishing fleet to conduct fishing operations in international waters, effectively combining modern marine observation technologies with fishing techniques to rationally utilize and protect distant-water fishery resources.

4.2 Challenges Facing "Marine Fishery 3.0"

(1) Fishermen' s livelihood issues. Implementing a complete fishing ban and total catch control will raise critical concerns regarding fishermen' s livelihoods. China currently has two types of fishermen: "subsistence fishermen" and "commercial fishermen," who should be treated differently. Subsistence fishermen are traditionally dependent on fishing for their livelihood and should receive certain catch quotas that can be either transferred for compensation or subsidized by the state according to social security requirements. Commercial fishermen are those employed by fishing fleet enterprises or individuals, mostly temporary inland workers on fishing vessels. They should operate according to market principles within allocated or purchased fishing quotas.

(2) Determination of total catch quotas. Establishing and applying integrated marine observation systems, conducting marine fishery resource surveys, and developing fishery resource assessment models require the organic integration of modern marine observation technologies, marine information technologies, and ecosystem assessment techniques with fishery resource assessment models—posing a severe challenge to both marine science and management departments. With substantial annual fluctuations in fishery resources, accurate assessment demands extensive in-depth research and the establishment of a specialized, lean team dedicated to long-term marine fishery research and management.

(3) Establishment of nearshore protected areas. China has designated fishery protection zones in some important areas, but the key challenge lies in effective implementation and proper designation. Currently, systematic

research on the life histories of many economic fish species is lacking. The establishment of marine fishery protected areas should be based on fundamental research on economic fish species and studies of marine ecosystem structure and function, requiring substantial detailed work. The greatest challenge involves optimizing benefits: balancing the needs of coastal industrial and urban development with fishery resource development requirements; otherwise, the approach lacks feasibility.

(4) Construction of marine super ranches. Issues to address include site selection, alignment of investors and beneficiaries, technical systems for super ranch construction, ranch management, and resource allocation. From a macro perspective, we should divide the entire continental shelf area into different types of marine ranches, conducting integrated marine management from a ranch operation standpoint—from protecting nearshore spawning and nursery grounds to rational utilization and protection of fishery resources across the shelf area. This presents enormous challenges in ranch construction concepts, philosophies, key technologies, and systematic implementation plans.

(5) Marine integrated management. Marine ranch construction, integrated fishery resource management, and marine protected area establishment may appear to be fishery resource issues but are fundamentally matters of comprehensive marine management capacity. The state must formulate corresponding policies and laws for vertical management, with a single department exercising unified control over marine resources and the environment.

4.3 Feasibility and Benefit Analysis of "Marine Fishery 3.0"

In 2016, an article analyzing global fishery prospects was published in the *Proceedings of the National Academy of Sciences* (PNAS). Christopher Costello et al. [4], a team of 12 scientists from three research institutions, conducted the most detailed analysis to date of 4,713 fisheries representing 78% of global fishing grounds. The results indicated that under different policy scenarios, global fisheries would show distinctly different trends by 2050. Under the Rights-Based Fishery Management (RBFM) model, which pursues economic value optimization rather than maximum yield, many regional fisheries worldwide could recover, with 98% of fishing grounds able to recover within 10 years. This is highly encouraging, and many experts and fishermen believe that with strict catch controls, China' s nearshore fishery resources could recover within 3–5 years. A crucial measure involves integrated management of nearshore fishery resources through marine super ranch construction, applying the concept of "farming and pastoralizing the sea" to China' s nearshore continental shelf areas. By combining moderate mariculture with natural fishery resource recovery and treating fish and other economic organisms as integral ecosystem components, we can accurately assess fishery resources from the perspectives of ecosystem structure and function, energy and material flows, and carrying capacity. This

enables determination of catch limits that do not compromise fish recruitment or ecosystem health, thereby achieving sustainable fishery resource development.

The implementation of Marine Fishery 3.0 will drive the development of marine science and transform our understanding of marine ecosystem services and production functions, concepts of marine exploitation and protection, and the essence of marine ranching. While the starting point is sustainable fishery resource development, the actual outcome is the construction of a comprehensive marine management system (Figure 2 [Figure 2: see original paper]), aligning with China' s strategic objectives for sustainable marine resource utilization, marine ecological civilization construction, and comprehensive marine management.

Figure 2 [Figure 2: see original paper] Marine scientific research and fishery management working on the same platform

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