Concept and Pathway for Developing a New Model of Coastal Ecological Agro-pastoral Farms: A Case Study of the Yellow River Delta (Postprint)

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Abstract

Against the backdrop of global climate change and intensified human activities, the development of China's coastal zones has been significantly affected, with exceptionally pronounced ecological vulnerability and numerous severe challenges. Currently, the relatively independent development of saline-alkali land agriculture, tidal flat aquaculture, and marine ranching in coastal zones can no longer meet the development requirements of modern agriculture. It is urgent to investigate the influence mechanisms and regulation pathways of land-sea connectivity, adopt new facilities and engineering technologies, and establish a new model of coastal ecological farms based on ecosystem management concepts. This article takes the Yellow River Delta—a typical representative and microcosm of China' s coastal zone development—as an example, analyzes the current status and existing problems of coastal zone resources and environment, and based on the current status and demands of saline-alkali land development and marine ranching industry development in coastal zones, discusses the construction concepts, content, scientific issues, key technologies, and development pathways of coastal ecological farms, with the aim of providing references for the protection and sustainable utilization of China' s coastal zones.

Full Text

Conception and Approach on New Model of Ecological Farm and Ranch Constructions in Coastal Zone —A Case of the Yellow River Delta, China

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Abstract

Against the backdrop of intensified global climate change and human activities, China' s coastal zones are experiencing significant impacts, with exceptionally prominent ecological vulnerability and numerous severe challenges. Currently, the relatively independent development of saline-alkali land agriculture, tidal flat aquaculture, and marine ranching in coastal zones can no longer meet the developmental requirements of modern agriculture. It is therefore urgent to ascertain the impact mechanisms and regulation approaches of land-sea connectivity, adopt new facilities and engineering technologies, and establish a new model of coastal ecological farm and ranch based on ecosystem management concepts. Taking the Yellow River Delta—a typical model and epitome of coastal zone development in China—as an example, this paper analyzes the current status and existing problems of coastal resources and environment; based on the current situation and demands of saline-alkali land development and marine ranching industry in coastal zones, it discusses the construction concept, content, scientific questions, key technologies, and development approaches of coastal ecological farms and ranches, aiming to provide references for the protection and sustainable utilization of China' s coastal zones.

Keywords: coastal zone, ecological connectivity, ecological farm and ranch, Yellow River Delta

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Introduction

The coastal zone represents the most frequent and active interface of interactions among the lithosphere, hydrosphere, atmosphere, biosphere, and human society. As a region of highly intensive human socio-economic activities and land-sea material and energy exchange, it has evolved into a critical zone for modern economic and social development as well as an ecologically vulnerable zone [1]. China' s mainland coastline extends 18,000 km, with an additional 14,000 km of island coastline. Located on the eastern edge of the Eurasian continent and the western margin of the North Pacific Ocean, the coastal zone spans approximately 32 degrees of longitude east-west and 44 degrees of latitude north-south, constituting a region characterized by multi-interface coupling, complex environmental and ecological processes, abundant natural resources, and intense human activities. Against the backdrop of global climate change, sea-level rise, and accelerated coastal urbanization, the scope and intensity of land-based pollution, seawater intrusion, and coastal erosion continue to expand. Typical coastal habitats are being or have already been severely damaged, placing enormous pressure on coastal biodiversity and ecosystem health, with ecological service functions continuously declining. For instance, since the founding of the People' s Republic of China, over 50% of China' s coastal wetlands have been lost. Nearshore fishery resources are becoming depleted and smaller in size, with the distribution patterns of coastal biological resources undergoing significant changes. This not only affects traditional industries such as agriculture but also hinders the development of strategic emerging industries like the bio-industry, while posing severe challenges to ecosystem health and impacting the sustainable development of coastal environments that serve as an important pillar of the blue economy. In summary, systematically understanding the current characteristics, evolution patterns, and driving mechanisms of land-sea ecosystem connectivity under human influence, developing new methods, equipment, and technologies for integrated land-sea coastal zone environmental monitoring and ecological restoration, promoting the development of coastal restoration engineering technologies, rationally utilizing coastal biological resources, and establishing new models for coastal ecosystem protection and sustainable utilization will contribute to advancing ecological civilization construction and sustainable social development in China' s coastal regions.

Current Situation and Challenges of the Yellow River Delta

The Yellow River Delta is a typical coastal zone ecosystem. As the core construction area of the Yellow River Delta Efficient Ecological Economic Zone and an industrial cluster area of the Shandong Peninsula Blue Economic Zone, it represents an important region for national marine development strategy and regional coordinated development strategy, as well as a pilot zone for extending China's regional development from land-based economy to marine economy and actively promoting the major strategy of integrated land-sea planning. Over the past 30 years, as a typical model and epitome of coastal zone development in China, the Yellow River Delta has experienced significant impacts from global climate change and human activities, with exceptionally prominent ecological vulnerability and numerous severe challenges [2].

The Yellow River is characterized by low water volume but high sediment load, with significant depositional dynamics in its estuary and adjacent sea areas. The multi-year average natural annual runoff of the Yellow River is 32 billion cubic meters (based on data from the Lijin Hydrological Station from 1950–2002), equivalent to only 1/30 of the Yangtze River' s discharge [3]. However, the multi-year average annual sediment load of the Yellow River mainstream is 811 million tons (based on data from the Lijin Hydrological Station from 1950–2002) [4], endowing the Yellow River Delta estuary with typical characteristics of rapid change and depositional dynamics. Since 2001, annual water-sediment regulation has altered ebb tide dynamics at the estuary, affecting sediment deposition processes and exerting multiple impacts on the nearshore ecological environment [5]. Meanwhile, the Yellow River's course has changed frequently, with dramatic erosion and deposition evolution in the delta. Since 1855 when the Yellow River captured the Daqing River channel to flow into the Bohai Sea, its course at the estuary has shifted 11 times, with Ninghai (1855–1934) and Yuwa (post-1934) serving as the apex points. Each diversion deposited sediments to form large sand spits at the river mouth, while abandoned channels continuously eroded under marine dynamics, maintaining the Yellow River' s course in a cyclical state of "deposition–elevation–overflow–swinging–diversion" [5,6].

From 1961 to 2015, the average annual rainfall in the Yellow River Delta region decreased by 241.8 mm, with an average annual decline rate of 4.5 mm/year [7]. Over the past 55 years, annual rainy days decreased from over 80 days in the 1960s to the current 50+ days, with a decline rate of 6.9 days per decade. During the same 55-year period (1961-2015), the average annual temperature in the Yellow River Delta region increased by 1.7°C, equivalent to 0.31°C per decade [7]. Consequently, the warming and drying trend in the Yellow River Delta is evident, which will further intensify soil salinization and drive halophytic vegetation succession, while the region' s dependence on freshwater resources will continue to increase.

Around 1990, Spartina alterniflora was introduced near Wuhazhuang on the north side of the Gudong oil extraction area in the Yellow River Delta [8]. During the subsequent 20 years, the distribution area of Spartina alterniflora changed little; however, starting in 2010, it began to grow and spread rapidly, with its distribution range and area expanding swiftly across the Yellow River Delta. By 2015, the Spartina distribution area in the Yellow River Delta had exceeded 20 km^2, covering the intertidal zones of the Yellow River Delta Nature Reserve. The uncontrolled expansion of Spartina alterniflora in the Yellow River Delta threatens the biodiversity of salt marsh vegetation, benthic animals, and the quality of bird habitats, while also creating numerous negative impacts on mariculture, shipping, and oil extraction.

Human activities such as oilfield development, reclamation for aquaculture, and agricultural cultivation are the primary factors causing the gradual reduction of natural coastal wetlands in the Yellow River Delta. Since the construction of the Shengli Oilfield in 1961, oilfield development has profoundly influenced the evolution and development of wetlands in the Yellow River Delta. Remote sensing interpretation shows that over the past 40 years (1976-2014), natural wetlands in the Yellow River Delta have continuously decreased [9], while farmland area has continuously increased [10]. From 1976 to 2015, the natural wetland area in the Yellow River Delta decreased substantially, with an average annual reduction rate of 3.4%, totaling a loss of 1,627 km^2. In contrast, artificial wetlands (salt pans, aquaculture ponds, etc.) increased from 163 km^2 in 1976 to 3,054 km^2 in 2015, with an average annual growth rate of 2.4%. The lost natural wetlands were mainly converted to dry land, aquaculture ponds, and salt pans. By 2015, the fragmentation of natural wetlands had intensified, and patch shape complexity had increased. Meanwhile, under the combined influences of natural factors such as saltwater action, reduced sedimentation growth rates, and Yellow River flow interruption, as well as human activities including oilfield development and reclamation for aquaculture, the tidal flat area in the Yellow River Delta has significantly decreased [11].

Land-sea ecological connectivity refers to the coupled connection among terrestrial, intertidal, and shallow sea areas through hydrological, biological, geological, and geochemical processes, playing a crucial role in maintaining biodiversity, restoring and reconstructing endangered populations, and protecting and sustainably utilizing biological resources. Influenced by climate change and human activities, the fragmentation and isolation of land-sea ecosystems in the Yellow River Delta have become increasingly severe, leading to a series of problems including habitat degradation and biodiversity loss [12,13]. For example, intensive reclamation activities in the Yellow River Delta in recent years have severed the ecological connectivity of wetlands, causing shallow-sea wetland organisms to lose terrestrial food sources while terrestrial wetland habitats gradually disappear, affecting the integrity of wetland biological habitats and the maintenance of biodiversity, and resulting in declining ecosystem service functions of coastal wetlands [14,15].

In recent years, China has attached great importance to marine ranching construction, approving the establishment of 42 national-level marine ranching demonstration zones that have achieved regional fishery resource conservation, ecological environmental protection, and comprehensive fishery development, thereby promoting the industrial upgrading of marine fisheries [16]. Coastal zones possess dual terrestrial and marine characteristics. Focusing solely on nearshore ecological protection and environmental utilization while neglecting land-sea ecological connectivity hinders the protection and sustainable utilization of coastal zones. The Yellow River Delta and its adjacent sea area, as a typical northern coastal zone region in China, cover a vast area with tens of thousands of mu of newly added land annually. The adjacent sea area also serves as an important spawning and nursery ground for fishery organisms in the Bohai Sea, with tremendous potential for resource utilization and development and extremely important ecological service values. Currently, saline-alkali land agriculture in this region remains dominated by cotton cultivation, tidal flat utilization focuses primarily on pond culture of sea cucumbers and shrimp, nearshore resource development relies mainly on traditional fishing, and marine ranching construction is still in its infancy. Due to the relative independence of land and sea areas and blocked connectivity, the comprehensive benefits of ecological shoreline protection and economic shoreline development are difficult to further enhance [17].

Construction Concept and Content of Coastal Ecological Farm and Ranch

At present, the relatively independent development of saline-alkali land agriculture, tidal flat aquaculture, and marine ranching construction can no longer satisfy the developmental requirements of modern agriculture. It is urgent to identify the impact mechanisms and regulation approaches of land-sea ecological connectivity, conduct research, development, and integrated application of new facilities and technologies for saline-alkali land ecological farms, tidal flat ecological farms and ranches, and shallow-sea ecological ranches according to local conditions, develop modern environmental guarantee and early warning and forecasting platforms for coastal ecological farms and ranches, build modernized coastal ecological farms and ranches with integrated land-sea linkages, and establish new models for coastal zone protection and sustainable utilization [18].

Coastal ecological farms and ranches are based on ecological principles, utilizing modern engineering technologies to construct saline-alkali land ecological farms, tidal flat ecological farms and ranches, and marine ecological ranches through integrated land-sea planning, thereby creating healthy coastal ecosystems and forming a new model of coastal zone protection and sustainable utilization characterized by "three-field connectivity" and "three-industry integration."

3.1.1 Prioritize Ecology and Develop Saline-Alkali Land Ecological Farms

It is essential to emphasize harmony between land and sea and adopt the concept of "Building with nature" [19]. Based on environmental carrying capacity and on the foundation of protecting ecological shorelines, we should vigorously develop modern ecological agriculture centered on forage planting and efficient restoration of salt-tolerant plants, supplemented by Tamarix-Cistanche cultivation and rice-fish-crab integrated ecological farming.

3.1.2 Promote Land-Sea Linkage and Construct Tidal Flat Ecological Farms and Ranches

Scientific planning must be conducted under the premise of emphasizing integrated land-sea coordination, implementing Spartina alterniflora control and habitat reconstruction, and efficiently utilizing local tidal flats through seawater vegetable cultivation, bare flat livestock and poultry farming, and healthy seedling breeding of marine animals, thereby restoring the ecological functions of most wetlands.

3.1.3 Promote Integrated Development and Construct Shallow-Sea Ecological Ranches

Through habitat restoration and modification, provide spawning, nursery, and feeding grounds for marine organisms, implement stock enhancement and effective resource management to supplement and restore biological resources, while simultaneously developing processing and utilization, leisure tourism, and other industries to achieve integrated development of primary, secondary, and tertiary industries [20,21].

3.1.4 Emphasize Engineering Demonstration and Construct New Protection and Utilization Models

Based on systematic assessment of the current status of land-sea ecological connectivity, we must strengthen engineering demonstrations of coastal zone construction and development activities, ensure stable structure and function of land-sea ecosystems, establish interconnected and integrated ecological farms and ranches across coastal zones, achieve "three-field connectivity" and "three-industry integration," and enhance the development space and comprehensive benefits of coastal zone utilization.

Key Scientific Questions and Technologies

The key scientific questions facing coastal ecological farm and ranch construction involve identifying the critical factors hindering land-sea ecological connectivity and their solutions. In recent years, due to the impacts of human activities and global change, the rate and intensity of coastal environmental changes have far exceeded "natural" variations, affecting land-sea ecosystem connectivity and posing severe threats to coastal ecosystems. Urgent implementation of integrated land-sea protection and restoration is therefore required. Systematically identifying the types of coastal ecosystems in China and the spatiotemporal distribution of factors blocking land-sea ecological connectivity, revealing the evolution patterns and driving mechanisms of land-sea ecosystem connectivity, scientifically diagnosing and screening the main controlling factors causing habitat degradation, conducting spatiotemporal heterogeneity analysis, and proposing targeted zonal restoration technologies can improve coastal habitat quality and ecosystem functions at the overall ecosystem level, and formulate integrated land-sea coastal protection and restoration strategies and measures.

Strengthening the original driving role of basic research, we must construct a "three-field connected" ecological farm and ranch system encompassing "saline-alkali land (salinity <10‰)–tidal flat (salinity <20‰)–shallow sea (salinity <30‰)." This requires clarifying the relationship between spatiotemporal evolution of water-salt transport in coastal zones and nearshore hydrodynamic changes, revealing the source fluxes and migration patterns of nearshore nutrients, increasing ecological connectivity among habitat patches, improving the habitat environment for important biological groups, and enhancing nutrient utilization efficiency and carbon sequestration capacity in coastal zones (Table 1).

Optimizing the rational layout and structure of the three industries: In the primary industry, saline-alkali land ecological farms should focus on forage-livestock breeding, rice-fish-crab integrated ecological farming, cultivation of salt-tolerant plants such as Jerusalem artichoke, and conservation and utilization of biological resources like reeds. Tidal flat ecological farms and ranches should emphasize Spartina alterniflora control and habitat reconstruction, Tamarix-Cistanche cultivation, seawater vegetable cultivation, bare flat livestock and poultry farming, vegetable-seafood integrated culture, and industrial application of healthy marine animal seedling breeding. Shallow-sea ecological ranches should prioritize seagrass bed protection and restoration, natural oyster reef conservation and maintenance, and fishery resource restoration and utilization. In the secondary industry, the focus should be on deep processing of biological products, deep processing of animal and plant foods, health product development, and functional fertilizer development. In the tertiary industry, emphasis should be placed on estuarine delta ecotourism, recreational fisheries, and cultural industries.

Strengthening the mutual support of ecological functions among the three fields, saline-alkali land ecological farms will provide high-quality feed supply for tidal flat ecological farms and ranches, tidal flat ecological farms and ranches will provide healthy seedling support for shallow-sea ecological ranches, and shallow-sea ecological ranches will provide functional fertilizer support for saline-alkali land ecological farms and tidal flat ecological farms and ranches. Through "three-field connectivity," we can achieve comprehensive ecosystem protection and full expression of ecological service values. Simultaneously, we can construct a new model of efficient ecological economy in the Yellow River Delta featuring "three-industry integration" of agriculture-aquaculture-fisheries, deep processing industry, and tourism (Figure 1 [Figure 1: see original paper]).

Development Approaches

4.2.1 Core Equipment and Key Technologies for Coastal Habitat Monitoring

We must develop new sensor technologies for rapid, sensitive, and highly selective detection of typical coastal pollutants, create proprietary intellectual property rights for new on-site and rapid monitoring facilities for pollutants, and integrate and innovate multi-parameter online monitoring systems for terrestrial and marine environments. Combining data acquisition and wireless communication technologies, observation/monitoring data can be transmitted to remote data control centers to achieve in-situ, online, and integrated monitoring of multiple environmental parameters. Based on quantitative extraction and rapid identification technologies from remote sensing imagery, we should establish remote sensing monitoring and regional forecasting and early warning technologies for coastal disasters. We must also develop multi-source data fusion, assimilation, data mining, and standardized modeling methods for coastal zones, and develop intelligent management information systems integrating modern scientific methods and technologies such as artificial intelligence, expert systems, and knowledge engineering.

4.2.2 Restoration and Comprehensive Regulation of Typical Degraded Coastal Habitats

Systematically identifying the spatiotemporal distribution characteristics of factors blocking land-sea ecological connectivity in China' s typical coastal ecosystems, we must study the ecological effects of spatiotemporal evolution of land-sea ecological connectivity in coastal zones. Through integrated land-sea studies on pollutant distribution fluxes, source-sink processes, and prediction models in coastal zones, we should assess environmental quality changes and ecological risks. Establishing diagnostic methods for typical coastal habitat degradation, we must develop coastal habitat restoration and functional enhancement technologies centered on habitat adjustment and adaptation, ecological network construction and optimization, and build assessment and carbon sequestration enhancement technologies for typical coastal blue carbon ecosystems.

4.2.3 Coastal Animal and Plant Breeding and Ecological Farm and Ranch Construction

Selecting coastal animal and plant species with high ecological and economic value, we should obtain superior varieties with advantages such as stress resistance and rapid growth through conventional breeding and molecular-assisted breeding methods. We must develop large-scale, mechanized high-yield cultivation technologies for salt-tolerant economic plants, breakthrough water quality regulation technologies for saline-alkali land ponds, and construct saline-alkali land ecological farms with coastal characteristics. Based on improved tidal flat environmental conditions, we should build tidal flat-type marine ranches featuring shellfish-algae integrated proliferation. Assessing the ecosystem service functions of seagrass beds, seaweed fields, and oyster reefs, we must develop ecological diversification and proliferation technologies for fish, sea cucumbers, and shellfish to construct shallow-sea marine ranches.

4.2.4 Efficient Development and Comprehensive Utilization of Coastal Biological Resources

Utilizing salt-tolerant economic plants such as Jerusalem artichoke and Suaeda, we should develop nutritional special dietary foods and diversified functional products like inulin-donkey-hide gelatin and inulin-chitosan oligosaccharide complexes. Using processing waste from fish, shrimp, crabs, and shellfish, we should reuse active components such as collagen, animal polysaccharides, lipids, and biological calcium to deeply develop functional foods, cosmetics, coatings, and related products. We must research methods and technologies for extracting active components like phycobiliproteins, functional polysaccharides, and dietary fiber from algae, screening health foods with special functions and food resources suitable for special populations. Targeting microbial resources and their metabolites in typical environments such as saline-alkali lands, intertidal zones, nearshore areas, and aquaculture zones in coastal zones, we should construct characteristic coastal microbial strain libraries, screen medicinal lead compounds with anticancer and antimicrobial activities, develop agricultural microbial agents or functional fertilizers with nitrogen fixation, bactericidal, insecticidal, and growth-promoting functions, and create functional products such as pollutant degradation agents and enzyme preparations.

Building Theoretical and Engineering Technology Systems for Coastal Protection and Utilization

We must reveal the impact mechanisms of land-sea ecological connectivity and assess coastal carrying capacity. Developing new paradigms for integrated agriculture-aquaculture-fisheries in coastal zones, we should improve technical levels in crop and salt-tolerant plant cultivation, livestock and aquatic breeding, shellfish-algae integrated proliferation, habitat restoration and resource conservation, and deep processing. We must develop real-time resource and environmental monitoring equipment and early warning and forecasting platforms to promote whole-process management and innovative development of coastal ecological farms and ranches, and construct new development models for coastal ecological farms and ranches.

Improving Standardization Systems for Coastal Ecological Farm and Ranch Construction

We should promote the standardized and scientific development of coastal ecological farms and ranches. Formulating technical regulations and standards for the integrated development of saline-alkali land ecological farms, tidal flat ecological farms and ranches, and shallow-sea ecological ranches, we must standardize assessments of carrying capacity, layout planning, design and construction, monitoring and evaluation, and early warning and forecasting for ecological farms and ranches. Through integrated land-sea efforts, we should improve the standardization system for coastal ecological farm and ranch construction to guide and regulate industry development.

Forming a Complete Industrial Chain for Coastal Ecological Farm and Ranch Systems

Promoting the integration of "government, industry, academia, research, and application," we should implement ecosystem-based coastal zone management, leverage government guidance and support, break institutional barriers among research organizations, strengthen the dominant position of enterprises in technological innovation, and enhance the participation enthusiasm of farmers and fishers. We must promote the formation of industrial technology innovation alliances with close cooperation among research institutes, enterprises, and farmers/fishers to facilitate the transformation of research achievements and changes in management methods.

Innovating Management Systems for Coastal Ecological Farms and Ranches

We should enrich and expand investment and financing channels and entities, gradually transitioning from government management to social and enterprise management. Coastal ecological farm and ranch construction requires large investment and long cycles. Initially, we should seek support from national fiscal funds and policy-based finance, establish a national ecological farm and ranch development fund, and launch demonstration projects for coastal ecological farm and ranch construction. We must expand financing channels for coastal ecological farm and ranch use rights, widely absorbing social capital, private capital, and foreign capital to participate in the operation, maintenance, management, and technological innovation of ecological farms and ranches.

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The Yellow River Delta is located at 117°32' –119°10' E, 36°56' –38°12' N and is one of China' s three major river deltas.

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