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Abstract

The Yellow River Delta is located on the west coast of the Bohai Sea. It is one of the regions with the most active interaction between land and ocean, and one of the three major estuary deltas in China. This region has the most complete, the most extensive, the youngest wetland ecosystem and abundant biological resources in China's warm zone. It plays an important role in regulating the climate, reducing exogenous pollution, restoring amphibious ecological ecotone, and other functions. In recent years, with the rapid development of the Yellow River Delta region, problems such as the continuous reduction of inflow seawater and sediment, the serious shrinkage of wetland areas, and the invasion of *Spartina alterniflora* Loisel, have become increasingly prominent. On the basis of summarizing and analyzing the development status of this region, we proposed four development concepts: ecological protection priority, adapt to local water conditions, deep integration of multiple elements, and reasonable spatial layout, then, suggested four development models: ecological farm and ranch, integrated development of fishery and tourism, integrated development of fishery and energy industry, and linkage of three kinds of industrial models, with a view to achieving green development of blue agriculture in the Yellow River Delta.

Keywords

the Yellow River Delta; blue agriculture; ecological farm and ranch; integrated development of fishery and tourism; integrated development of fishery and energy industry; linkage of three kinds of industrial models

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Study on Green Development Model and Approach of Blue Agriculture in the Yellow River Delta

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Abstract: The Yellow River Delta is located on the west coast of the Bohai Sea. It is one of the regions with active interaction between land and ocean and one of the three major estuary deltas in China. This region has the most complete, the most extensive, the youngest wetland ecosystem and abundant biological resources in China's warm temperate zone. It plays an important role in the regulation of climate, mitigation of exogenous pollution, and restoration of amphibious ecological ecotone. In recent years, with the rapid development of the Yellow River Delta region, problems such as the continuous reduction of inflow water and sediment, the serious shrinkage of wetland areas, and the invasion of *Spartina alterniflora* Loisel, have become increasingly severe. On the basis of summarizing and analyzing the development status of this region, we proposed four development concepts: ecological protection priority, adaptation to local water conditions, deep integration of multiple elements, and reasonable spatial layout. We then suggested four development models: ecological farm and ranch, integrated development of fishery and tourism, integrated development of fishery and energy industry, and linkage of three kinds of industrial models, with a view to achieving green development of blue agriculture in the Yellow River Delta. DOI: 10.16418/j.issn.1000-3045.20200107005-en

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The Yellow River Delta, an alluvial plain covering an area of 5 450 km² on the west coast of the Bohai Sea, is one of the three major estuary deltas in China and expands at a rate of 2–3 km² per year^[1]. The Yellow River Delta is located in the overlapping area of the Yellow River Delta Efficient Ecological Economic Zone and Blue Economic Zone of Shandong Peninsula. As an important part of the Bohai Granary project, the delta has unused land of 3.013×10^7 hm², which is the largest reserved land with the greatest development potential in the eastern coast of China^[2]. In recent years, the problems of environment, ecology, natural disasters, and resources in the Yellow River Delta have become serious. Industrial and agricultural pollution, sea reclamation, species

invasion, land-based pollution, and ecological disaster have led to the sharp declines in wetland area, biodiversity, and landscape diversity, depletion of fishery resources, and serious degradation of ecosystem.

The development of high-efficiency ecological economy has been a national plan and included in the planning outline for the Yellow River Delta since the Tenth Five-Year Plan. On September 18, 2019, General Secretary Xi Jinping delivered an important speech on the ecological protection and high-quality development of the Yellow River Basin, emphasizing ecological protection. He points out that the Yellow River Delta is the most complete wetland ecosystem in the warm temperate zone of China and we must strive to protect

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it, to maintain the health of river ecosystems, and to increase biodiversity. Blue agriculture^{[3]①} is an important component of agriculture and a part of national economic and social development, playing a role in resource utilization, benefit enhancement, and sustainable development in the Yellow River Delta. In February 2019, the No. 1 Central Document made clear to determine the rational scale of aquaculture in inland waters, reduce the over-dense cage culture in the offshore area, lake, and reservoir, promote the construction of marine ranch, and standardize pelagic fishery. Therefore, it is urgent to establish a new development model for blue agriculture in the Yellow River Delta.

1 Necessities of green development of blue agriculture in the Yellow River Delta

Water conservancy is the lifeline of agriculture, and the shortage of fresh water resources restricts the development of traditional agriculture in the Yellow River Delta. Therefore, it is imperative to explore a new mode of agricultural development. The serious impact of human activities, the aggravated environmental pollution, and the biological resource problems have highlighted the necessity of green development of blue agriculture. Besides, the invasion of *Spartina alterniflora* Loisel has made it urgent to develop blue agriculture in the Yellow River Delta.

1.1 Shortage of fresh water resources

The unique ecosystem and location of the Yellow River Delta are good conditions for the development of efficient ecological economy and green development of blue agriculture. Water resource is an important part of the long-term sustainable development of the Yellow River Delta. In recent years, the shortage, uneven distribution, and pollution of water resources in the Yellow River Delta have been severe. The water resource is short in the central area and rich in the east and west, and the precipitation in summer accounts for 70% of the annual precipitation (600 mm). These problems have become the major factors slowing down the development of the Yellow River Delta^[4]. The main water resources in the delta include groundwater, precipitation, and guest water. At present, the exploitation of groundwater is approaching the limitation; the annual mean precipitation varies greatly and shows a downward trend year by year; Yellow River, the main guest water source, faces problems such as cutout, pollution, and waste. Meanwhile, the afflux of many rivers carrying industrial wastewater, seawater encroachment, and

exhausted water resources have exacerbated the water resource problems in the delta.

1.2 Severe impact of human activities

The Yellow River Delta is an important oil development area, salt production base, and breeding area, with intense human activities. In addition, the coastal wetlands in this region have ample resources and a high value of ecological service. However, the intensive reclamation activities and the escalated impact of human activities have adversely affected the landscape and ecology in coastal wetlands^[5]. In recent years, the intensified human activities such as breeding, port and oilfield construction, salt industry, and farmland reclamation have aggravated the erosion of coastline, degradation of ecosystem, lack of fresh water resources, and natural disasters in the region. The increasingly serious environmental problems pose direct threats to the soil security and sustainable social and economic development in the Yellow River Delta^[6].

1.3 Aggravation of environmental pollution

The rapid development of economy in recent years has drastically deteriorated the air quality and led to frequent fine particle pollution incidents in the Yellow River Delta. Moreover, due to the development of oil industry in Dongying City in the Yellow River Delta, the emission of volatile organic compounds in the area has increased. Besides, the Yellow River Delta is close to the Bohai Sea, with high relative humidity, which is conducive to formation of soluble organic carbon, intensifying the air pollution^[7]. In addition, the heavy metals with significant biotoxicity, from multiple sources, concealed, and accumulated in a long term, also posed a potential threat to the animals, plants, humans and the environment in the delta. Due to the rapid economic and social development in the delta, the pollutants from industry, agriculture, animal husbandry, and residents' living activities have entered the sea through rivers, and thus the wetland pollution caused by heavy metals is becoming increasingly serious^[8].

1.4 Threat of biological invasion

The invasion of alien species has become a major issue in the research on global change since these species have strong competitiveness due to the lack of natural enemies. *S. alterniflora* is originated from the Atlantic coast, with strong reproductivity including sexual and asexual reproduction and strong adaptabilities to various environments^[9]. *S. alterniflora* was introduced into the Yellow River Delta in 1990 and then spread rapidly in the salt marshes. Especially in the last

① Blue agriculture refers to human activities such as planting, breeding, intensive processing, and comprehensive utilization of biological resources in water bodies (including inland water and ocean).

five years, it continued to expand and exponentially grow, forcing *Suaeda salsa* and reed to migrate towards the land. No native plant could survive in the intertidal zone at the north side of the Yellow River estuary where *S. alterniflora* grow intensively, which seriously threatens the ecosystem safety of native coastal wetlands^[10]. The prevention and control of *S. alterniflora* is of great significance for restoring the ecology of coastal wetlands and protecting the biodiversity on the mud flat.

2 Conception and strategies of green development of blue agriculture in the Yellow River Delta

2.1 Ecological protection priority

During the development of the Yellow River Delta, we must follow ecological principles, bear in mind that protecting ecology is protecting productivity, and emphasize natural restoration and the concept of building with nature. Based on the environmental capacity and the needs of ecological protection, a compound model involving functional group construction and farming of important species should be established to achieve beneficial and sustainable development. (1) Land–ocean ecosystem restoration and coast ecology protection should be carried out. The restoration of coastal wetlands, shoreline remediation, and coastline monitoring should be conducted first to provide a good environmental foundation for the development. (2) On the basis of environmental capacity, measures should be taken to identify the mechanism and regulatory ways of land–ocean connection and determine the bottom line of environmental security, the upper limit of resources utilization, and the baseline of securing ecological functions in the Yellow River Delta. (3) Complementary industrial models should be implemented to reduce the impact on the stability of ecosystem, regulate production activities in strict accordance with the main functional area, and optimize the spatial layout.

2.2 Adaptation to local water conditions

In order to ensure the health of the river and wetland ecosystems in the Yellow River Delta, it is necessary to set a warning line within the water capacity for the development and utilization of water resources. Abiding the rule of well-coordinated environmental conservation and avoiding excessive development, we should make clear the resources, environment, and ecological functions, and distinguish living, production, and ecological water use, so as to realize rational development, efficient use, effective protection, and scientific management of the water. (1) Prevention and control of water pollution: The prevention and control of water pollution in wetlands and offshore areas should be strengthened. The total pollutants into the sea should be strictly

controlled, and a list of sewage outlets should be established. The management should follow a case-by-case manner. For the outlets with problems, the main body of responsibility should be determined for the application of different measures. (2) Water environment protection: the connection of rivers, wetlands, and sea should be built, and modern water network with unblocked circulation, balanced abundance and dryness, planned storage and drainage, and complementary multi-sources should be constructed. (3) Water ecological restoration: The restoration schemes of freshwater, brackish water, seawater, and wastewater should be explored. The wetland water use and freshwater supplementation in offshore ecosystems should be controlled to ensure the ecological water use of the Yellow River watercourse and estuary. Attention should be particularly paid to the ecological fragile area to make green vitality reappear in the region.

2.3 Deep integration of multiple elements

The Yellow River Delta is an area where land, ocean, and atmosphere meet and interact. Giving full play of the land potential and extending the function of estuary wetland can help to realize the simultaneous development of modern agriculture and animal husbandry in the Yellow River Delta and the land–sea co-development. Insisting on land–sea co-development, coordination, and complementation can help to achieve efficient modern agriculture. (1) The main ecological functions and environmental stress factors should be clarified for the coordination of farming activities and further deep integration of multiple elements. Since different habitats have different ecological functions and stress factors, it is necessary to make full use of different habitats according to their unique characteristics. (2) Data, a new production element, is becoming a new source of power for economic and social development. We should vigorously promote the application of big data in the determination of environmental capacity, environmental prediction, and disease control and prevention, to promote and realize intelligent agriculture, real-time monitoring, precise management, remote control, and intelligent decision-making. Besides, big data can be used to link the production, processing, and transportation to form a traceable, queryable, and accountable closed information loop for blue agriculture in the Yellow River Delta.

2.4 Rational layout

In the development and construction of the Yellow River Delta, the social economic and ecological benefits should be combined to integrate ecology and industry and realize the integrated development of economy, living, and ecology. For the spatial layout, multiple plans should be adopted, including the main functional area plan, the coastal economic belt plan, the overall plan for land utilization, and overall urban plan^[11]. Furthermore, the warning line for ecological protection, the bottom line for environmental quality and

ecological risk management, and the upper line for resource usages should be set. The standards for industry entry and exit should be suggested in the Yellow River Delta^[12]. The basic spatial pattern of production, living, and ecology in the Yellow River Delta should be determined for the land–sea coordination and orderly development of the Yellow River Delta. In land areas, priority should be given to the development of accurate breeding and high-efficiency protected agriculture. Mud flats should be used for the breeding of precious aquatic products and modern marine ecological farms should be constructed in offshore areas. Meanwhile, modern logistics, aquatic product processing, and ocean tourism should be developed.

3 A new mode of green development of blue agriculture in the Yellow River Delta

The development of blue agriculture in the Yellow River Delta should be based on the following principles. The industrial structure of the region should be improved based on ecological theories. Industrial transformation and upgrading should be driven by innovation for the building of a new accurate agricultural system with international competitiveness. The developmental space and layout should be expanded to achieve engineering, mechanization, intelligentization, and informatization. Specifically, we should focus on ecological farm and ranch in coastal area, the integration of fishery and tourism in wetland, and the integration of fishery and energy industry in the areas with rich renewable energy. The industrial models should be linked to form an intact industrial system and finally realize the green and sustainable development of the Yellow River Delta.

3.1 Ecological farm and ranch

The ecological farm in the saline-alkali land, farm and ranch in mud flat, and marine ranch in shallow sea area in the Yellow River Delta should be constructed using modern engineering technology based on ecological theories. In this way, a healthy ecosystem model for coastal protection and sustainable utilization can be established, with the integration of planting, fishery, and breeding^[13]. (1) In the saline-alkali farm and ranch, the forest–grass mode can significantly improve soil physical and chemical properties, soil porosity, water conservation, available nutrients, and the number of microorganisms. For example, the planting mode of *Fraxinus chinensis* + *Tamarix chinensis* + *Medicago sativa* well remediates the coastal saline soil in the Yellow River Delta^[14]. In addition, *Helianthus tuberosus* and *Sesbania* can be cultivated for animal husbandry. The cycling mode of rice–fish–crab can be adopted. Furthermore, intensive processing of biological products and cultivation of Chinese herbal medicine can be carried out. (2) In the ecological farm

and ranch in mud flat, the control of *S. alterniflora* and habitat reconstruction should be realized for the cultivation of *Tamarix chinensis*–*Cistanche deserticola*, animal breeding, fry rearing, farming of vegetable–rare sea products, conservation and clean production of shellfish resources, development of health products, and animal food intensive processing. (3) In the marine ranch in shallow sea area, oyster reef, seagrass bed, and fishery resources should be protected and restored, and the development of functional fertilizer and intensive processing of marine products should be promoted.

3.2 Integrated development of fishery and tourism

The following measures can be taken to extend the industrial chain for the development of blue agriculture in the Yellow River Delta. (1) Areas with good infrastructure conditions can be chosen to develop recreational fisheries and breed and release fish with high economic value. Land- or ship-based tourism units can be built for the reasonable development of fishing and underwater diving. (2) The conservation of seagrass bed and oyster reef, construction of fish-attracting artificial reef, and arrangement of landscape artificial reefs should be conducted to restore fish resources. (3) Wetland museums, bird museums, etc. should be established to spread the knowledge on the status of wetlands in the Yellow River Delta, as well as on birds such as red-crowned crane, white-head crane, white stork, and golden eagle, thus popularizing local culture. (4) A tourist center should be set up to provide personalized tourism services such as theme tours and team tours.

3.3 Integrated development of fishery and energy industry

General Secretary Xi Jinping has pointed out that it is necessary to protect the marine environment and strive to promote the transformation of marine development toward recycling mode. The Opinions on Sea Management of Offshore Wind Power released by State Oceanic Administration stated that intensive and economical use of the sea should be kept to improve the use efficiency of sea resources. The integrated development of offshore wind power, solar power, and wave power in the Yellow River Delta is a development mode sustainable for the intensive and economical use of the sea, with both ecological and efficiency benefits^[15–18]. At present, the offshore renewable energy is still in infancy and tangled with problems such as regulation complexity and imperfect development technology. However, the conversion of wind energy, solar energy, wave energy, and tide energy can satisfy the increasing energy demand of fishery^[19]. We put forward the following suggestions to realize the efficient and reasonable use of wind energy, solar energy, wave energy, and other renewable energy. (1) A renewable energy monitoring system should be established. The monitoring

results can be taken as reference for the location selection and spatial layout. The construction of wind farms can be integrated with aquaculture farms, ecological ranches, and sport fishing and fishery. (2) A wind-powered water pumping system should be built to improve water use for fishery development and mitigate land salinization. (3) Equipment and technology should be upgraded to resolve the randomness, eruptiveness, and instability of renewable energy. A power system with the complementation of wind energy, light energy, and tide energy can be built to achieve integrated development of fishery and energy industry.

3.4 Linkage of three kinds of industrial models

The traditional farm and ranch in the Yellow River Delta, conducting only coastal planting and mud flat breeding, are characterized simple structure and low efficiency. The space needs to be expanded for the future development of blue agriculture in the Yellow River Delta. The primary industry (agriculture, animal husbandry, and fishery), the secondary industry (intensive processing), and the tertiary industry (culture and tourism) should be integrated, which can not only increase the value of ecological services but also help maintain and improve the environment. (1) The development of agriculture, animal husbandry, and fishery should be promoted according to local conditions to optimize the regional planting structure. For example, the saline-alkali low-yield fields in Dongying City could be used to develop coarse cereals with both food and medicine use or grain and feed functions. (2) Intensive processing should be developed to reduce the transportation cost and increase the added value of agricultural products. For instance, irradiation, together with ultra-high pressure treatment, low-temperature treatment, and preservative treatment for *Lateolabrax japonicus*, a native species in the Yellow River Delta, can realize the high-quality preservation with low energy consumption. (3) Ecological restoration can be combined with ecological tourism and recreational fishery to support the running of farms and marine ranches. For example, in the Yellow River Estuary Eco-tourism Area, Hongtan Wetland Coastal Park, Dongying Haihonggang Tourist Area, animal and plant museums can be built for science education and ecological protection purposes.

4 Principles and measures for green development of blue agriculture

4.1 Mechanisms of land–sea connection

The land–sea ecological connection plays an important role in the protection of biological resources, the maintenance of biodiversity, and the restoration of endangered species in the Yellow River Delta. Land–sea connection refers to the connection of shallow sea, intertidal zone, and land through

biological, hydrological, geological, and geochemical processes^[13]. Recently, the current model of saline-alkali agriculture and fishery can no longer meet the requirements of developing modern agriculture. It is urgent to investigate the regulatory mechanism and control methods of land–sea connection, and new facilities and measures should be adopted to establish an ecological farm and ranch model based on ecosystem management theory. Blue agriculture in the Yellow River Delta requires efficient use of mud flat and restoration of ecological functions. The development plan should be made in accordance with land–sea coordination. Fry and fingerling breeding, control of *S. alterniflora*, habitat reconstruction, animal breeding, intensive processing, and eco-tourism should be carried out to achieve green and efficient development.

4.2 Capacity evaluation

The capacity of blue agriculture in the Yellow River Delta should be assessed to promote the green development. Specifically, ecological capacity, environmental capacity, and biological capacity are the overall requirement, foundation, and acting point, respectively. Through scientific and precise control, the capacity, quality, and efficiency of economic development in this region can be improved. Regulating the capacity of key environmental indicator species and repairing species in the farm area will effectively protect and restore the environment. Environmental protection should be combined with resource conservation, high-efficiency production, and recreational fishery to achieve ecological priority, land–sea coordination, and linkage of three kinds of industrial models. The modernization and sustainable development of the Yellow River Delta can be realized through scientific planning and precise management. In the coastal city Dongying, the recent capacity and developmental trend can be clarified through water quality monitoring, wetland remote sensing, and socio-economic statistics. Ecological tourism should be developed and port advantages should be taken to promote green development in the region while maintaining ecological and environmental superiority.

4.3 Monitoring and restoration

Ecosystem monitoring in the Yellow River Delta provides the reference for evaluating and predicting the impact of human activities on the ecosystem and serves as a basis for policy-making such as the rational use of natural resources and the environmental improvement in the region^[20–22]. The Yellow River Delta is an alluvial plain formed by the accumulation of sediments in the Yellow River, which is the transition zone from ocean to land. Natural evolution processes such as river swing, coastal erosion, estuary sedimentation, vegetation succession, and soil development are typical and unique in this region, making it an ideal area for the monitoring and research of environment^[23]. Currently,

the multi-source data fusion, assimilation and data mining, and standardized modeling of the Yellow River Delta should be studied, which, combined with artificial intelligence and knowledge engineering, could monitor the water environment, industrial wastewater, carbon emissions, land resources, wetlands ecosystem, species and number of animals and plants, natural disasters, biological invasion, etc. in the delta. Modern scientific methods and intelligent management systems can be established to explore habitat changes, warn for environmental security, and repair contaminated areas and damaged vegetation, providing data support for the development of blue agriculture in the Yellow River Delta.

4.4 Blue agricultural germplasm industry

Blue agricultural germplasm industry involves the taxonomic research on the genetic resources of aquatic products, the establishment of libraries for conservation, and the formation of an integrated system for the research and management of marine genetic resources. The future germplasm industry in the Yellow River Delta should put emphasize on the basic research of protection and utilization of important germplasm resources such as *Eriocheir sinensis*, *Stichopus japonicus*, *L. japonicus*, and *Meretrix meretrix*. The biological basis of economic traits such as growth and disease and stress resistance should be studied. The problems in the protection and utilization of local germplasm resources, the assessment of germplasm, and the production of breeding materials should be solved. A molecular breeding platform suitable for the Yellow River Delta rich in biological resources and genetic polymorphism should be constructed to form an integrated system of breeding, reproduction, and commercialization.

4.5 Green breeding

It is necessary to develop green breeding technologies suitable for the Yellow River Delta. Attention should be attached to the nutritional requirements of important aquaculture species such as *E. sinensis*, *S. japonicus*, *L. japonicus*, and *M. meretrix*, and to improve the feed processing technology, safety, and efficiency. The breeding management, basic research of emerging diseases, development of bio-control technologies and new vaccines should be enhanced. The technologies of intensive breeding should be enhanced to realize the mechanization, automation, and intelligentization of breeding. The principles of green development should be followed, which emphasizes the integrity, coordination, and multi-participation in ecosystem management. The biological capacity of ecosystem should be assessed scientifically for the promotion of the integrated ecological breeding.

4.6 Intensive processing of products

It is the primary way to improve the resource utilization in the Yellow River Delta by establishing a complete industrial chain of primary, moderate, and intensive processing^[24].

However, intensive processing in the Yellow River Delta has poor automation and high energy and material consumption^[25]. With the development of blue agriculture, the use efficiency of resources should be enhanced^[26]. For example, the equipment and technologies for processing aquatic products should be developed based on enzyme engineering, fermentation engineering, and bioreactor engineering. The extraction and modification of proteins and sugars in aquatic products, green processing and allergen control of animal lipids, and intensive processing of chitosan should be developed to build an intact intensive processing system with high efficiency.

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