Ecological and Environmental Impacts of Coastline Development and Utilization in Mainland China and Policy Recommendations: Postprint

Authors: Hou Xiyong, Liu Jing, Song Yang, Li Xiaowei

Date: 2016-11-04T00:00:00+00:00

Abstract

Over the long term, eastern coastal regions have served as the "power engine" in China' s rapid economic and social development. Accordingly, the development and utilization of China' s mainland coastline has been extensive and profound, particularly over recent decades, with the rate and extent of natural coastline loss and destruction being alarming and severe. Intensifying reclamation activities and rapid coastline development and disturbance processes have triggered a series of resource, environmental, ecological, and disaster-related issues, posing extremely severe challenges to China' s current and future integrated coastal zone management and the sustainable development of coastal economies and societies. This article outlines the process characteristics of mainland coastline development and utilization in China over the past nearly 70 years, summarizes existing problems and their impacts on the coastal zone, and on this basis, identifies priorities and strategies for integrated coastal zone management in China for the current and future periods. These include: strengthening coastal zone monitoring, observation, and scientific research with a focus on coastlines; enhancing protection of natural coastlines while optimizing development and utilization of artificial coastlines; launching a "Restore China' s Estuaries" initiative to maintain and enhance hydrological and ecological connectivity of estuaries; using bays as a key lever to promote mainland coastline protection through implementation of classified bay management; establishing and improving laws and regulations; and promoting multi-departmental and regional coordination in integrated coastal zone management.

Full Text

Special Topic: Coastal Science and Sustainable Development

Environmental-ecological Effects of Development and Utilization of China' s Coastline and Policy Recommendations

Hou Xiyong[1], Liu Jing[1,2], Song Yang[1,2], Li Xiaowei[1]

[1]Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai 264003, China
[2]University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

For a long time, eastern coastal regions have served as the "power engine" of China' s rapid socioeconomic development. Correspondingly, the development and utilization of China' s mainland coastline have been extensive and profound. Especially in recent decades, natural shorelines have disappeared and been destroyed at an alarming rate and with severe intensity, while sea reclamation has become increasingly rampant. This rapid shoreline development and disturbance has triggered a series of resource, environmental, ecological, and disaster-related problems, posing extremely severe challenges to current and future integrated coastal zone management and sustainable socioeconomic development in coastal China. This paper outlines the process characteristics of mainland coastline development and utilization over the past 70 years, summarizes existing problems and their impacts on the coastal zone, and identifies key priorities and strategies for integrated coastal zone management in China. These include: strengthening coastal zone monitoring, observation, and scientific research with a focus on shorelines; enhancing natural shoreline protection while optimizing artificial shoreline development; launching a "Restore China' s Estuaries" initiative to maintain and strengthen hydrological and ecological connectivity; promoting mainland coastline protection through classified management of bays; and establishing and improving laws and regulations to advance multi-departmental and regional coordination in integrated coastal zone management.

Keywords: China, mainland coastline, natural shoreline, artificial shoreline, reclamation, integrated coastal zone management

DOI: 10.16418/j.issn.1000-3045.2016.10.002

Coastal zones are simultaneously influenced by land, ocean, and atmosphere, with complex dynamic mechanisms. They represent the most sensitive areas to climate change and human activities, as well as the most frequently fluctuating regions of the Earth' s surface, where ecosystem vulnerability is particularly pronounced. Coastal zones are economically and socially developed, with 60% of the global population concentrated in these areas, and two-thirds of cities

with populations exceeding 1.6 million located in coastal zones, making human impacts on coastal environments and ecology extremely profound [1]. China has an extensive coastline with prominent characteristics of diversity, complexity, heterogeneity, and dynamism in its coastal zone natural environment. These areas are rich in resources, strategically located, densely populated, and economically developed, yet they face extremely diverse and severe problems, such as: relative sea-level rise exacerbating environmental disasters and flood risks; sharp declines in riverine material flux into the sea, significantly altering land-sea interaction processes and mechanisms; intensified land-based pollution causing environmental degradation and ecological deterioration, with ecological disasters becoming more frequent; and astonishing scale and speed of reclamation causing severe destruction of natural habitats in coastal zones [2].

The coastline is the boundary line between land and sea contact. Its spatial oscillation and attribute changes reflect the transformation of coastal erosion-accretion processes and the patterns and dynamics of human shoreline development, utilization, and protection. Monitoring coastline changes is an effective approach to studying coastal environmental and ecological changes, making coastline change characteristics a hot research topic in recent years [3]. Research on coastline changes primarily focuses on two aspects: characterizing shoreline spatiotemporal changes through shoreline change rates and resulting land-sea area changes [4,5]; and analyzing spatiotemporal change characteristics and trends while exploring the influence of climate, geology, human activities, and other factors on shoreline changes [6-9]. Representative national-scale research includes the U.S. Geological Survey' s "Shoreline Change Project" conducted in the late 20th century, which evaluated and summarized the advantages and disadvantages of various linear rates for analyzing shoreline changes. In recent years, the USGS further launched the "National Shoreline Assessment Project," proposing the concept of shoreline position spatial correlation and studying polynomial fitting models that consider correlations between adjacent shoreline positions to improve representation of non-linear shoreline changes. In China, numerous studies have focused on regional scales, while national-scale research has primarily examined shoreline fractal dimensions and their changes, as well as spatiotemporal dynamic characteristics of shoreline position and development intensity [10-13]. However, these studies generally cover no more than the past 30 years, with few results on longer timescales. Additionally, research on the impacts of shoreline development and utilization on coastal resources, environment, and ecology, as well as shoreline resource management strategies, remains relatively scarce. Therefore, the Chinese Academy of Sciences specifically included research on human adaptation and response under centennial-scale warming as a key focus in its "Strategic Priority Research Program," with long-term changes in mainland coastline being one of the priority issues. Through this research, we have established classified information on mainland coastline distribution from the early 1940s to 2014 across six time phases spanning approximately 70 years, completed field investigations covering the entire mainland coastal zone, and analyzed and revealed the basic characteristics and main impacts of mainland

coastline development and utilization over the past 70 years. This paper summarizes these research advances, focuses on the resource, environmental, and ecological problems caused by mainland coastline development and utilization, and identifies key priorities and strategies for integrated coastal zone management in current and future periods.

1. Process Characteristics of Mainland Coastline Development and Utilization in China

1.1 Multi-temporal Mainland Coastline Classification Results

Based on comprehensive research findings [12,14,15], mainland coastlines are classified into two primary categories: natural shoreline and artificial shoreline. Artificial shoreline is further divided into seven types: groins and jetties, port terminals, shoreline under reclamation, aquaculture embankments, salt field embankments, transportation embankments, and seawalls [16]. Using multi-temporal map data and remote sensing imagery since the 1940s, we established classified data for China' s mainland coastline across six time phases spanning nearly 70 years (Figure 1 [Figure 1: see original paper]).

1.2 Characteristics of Mainland Coastline Length Changes

Causes of coastline length changes include both natural and anthropogenic factors [11]. However, on timescales of less than a century, natural factors mainly manifest as local estuarine delta development and sandy shoreline erosion, while anthropogenic factors represent the primary influence, particularly various types of reclamation activities. From the 1950s to the end of the 20th century, national reclamation experienced three major 高潮 (high tides): the first was sea enclosure for salt production in the early years of the People' s Republic, forming four major coastal salt fields; the second was sea enclosure for farmland from the mid-1960s to the 1970s, creating large areas of agricultural land that made important contributions to grain production and economic construction; the third was the sea enclosure for aquaculture that began in the 1980s-1990s, making China the world' s largest aquaculture nation.

Over the past 70 years, mainland coastline length changes have been significant [18]. As shown in Figure 1, coastline lengths were 1.81×10 km, 1.92×10 km, 1.65×10 km, 1.72×10 km, 1.88×10 km, and 1.97×10 km for 1940, 1960, 1990, 2000, 2010, and 2014, respectively. Since 1990, shoreline data interpretation has been based on 30 m resolution Landsat imagery, making the data comparable. Coastline length has shown a rapid growth trend, increasing by 3,200 km over 20 years, representing a growth rate exceeding 19%. Since 2000, coastal provinces and municipalities have experienced explosive growth in reclamation scale, entering a fourth 高潮 (high tide) characterized by port construction, port-adjacent industrial park development, and coastal economic zone expansion.

1.3 Characteristics of Mainland Coastline Structure Changes

Corresponding to the four development stages of national reclamation, mainland coastline structure changes have been significant and stage-specific [18,19]: the scale and speed of coastline development and artificialization have been astonishing, with artificial shoreline length increasing from 0.33×10 km in the early 1940s to 1.32×10 km in 2014, and its proportion rising from 18.30% to 67.08%. Natural shoreline length decreased from 1.48×10 km in the early 1940s to 0.65×10 km in 2014, with its proportion dropping from 81.70% to 32.92%. Since the 1990s has been a period of accelerated development in mainland coastline utilization intensity (Figure 2 [Figure 2: see original paper]), with major changes also occurring in the purposes, uses, and macro patterns of shoreline development. After 1990, the length proportions of aquaculture embankments and transportation embankments in artificial shoreline exceeded those of seawalls and salt field embankments, reflecting socioeconomic development needs and impacts. With increasingly intensive reclamation in the Bohai Sea and Yellow Sea coastal zones, the development intensity in northern regions has clearly surpassed that in southern regions.

1.4 Characteristics of Mainland Coastline Spatial Position Changes

Estuarine delta development and various reclamation activities cause shoreline seaward movement, while coastal erosion and artificial excavation cause shoreline landward retreat. Calculating shoreline change rates for different periods reflects the intensity and speed of coastline position changes. Results show [18]: the endpoint rates for mainland coastline were 5.28 m a ^{1}, 19.65 m a ^{1}, 14.13 m a ^{1}, 16.46 m a ^{1}, and 34.62 m a ^{1} for the periods 1940-1960, 1960-1990, 1990-2000, 2000-2010, and 2010-2014, respectively. All time periods were dominated by seaward expansion trends, while landward retreat was still common before 1960 but thereafter only occurred in parts of northern Jiangsu and the Bohai Sea rim. Over the past 70 years, the weighted linear regression rate of mainland coastline change was 15.81 m a ^{1}, with over 68% of coasts showing seaward expansion trends at an average rate of 24.30 m a ^{1}, distributed across both northern and southern coastal zones. Over 22% of coasts showed landward retreat trends at an average rate of -3.27 m a ^{1}, mainly distributed along the Jiangsu coast, Laizhou Bay coast, and the old Yellow River estuary area. The remaining approximately 10% of coasts were stable sections, primarily rocky coasts.

2. Problems and Impacts of Mainland Coastline Development and Utilization

2.1 Problems in Coastline Development and Utilization

Processes such as sharp natural shoreline reduction, dramatic artificial shoreline increase, intensified reclamation, and shoreline seaward advancement reflect long-standing deficiencies and problems in China' s shoreline development

planning and management, concentrated in two aspects [20-22].

2.1.1 Extensive Utilization with Low Efficiency and Insufficient Reserve Resources Natural shoreline is a precious and scarce resource with comprehensive and diverse ecological functions and extremely high ecological service value, making its economic development multi-purpose. China' s shoreline resource development and utilization methods mainly include salt fields, aquaculture, fishing, ports, oil fields, petrochemicals, power generation, industrial parks, tourism, and protected areas. For a long time, China' s coastal regions have generally followed a resource-dominated development model characterized by single industrial types, small scale, exclusivity rather than comprehensiveness in shoreline utilization, lack of optimization and combination among different utilization methods, low economic benefits, resource waste, and failure to fully realize the comprehensive benefits of shoreline resources.

2.1.2 Fragmented Management Across Departments and Regions, Lacking Unified Scientific Planning and Management Located in the transitional zone between land and sea, coastline resources have long been in an unreasonable state where multiple departments—including oceanic, land, port, maritime, fisheries, environmental protection, urban construction, tourism, and energy authorities—have overlapping yet separate jurisdictions. Shoreline development has emphasized utilization over protection, with inadequate follow-up management. Each department formulates relevant plans or management systems only from its own business or industry development perspective, resulting in inconsistent goals and standards, lack of coordination, comprehensiveness, and inter-departmental connectivity, with overlapping jurisdictions as well as gaps and vacuums.

Moreover, regional and administrative fragmentation in shoreline resource development, utilization, and management is extremely severe, lacking macro-level principles and objectives. Ports and estuaries are the most typical cases: redundant port construction and disorderly competition lead to waste of deep-water shoreline resources, overcapacity, and transboundary pollution issues. China has numerous rivers entering the sea, especially small and medium-sized rivers that serve as administrative boundaries. These generally feature unregulated water resource development in upstream areas and complete degradation into sewage channels in middle and downstream reaches, with severe problems of black and odorous rivers and estuaries. Additionally, numerous sluice dams built at estuaries have completely altered estuarine hydrological processes and characteristics. Large and medium-sized estuaries often develop deltas that are typically areas of urbanization and economic development, facing serious problems of estuarine pollution, ecological degradation, estuarine sedimentation, coastal erosion, land subsidence, saltwater intrusion, and seawater intrusion.

2.2 Impacts on Coastal Landscape Patterns

From three perspectives—coastline fractal dimension, land-sea patterns, and bay morphology—we can reflect the impacts of mainland coastline development and utilization on coastal landscapes at the macro level [18,23].

2.2.1 Impact on Coastline Fractal Dimension The fractal dimension of China' s mainland coastline generally shows a macro pattern of "Northern < Overall < Southern." Since 1990, reclamation and shoreline artificialization have caused significant increases in fractal dimensions nationwide and in most provinces and municipalities. In particular, the dramatic reclamation and shoreline artificialization in northern coastal areas in recent years have caused continuous increases in fractal dimensions in northern coastal zones, gradually narrowing the gap between northern and southern coastline fractal dimensions.

2.2.2 Impact on Land-Sea Distribution Patterns Influenced by shoreline development, utilization, and estuarine delta development, changes in China' s coastal land-sea distribution patterns are relatively complex. At the provincial/municipal and overall coastal levels, both significant landward-seaward movement areas and identifiable seaward-landward movement areas exist, but net changes all show substantial increases in land area. The entire mainland coastal zone has experienced a net land area increase of nearly 1.42×10 km^2, with an average annual growth rate of 202.82 km^2 a^{-1}, equivalent to the entire 1.8×10 km mainland coastline advancing seaward by 788.65 m overall, at a rate greater than 11 m a^{-1}.

2.2.3 Impact on Bay Morphology Bays are the most vulnerable parts of the ocean to various human activities. Over the past 70 years, the rapid disappearance of natural shorelines and dramatic growth of artificial shorelines, along with continuously intensifying shoreline development, have been particularly prominent in major coastal bays. Most bays are primarily affected by reclamation, with bay shorelines generally moving landward to seaward, bay areas generally shrinking substantially, and some bays even disappearing completely. Bay shapes have generally become more complex, but differences among individual bays are narrowing, and the distribution positions of bay centroids have also generally migrated landward to seaward.

2.3 Impacts on Coastal Resources and Environment

Coastline development and utilization, reclamation, and shoreline artificialization have brought a series of coastal resource and environmental problems that affect and constrain sustainable socioeconomic development in coastal zones.

2.3.1 Wastage and Degradation of Shoreline Resources Natural shoreline is one of the most basic and precious resource elements in coastal zones. Over the past 70 years, mainland natural shoreline length and proportion have

sharply decreased, with increasingly fragmented spatial distribution. Particularly severe losses have occurred in biogenic shorelines (mangroves, coral reefs, seagrass beds) and intertidal mudflats that have outstanding ecosystem service functions and values, making protection work extremely urgent. Unordered port shoreline development and resource waste, lack of unified national-level planning for port construction and layout, and administrative fragmentation have led to unreasonable port spatial distribution, regional competition, redundant construction, homogeneous functional positioning, low efficiency, and malicious competition. Sandy coasts are natural shorelines with prominent ecological and sociocultural functions, but their stability is relatively poor. Unordered sand mining, unreasonable shore-based engineering, and storm surge impacts have caused serious coastal erosion problems, with approximately 70% of China' s sandy coasts experiencing erosion. Low-efficiency development, unreasonable development, overdevelopment, resource waste and destruction, and the enclosure and privatization of shoreline resources coexist in tourism shorelines such as natural and historical cultural sites, sandy sections, and rocky sections. Large-scale reclamation has caused some islands to become land-connected, with some islands even being completely "swallowed" by land.

2.3.2 Exacerbation of Coastal Environmental and Ecological Problems
Nutrients and pollutants from land areas continuously accumulate in coastal zones through rivers and stormwater processes, making coastal zones one of the Earth's regions with prominent environmental problems. In China, influenced by shoreline resource development and artificialization, reclamation development, and other factors, problems of industrial discharge, aquaculture discharge, urban sewage, and non-point source pollution are exceptionally prominent. However, basic, continuous, and long-term monitoring and observation are lacking, with extremely inadequate supervision and management. Pollution in some shoreline sections is exceptionally severe, with coastal litter quantities (by weight and count) far exceeding global averages. Reclamation development has caused prominent problems of coastal wetland destruction, degradation, disappearance, and fragmentation, seriously degrading and eliminating coastal zone functions in pollutant absorption and degradation, climate regulation, global carbon cycle maintenance, and biodiversity conservation. Problems in estuarine areas are becoming increasingly diverse, complex, and severe: large increases in estuarine sluice dams, sharp reductions in estuarine shoreline length, decreases in terrestrial freshwater runoff and sediment flux, estuarine degradation into sewage outlets, severe damage to land-sea interaction processes in watershed-estuary-offshore systems, significant declines in large estuarine delta development and growth rates, and destruction of critical land-sea ecological connectivity that depends on estuaries and river channels in coastal zones. Shoreline development and utilization significantly affect and alter material transport and interactions between land and sea, influencing hydrodynamic, water environmental, and biological processes in nearshore waters and exacerbating environmental and ecological problems, including the occurrence of ecological disaster events.

2.3.3 Weakening of Coastal Disaster Prevention and Mitigation Capacity and Increased Coastal Vulnerability Coastal zones are hotspots for socioeconomic development, ecologically vulnerable areas, and sensitive zones for climate change and sea-level rise. Coastal wetlands can protect coastal cities and communities from sea-level rise and extreme weather events such as storm surges, serving as extremely important and irreplaceable natural disaster buffer zones. Mainland coastline changes over the past 70 years reflect the overall characteristic of "human advance and sea retreat" in coastal zones, a process that massively squeezes and occupies natural disaster buffer zones, directly or indirectly exacerbating the risk characteristics of various natural disasters in coastal zones (especially low-lying coastal areas). These include significantly increased distribution density, exposure levels, and vulnerability grades of disaster-bearing bodies, significantly elevated risk levels of disaster-causing factors, increasingly prominent interconnections and superposition characteristics among primary, secondary, and derivative disasters, and significantly intensified both sudden and gradual-onset disasters, greatly increasing disaster prevention and mitigation costs. Major disaster threats include: meteorological disasters such as terrestrial rainstorm floods, typhoons and storm surges, sea fog, sea ice, and tsunamis; environmental and geological disasters such as saltwater intrusion and seawater intrusion, coastal erosion, salinization and land degradation, harbor sediment deposition, and port channel siltation; and nearshore environmental and ecological disasters such as oil spill pollution, harmful algal blooms, and jellyfish blooms.

3. Recommendations for Strengthening Shoreline Protection and Integrated Coastal Zone Management

Based on the above analysis and summary of coastline development and utilization process characteristics, existing problems, and impact features, we propose policy recommendations for integrated coastal zone management with a focus on shorelines.

3.1 Strengthen Monitoring, Observation, and Scientific Research in Coastal Zones with a Focus on Shorelines

Focusing on the spatial areas of shoreline reciprocating oscillation over long periods, with appropriate radiation toward both land and sea directions, we should develop a three-dimensional, long-term, dynamic, and continuous monitoring and observation technology system combining space-air, ground-based, and underwater approaches. Monitoring content should include: position changes of natural shorelines, development of artificial shorelines, reclamation dynamics, estuarine morphological changes, estuarine delta development, sea-level changes, elevation changes of different coastline types, underwater topographic changes, hydrodynamic characteristics, seawater and groundwater environmental quality, soil or sediment environments, atmospheric environments, biological composition and ecological processes, and multi-interface material-energy-ecological pro-

cesses. For shoreline-focused monitoring, the emphasis should be on dynamic monitoring and information extraction based on medium- to high-resolution satellite imagery, aerial imagery, and unmanned aerial vehicles over long time series, supplemented by field surveys to obtain real-time information on shoreline changes and reclamation dynamics. By developing multi-disciplinary, multi-element, multi-process, and multi-scale monitoring and observation focused on shoreline reciprocating oscillation areas, we can accumulate long-term, standardized monitoring data, build big data platforms and information systems, promote the development of basic scientific research in coastal zones, rapidly advance scientific understanding of coastal zones, and provide strong scientific and technological support for shoreline protection, sustainable development and utilization, and scientific and effective integrated coastal zone management decision-making.

3.2 Optimize Development, Utilization, and Management of Artificial Shorelines

Coordinate the contradictions between protection and development, rescue the rapidly decreasing and fragmented natural shorelines, especially intertidal wetland sections, biogenic shorelines, sandy shorelines, and rocky shorelines that have outstanding environmental and ecological significance and are irreplaceable, and elevate natural shoreline protection to national-level goals, tasks, and strategies as soon as possible. At the regional level, promptly advance shoreline protection "red line" policies, demarcate "red line zones" for shoreline protection, and implement classification and graded management of shorelines. For example, shorelines could be categorized as strictly protected, development-restricted, or moderately developed sections, with effective, implementable shoreline "red line zone" protection policies, measures, and supervision and management systems tailored to local conditions. For the few remaining natural shorelines, "strict protection" should be implemented as a rescue measure. Meanwhile, coastal provinces and municipalities should compile shoreline utilization plans, implement key shoreline section protection and restoration projects, rectify coastal sea space, enhance coastal spatial resource value and shoreline utilization benefits, implement shoreline paid-use systems and shoreline project access systems, and promote ecological compensation mechanisms in shoreline utilization.

Strengthen the optimized development, rational utilization, and effective management of various artificial shorelines. For shoreline sections with outstanding environmental and ecological significance but still relatively low artificialization, attempt to restore their natural shoreline attributes and functions through effective restoration and recovery. At the national level, strengthen unified planning and management of port shorelines, including existing port shorelines and their supporting sections, as well as undeveloped deep-water shoreline resources, all of which should be incorporated into national-level unified planning and management. The emphasis should be on orderly port development, optimizing coastal port spatial layout and functional positioning, emphasizing differentiated devel-

opment, complementary advantages, and mutual benefits at both regional and individual port levels, enhancing functional synergy among ports, and promoting orderly development of the marine economy. Strengthen dynamic monitoring and environmental impact assessment of reclamation projects and coastal engineering, and promote environmentally friendly coastal engineering technical measures with lower ecological negative impacts. In natural shoreline and low-artificialization sections, emphasize beach protection and ecological shoreline protection measures to restore and enhance coastal disaster prevention, resistance, and mitigation capabilities. Optimize shoreline functions, emphasize principles of concentrated development and extensive protection, break the enclosure and privatization of shoreline resources, especially in sections with high cultural and tourism-recreation functions. In waterfront cities, prioritize promoting shoreline openness and enhancing accessibility to shoreline areas, returning beautiful shoreline resources to the people.

3.3 Launch a "Restore China' s Estuaries" Initiative to Maintain and Strengthen Estuarine Hydrological and Ecological Connectivity

"Restore America' s Estuaries," founded in 1995, is a non-profit organization whose mission is to protect and restore water bodies and lands important to coastal biodiversity, thereby protecting America' s coasts and estuaries. The organization advocated for and drafted the "Estuary Restoration Act," a landmark federal legislation in the United States, and led the development of the "National Strategy for Restoration of Coastal and Estuarine Habitats," jointly publishing "Principles for Estuarine Habitat Restoration," making significant contributions to estuary restoration and coastal protection in the United States [24]. We recommend learning from the United States based on China' s reality by formulating and implementing a "Restore China' s Estuaries" action plan, making estuary restoration and protection a binding indicator task for both watershed integrated management and integrated coastal zone management. Specific objectives include: ensuring adequate runoff and restoring flood processes in large and medium estuaries, preserving certain areas of coastal floodplains, allowing small and medium rivers to "flow freely," reducing pollutants from rivers entering the sea, restoring waterfowl habitats, reconstructing or removing estuarine sluice dams, and restoring and maintaining hydrological and ecological connectivity of "watershed-estuary-coastal zone" systems.

3.4 Use Bays as Key Focus Areas to Promote Mainland Coastline Protection Through Classified Bay Management

China' s coastal bays are numerous and diverse, with 109 included in the "China Bay Gazetteer."Bay shorelines account for more than two-thirds of China's mainland coastline, and China' s coastal intertidal wetlands are mainly distributed in bay areas. Therefore, we recommend that China' s marine functional zoning and integrated coastal zone management strengthen bay-level positioning, objectives, and actions. Specifically, major coastal bays should be used as basic

units for functional positioning classification and implementation of classified management. For example, bays with ecological conservation as their primary functional positioning should strictly control bay shoreline development, strictly control pollutant discharge into bays through rivers, attempt to restore natural bay shorelines and tidal flat wetlands, implement tidal flat aquaculture exit mechanisms, implement ecological red line systems, and maintain bay area and morphological characteristics. Bays with port and shipping as their primary functional positioning should optimize and improve shoreline resource utilization efficiency while implementing strict water pollution monitoring and control.

3.5 Establish and Improve Laws and Regulations to Promote Multi-departmental and Regional Coordination

The development, utilization, and protection of shoreline resources are core tasks of integrated coastal zone management. Only through establishing and improving laws and regulations and perfecting management systems and mechanisms can rational development and utilization and effective protection of shorelines be fundamentally guaranteed. China' s current coastal zone management system is generally a "loose management" system, characterized by traditional division of labor and classified management. Its shortcomings include failure to view the coastal zone as an integrated system, numerous industry-specific regulations and management agencies, and the existence of vacuums, overlaps, or conflicts in specific management processes, which cannot meet the practical needs of coastal socioeconomic development and coastal resource and environmental management. Therefore, calls for coastal zone legislation in China are growing, but the main difficulties hindering the legislative process lie in two aspects: defining the spatial scope of coastal zones and setting up competent authorities. We therefore recommend: (1) conducting scientific coastal zone surveys and zoning jointly with competent authorities from various coastal zone industries and multi-disciplinary experts and scholars, formulating reasonable demarcation principles and schemes, defining coastal zone spatial scope, and determining the scope and boundaries of supervision and management based on zoning results; (2) enhancing and upgrading the functional authority of existing marine management departments, or establishing a specialized coastal zone management committee and granting it the functional authority to implement integrated management and coordinate management work among various industry authorities in coastal zones. Additionally, we recommend first conducting regional pilot projects, continuously summarizing experiences and making improvements through pilot implementation, and forming reasonable and feasible coastal zone legislation based on this foundation.

References

1. Xu XG, Peng HF, Xu QZ. Land resource conflicts and coordination under rapid urbanization in coastal zones: A case study of Shandong Peninsula. *Acta Scientiarum Naturalium Universitatis Pekinensis*, 2006, (04): 527-

533.

2. Xu Y, Cao K, Li M, et al. Research progress on ecological risk assessment in coastal zones. *Advances in Earth Science*, 2016, 31(2): 137-146.
3. Zhu GR, Xu XG. Analysis of annual reclamation progress in the northwest coast of Bohai Bay from 1974 to 2010. *Scientia Geographica Sinica*, 2012, 32(8): 1006-1012.
4. Kuleli T, Guneroglu A, Karsli F, et al. Automatic detection of shoreline change on coastal Ramsar wetlands of Turkey. *Ocean Engineering*, 2011, (38): 1141-1149.
5. Romine BM, Fletcher CH, Frazer LN, et al. Historical shoreline change, Southeast Oahu, Hawaii; Applying Polynomial Models to Calculate Shoreline Change Rates. *Journal of Coastal Research*, 2009, 25(6): 1236-1253.
6. William RV, Keqi Z, Dean W. Hurricane-induced beach change derived from airborne laser measurements near Panama City, Florida. *Marine Geology*, 2007, (237): 191-205.
7. Ashton AD, Donnelly JP, Evans RL. A discussion of the potential impacts of climate change on the shorelines of the northeastern USA. *Mitigation and Adaptation Strategies for Global Change*, 2008, (13): 719-743.
8. Peter R, Maarten B, George MK, et al. Modeling the effects of wave climate and sediment supply variability on large-scale shoreline change. *Marine Geology*, 2010, (273): 127-140.
9. Micha K, Michal L. Monitoring changes in shoreline position adjacent to the Hadera power station, Israel. *Applied Geography*, 2006, (26): 210-226.
10. Zhu XH, Cai YL. Study on fractal dimension and its properties of China' s coastline. *Advances in Marine Science*, 2004, 22(2): 156-162.
11. Zhang Y, Zhang JL, Jing XD, et al. Study on mainland coastline changes and fractal dimension in China since 1990. *Marine Environmental Science*, 2015, 34(3): 406-410.
12. Liu BQ, Meng WQ, Zhao JH, et al. Changes in characteristics of mainland coastline resource development and utilization in China from 1990 to 2013. *Journal of Natural Resources*, 2015, 30(12): 2033-2044.
13. Zhang M, Jiang XZ, Zhang JR, et al. Research progress on shoreline feature extraction from remote sensing images. *Yellow River*, 2008, 30(6): 7-9.
14. Xia DX, Duan Y, Wu SY. Study on modern coastline delimitation methods. *Marine Science Research*, 2009, 27(sup): 28-33.
15. Hou XY, Wu T, Wang YD, et al. Method and accuracy assessment of multi-temporal mainland coastline extraction since the 1940s. *Marine Sciences*, 2014, 38(11): 66-73.

16. Chen JY (Editor-in-Chief), Sea Enclosure Development Professional Committee of Chinese Hydraulic Engineering Society (Editor). *Sea Enclosure Engineering in China*. Beijing: China Water & Power Press, 2000.

17. Hou XY, Wu T, Hou W, et al. Characteristics of coastline changes in mainland China since the early 1940s. *Science China Earth Sciences*, 2016, (59): 1-12, doi: 10.1007/s11430-016-5317-5.

18. Hou XY, Hou W, Wu T. Morphological changes of major coastal bays in mainland China since the early 1940s. *Acta Geographica Sinica*, 2016, 71(1): 118-129.

19. Xu XG, Gaboury Benoit, Cui CW. Enlightenment from "Restore America' s Estuaries" . *Pearl River*, 2007, (1): 35-38.

20. Hou XY, Wu T, Song Y, et al. Temporal and spatial characteristics of mainland coastline utilization degree over the last 70 years in China. *Ocean & Coastal Management*, 2014, (98): 150-157.

Hou Xiyong is a professor and Ph.D. at the Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, a member of the Yantai Municipal Political Consultative Conference, and a local legislative consultant for the Standing Committees of Yantai and Weihai Municipal People' s Congresses. His research focuses on monitoring coastal land use change and shoreline change, coastal vulnerability assessment, and integrated coastal zone management. E-mail: xyhou@yic.ac.cn

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