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Issues in the Development and Utilization of China' s Bays and Protection Strategies (Post-print)

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Abstract

Bays, by virtue of their unique natural conditions, possess numerous advantages in terms of location, environment, and resources, serving as sea-land transportation hubs, coastal industrial bases, important urban centers, and nurseries for marine life. They hold an extremely important strategic position in national economic construction and social development; therefore, maintaining the sustainable development of bays is of great significance. However, in recent decades, high-intensity human activities have resulted in reduced bay areas and natural coastlines, severe sediment accumulation, environmental degradation, and ecosystem imbalance, which have seriously threatened the sustainable economic and social development of China' s coastal regions. In response to the major problems emerging in the current development and utilization of bays, there is an urgent need to develop bay area and watershed development plans based on integrated land-sea coordination, implement comprehensive bay remediation and ecological environment restoration, control the input of watershed non-point source pollutants, and promote ecosystem-based bay management, so as to achieve orderly bay development and ensure ecosystem health and sustainable utilization.

Full Text

Preamble

Special Topic: Coastal Science and Sustainable Development

Problems in the Development and Utilization of Chinese Bays and Protection Strategies*

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Abstract

Bays possess inherent advantages in location, environment, and resources due to their unique natural conditions, serving as critical sea-land transportation hubs, coastal industrial bases, important urban centers, and nurseries for marine organisms. They hold a strategically vital position in national economic and social development, making the maintenance of sustainable bay development profoundly significant. However, over recent decades, intensive human activities have caused reductions in bay area and natural shoreline, severe sediment accumulation, environmental degradation, and ecosystem imbalance, seriously threatening the sustainable economic and social development of China's coastal regions. To address these primary issues in current bay development and utilization, there is an urgent need to implement integrated land-sea development planning for bay regions and their watersheds, carry out comprehensive environmental remediation and ecological restoration, control watershed non-point source pollutant inputs, and promote ecosystem-based bay management. These measures will enable orderly bay development and safeguard ecosystem health and sustainable utilization.

Keywords: bay health, relative enclosure, integrated land-sea planning, ecosystem-based management

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Bays are extremely valuable resources that hold a strategically important position in China's economic construction and social development. Due to their location at the sea-land interface, bays are highly vulnerable to human impacts, resulting in deteriorating ecological environments, reduced spatial area, and severe sediment accumulation, which pose grave challenges to sustainable coastal development. This paper analyzes the main problems emerging during bay development in China and proposes countermeasures and recommendations for sustainable bay utilization, providing a basis for improving bay ecological environments and achieving regional sustainable development.

1. Overview and Strategic Position of Bay Development in China

According to Article 10, Paragraph 2 of the United Nations Convention on the Law of the Sea, a bay is defined as a well-marked indentation of the coast whose area equals or exceeds that of a semicircle with a radius equal to the width of the bay's mouth. China's national definition similarly describes a bay as "a sea area surrounded by land with an area not less than that of a semicircle with the mouth width as its diameter" (GB/T8190-2000), essentially consistent with the UN definition. The most prominent natural characteristic of bays is

their relatively enclosed environmental conditions, featuring small waves and long water exchange cycles.

China's vast coastal territory contains numerous large, medium, and small bays. Preliminary statistics from *China Bay Records* indicate that China has over 50 bays larger than 100 km², more than 150 bays exceeding 10 km², and approximately 200 bays above 5 km². Major Chinese bays include Bohai Bay, Liaodong Bay, Laizhou Bay, Jiaozhou Bay, Xiangshan Bay, Xiamen Bay, Daya Bay, Zhanjiang Bay, and Haikou Bay. Since ancient times, Chinese people have utilized bays for fishing, salt production, and navigation, achieving remarkable success. Since the founding of the People's Republic, particularly after reform and opening-up, traditional development projects have expanded and numerous new initiatives have been added. China's bay development achievements primarily include: port resource development, aquatic resource utilization, land resource development, tourism resource exploitation, seawater chemical resource utilization, and mineral resource development [1].

China's bays enjoy superior natural conditions and hold crucial strategic positions in modern economic and social development. Their excellent berthing conditions make them sea-land transportation hubs, such as Qingdao Port in Jiaozhou Bay, Xiamen Port in Xiamen Bay, and Huizhou Port in Daya Bay. Their unique location and resource advantages have created coastal industrial bases, including shipbuilding facilities in Dalian Bay, the Nanhua petrochemical base and Daya Bay Nuclear Power Station in Daya Bay. Their favorable geographic position, abundant hinterland resources, and beautiful natural environments have fostered important cities like Shenzhen (relying on Shenzhen Bay, Dapeng Bay, and Daya Bay), Qingdao (relying on Jiaozhou Bay), and Xiamen (relying on Xiamen Bay). Meanwhile, abundant feed organisms and relatively enclosed conditions make bays critical spawning, nursery, and feeding grounds for marine organisms, serving as cradles for economically important species in Bohai Bay, Laizhou Bay, and Daya Bay. The calm waters also make bays important areas for mariculture, including offshore cage culture (in Daya Bay and Xiangshan Bay) and land-based (tidal flat) aquaculture (in Jiaozhou Bay and Daya Bay). Given their vital importance, maintaining sustainable bay development represents a major national strategy.

Internationally, many bays also play significant roles in modern economies and societies. For example, Japan's Tokyo Bay not only supports major cities like Tokyo and Yokohama but has also developed into a primary component of the Keihin industrial zone. The Chesapeake Bay in the United States hosts major ports like Baltimore and Norfolk and contains the Norfolk-Newport News port city cluster, serving as an important industrial and commercial center.

2. Main Problems in Bay Development and Utilization

China's rich bay resources have a long development history. Over recent decades, bay development has generated enormous economic benefits while creating seri-

ous problems. During resource exploitation, insufficient understanding of how natural, social, and economic pressures drive bay environmental changes has led to overdevelopment, damaging bay ecosystems and reducing their self-regulation capacity and ecological service functions. Furthermore, the lack of integrated resource development planning and rational protection that combines bay waters with their watersheds has meant that rapid development of marine transportation, land reclamation, coastal industries, and watershed exploitation has increasingly impacted traditional bay uses and ecological environments.

2.1 Deterioration of Bay Ecological Environment

Over recent decades, rapid economic development in China's coastal regions and intensive human activities have significantly impacted bay ecological environments, posing serious threats to bay ecological security.

2.1.1 Serious Environmental Pollution and Eutrophication Intensification Intensive human development activities in bays and their watersheds have introduced large quantities of nitrogen, phosphorus, and toxic pollutants, significantly affecting water and sediment quality in Chinese bays. Most semi-enclosed bays suffer from serious water pollution and excessive trace metals in sediments. For example, inorganic nitrogen in Jiaozhou Bay increased from 0.03 mg/L in the 1960s to 0.29 mg/L in the early 21st century, while the nitrogen-to-phosphorus ratio rose from 18 to 57 between 1981 and 2001 [2]. Guangdong's Daya Bay, a semi-enclosed subtropical bay, has shifted from oligotrophic to mesotrophic status, with some areas showing eutrophication, as industrial wastewater, mariculture pollutants, watershed non-point source sewage, and municipal sewage discharge have increased rapidly. Inorganic nitrogen concentrations have risen progressively, with the nitrogen-phosphorus ratio increasing from 1.3 in 1985 to 61.9 in 2003 [3,4]. Chromium, lead, and zinc concentrations in some Daya Bay sediments have approached twice their natural background values [5].

Many bays worldwide face similar environmental problems due to rapid economic development and weak water exchange capacity. For instance, Japan's Seto Inland Sea suffered from severe mercury pollution that caused the world-renowned Minamata disease incident. Tokyo Bay's economy accounts for one-third of Japan's national total, but at a heavy environmental cost, with total nitrogen and phosphorus inputs reaching 208 t/d and 15.3 t/d respectively in 2004 [6]. In the northern Gulf of Mexico's Grand Bay National Estuarine Reserve, arsenic and lead have accumulated severely in sediments [7].

2.1.2 Simplification of Biological Composition and Alteration of Community Structure Eutrophication and changes in nutrient composition have significantly altered bay biological community structures in China. From the 1960s to early 2000s, dominant phytoplankton species in Jiaozhou Bay shifted markedly, with eutrophication-preferring species like *Skeletonema costatum* be-

coming dominant and phytoplankton diversity indices declining [8]. Zooplankton community structure has also changed substantially, with average gelatinous zooplankton (such as tunicates) abundance in 2008 exceeding five times that of the 1990s [9]. In Daya Bay, phytoplankton species decreased from 159 in 1982 to 126 in 2004 [3], while zooplankton species and dominant species replacement frequency increased gradually, with dominant species composition becoming simplified [10].

2.1.3 Degradation of Ecological Functions and Ecosystem Imbalance Human-induced nutrient inputs may affect food web structure and energy transfer efficiency by altering biological community structure, attracting widespread attention both domestically and internationally. Increased nitrogen-silicon ratios can weaken diatom-supported food chains while strengthening dinoflagellate-supported ones, altering trophic structure and potentially causing food chain disruption and ecosystem imbalance. In Jiaozhou Bay, human activities have caused obvious ecological function degradation and significant biological resource decline [11], with nekton becoming smaller-sized [12], possibly related to food chain disruption caused by increased gelatinous zooplankton.

2.2 Bay Area Reduction and Sediment Accumulation

Bay spatial reduction manifests as decreased natural shoreline, tidal flats, wetlands, and usable sea area, even leading to bay disappearance. Over recent decades, accelerated bay reclamation and aquaculture projects have altered natural shoreline characteristics, reduced bay area and tidal prism, and caused environmental deterioration and functional degradation. For example, Jiaozhou Bay's water area decreased from 560 km² in 1928 to 367 km² in 2004—a reduction of nearly one-third [13]—while its tidal prism dropped from 1.36 billion m³ in 1935 to 1.11 billion m³ in 2005 [14], severely reducing water exchange capacity and causing serious sediment accumulation. Jiaozhou Bay's original natural coastline has gradually become artificial, with the shoreline advancing substantially landward. Between 1863 and 2008, natural shoreline shrank from 203.8 km to 19.3 km, while artificial shoreline increased from 0 to 158.8 km [14]. Due to intensive reclamation, Quanzhou Bay's area decreased from 163.3 km² in 1955 to 132.6 km² in 1990, while waters shallower than the 0 m isobath decreased from 19.8 km² to 10.4 km², nearly halving the water area and markedly reducing tidal prism, weakening hydrodynamics, and intensifying sedimentation [15]. Between 1973 and 2013, Zhejiang's Sanmen Bay mainland shoreline advanced seaward due to reclamation and coastal development, with total shoreline length decreasing by 40.18 km and coastal land area increasing by 155.89 km², causing bay sedimentation due to reduced tidal currents [16].

Similar phenomena exist in bays worldwide. For example, due to large-scale reclamation of intertidal zones and shallow waters, Tokyo Bay's water area in 2000 was only 92.6% of its original size, with substantial losses of coastal

wetlands [17].

3. Countermeasures and Recommendations for Sustainable Bay Development

As problems from China's bay development become increasingly severe, improving bay ecological environments and restoring normal utilization functions has become a major strategic task for sustainable coastal economic and social development. The following countermeasures and recommendations are proposed.

3.1 Control of Watershed Non-Point Source Pollution in Bays

Since the 1970s, environmental pollution control experience in developed countries has shown that with effective control of point source pollution from industrial wastewater and municipal sewage, non-point source pollution has replaced point sources as the most important pollution source. Organic matter and nutrients from land entering the sea through surface runoff constitute the primary cause of coastal eutrophication. The proportion of non-point source pollution loads in China is gradually increasing, making it undoubtedly the key and most challenging aspect of future bay water pollution control. For example, Jiaozhou Bay's watershed covers nearly 8,000 km², with more than 10 rivers flowing into the bay, making riverine input the main pollution source. Therefore, strengthening pollution control of rivers and other land-based sources entering the bay and reducing total pollutant discharge is a crucial foundation for protecting and improving Jiaozhou Bay's environment.

Non-point sources are mainly divided into agricultural and urban runoff non-point sources, including pollutants from agricultural land runoff, livestock and poultry farming, and urban/rural life that enter rivers and the sea through rainwater scouring or runoff. These sources feature strong emission randomness and management difficulty. We must strengthen comprehensive rural environmental improvement, accelerate township environmental infrastructure construction, improve sewage pipe networks, achieve centralized sewage treatment, and develop common technologies for rural sewage treatment. We should vigorously develop ecological agriculture, strictly control pesticide and plastic film pollution, prohibit highly toxic and persistent pesticide use, promote rational fertilizer application, and establish reasonable new agricultural production systems with corresponding technical systems. We must strengthen pollution control from livestock and poultry farming, actively develop large-scale breeding, control pollution discharge, and efficiently utilize organic fertilizers.

3.2 Integrated Planning Based on Land-Sea Coordination

For bays, geographic space management extends beyond the bay itself to include its watershed. Watershed development profoundly impacts bay ecological environments, so bay environmental protection must begin on land, treating land and bay as an integrated whole for planning. Planning should focus on land use

and industrial layout in bays and their watersheds, examining watershed urban construction, industrial distribution, and coastal development activities. From a sustainable development perspective, we must study how bay water environments support and constrain regional productivity and analyze major issues in bay socio-economic development planning. By coordinating development activity types and intensities and comprehensively regulating nutrient types, fluxes, and forms entering from watersheds and sea areas, we can propose bay environmental capacity planning.

Bays are unique water bodies whose relative enclosure creates obvious differences in development intensity, depth, and breadth compared with open sea areas. Therefore, rational bay resource development is crucial, and planning suited to natural bay conditions is particularly important. We must prohibit blind occupation of coastal wetlands and shoreline resources, establish strict control targets for important ecologically sensitive areas, natural shoreline ratios, natural wetland protection rates, and important habitat protection rates, and maintain stable and healthy bay ecological environments. Special attention must be paid to optimizing bay reclamation scale and spatial layout, strictly limiting reclamation activities to maintain bay ecological balance.

3.3 Comprehensive Remediation and Restoration of Bays

Comprehensive remediation and restoration are important means to improve bay ecological environments. Developing remediation and restoration plans suited to each bay's unique characteristics is the prerequisite. Based on careful study of bay hydrology, hydrodynamics, environmental capacity, and carrying capacity, and according to each bay's specific features combined with local development needs and regional planning, we should conduct functional positioning studies and special remediation research to compile bay remediation and restoration plans. Following the principle of "protection during development and development during protection," we should gradually remove obstacles such as aquaculture ponds and embankments occupying sea areas, restore and protect natural shorelines, recover bay tidal prism, and enhance water exchange rates. We must strengthen protection of natural coastal zones, tidal flat wetlands, and shallow seas to maintain the ecological health of coastal wetlands, nature reserves at all levels, and important tidal flat and shallow-water aquaculture areas. Sea area ecological restoration should focus on improving individual habitats and ecosystems, scientifically identifying vulnerable zones for ecological recovery and reconstruction. We should restore damaged bay wetlands, shorelines, beaches, and surrounding sea areas, conduct ecological conservation for rare and endangered species habitats, and restore bay ecosystem service functions.

We must strengthen bay water quality pollution management, accelerate construction of sewage treatment facilities in surrounding port industrial zones according to bay environmental capacity, and strictly control total pollutant discharge into the sea. Dynamic monitoring should be implemented at key areas such as river mouths and discharge outfalls. We should strengthen bay envi-

ronmental monitoring infrastructure and establish integrated three-dimensional monitoring systems using multiple technologies to monitor bay resource development and environmental changes.

3.4 Ecosystem-Based Bay Management

To put China's bay development on a virtuous cycle track, we must strengthen bay management and achieve orderly development. Ecosystem-based marine integrated management theory has gained increasing international attention [18]. This theory emphasizes protecting marine ecosystem structural integrity and functional stability to achieve balanced, healthy, and safe ecosystems. Marine ecosystem integrated management generally targets specific topographic regional ecosystem units, with ecosystem unit division adapting to management spatial scales. Bays are often relatively independent and complete ecosystem units and have become among the most vulnerable areas to human activities, with increasingly prominent problems including environmental pollution, sediment accumulation, eutrophication, and resource depletion. Therefore, implementing ecosystem-based bay integrated management is realistically necessary.

Ecosystem-based management concepts have been preliminarily practiced in some bays and coastal zones. For example, Xiamen and other coastal bays have attempted to transition from environmental quality management focused on pollution control to ecological function assurance management based on ecosystem concepts [19]. The theoretical and methodological system of ecosystem-based bay integrated management remains in the exploratory stage and requires in-depth research to form a more systematic theoretical framework to better guide bay management practice. Particularly, strategies for pollutant total amount and form control based on ecological capacity, and theories and methods for bay ecosystem health assessment systems based on ecosystem structural integrity and functional stability, require further research to improve ecosystem-based bay integrated management theory and provide scientific support for sustainable bay development.

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Problems in Development of Chinese Bays and the Protection Strategy

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Abstract: Bays have the inherent advantages in location, environment, and resources because of the unique natural conditions. Bays have been the hub of sea and land transport, industrial base, important city center, and the cradle of marine organism. They have a strategic position in the national economic and social development, thus it is of great significance to keep sustainable development in bays. In last several decades, intense human activities have resulted in the decrease of area and natural shoreline, sediment accumulation, ecological environment deterioration, and ecosystem imbalance in bays, which have seriously threatened the sustainable development of economy and society in coastal areas. Therefore, it is urgent to carry out the integrated marine and land development planning, and the comprehensive ecological environment management and renovation planning in Chinese bays. The input of non-point pollution from watershed should be controlled, and the ecosystem-based management should be promoted in order to maintain ecosystem health and sustainable development in bays.

Keywords: bay health, semi-closure, integrated marine and land planning, ecosystem-based management

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