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Study on technical measures for wetland restoration —Taking the wetland restoration project of Luting Luan River estuary as an example

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Abstract: *In response to the primary ecological issues of declining ecological quality and reduced ecosystem service functions at the Luan River estuary wetland, we have adopted micro-terrain modification measures to achieve the restoration of wetlands from aquaculture. We have also employed vegetation restoration methods to improve the ecological environment of the estuary wetland and implemented hydrodynamic recovery measures to regulate the water dynamics of the wetland. This has comprehensively enhanced the ecological quality of the Luan River estuary wetland. It has improved the deterioration of water quality in surrounding waters, effectively protected the estuary ecosystem, and promoted sustainable development of resources and the economy. Moreover, in the long term, the formation of positive self-regulation and restoration capabilities through these restoration projects can provide a healthy ecological security guarantee for the sustained development of the marine economy.*

Keywords: *wetland restoration; environmental management; Luanhe Estuary Wetland*

1. Introduction

Wetlands are unique ecosystems formed by the interaction between water and land systems. Along with forests and marine ecosystems, they are known as one of the three most important ecosystems on Earth, often referred to as the "kidneys of the Earth." As dynamic productive ecosystems, wetlands play crucial roles such as flood control, maintaining biodiversity, and water conservation [1]. They are also significant carbon sinks, playing a vital role in the global carbon cycle. However, due to both natural and human impacts, wetland ecosystems are continuously changing. In particular, excessive exploitation of natural resources by humans has caused severe damage to wetland ecology, leading to issues such as water pollution, area reduction, and depletion of biological resources [2]. Therefore, wetland restoration is becoming increasingly important in ecological management. This article focuses on the Lueting Luan River Estuary Wetland Restoration Project in Tangshan City to study some commonly used technical measures for wetland restoration.

2. Overview of Lianhekou Wetland

2.1. Location of Luanhe Estuary Wetland

Luan River is the boundary river between Changli County and Leting County in Hebei Province. It is adjacent to Leting County in the south and Changli County in the north, and finally flows into the Bohai Sea.

The restoration area of this study was selected from the southern estuary wetland of the Luanhe River in Leting County.

2.2. Current situation of Luanhe Estuary Wetland

The tidal flats near the mouth of the Luan River have experienced significant shrinkage in their active surface area, leading to a decline in biodiversity and a noticeable reduction in tidal flat ecological resources. Large-scale reclamation activities not only occupy valuable coastal wetland resources but also severely damage the wetland habitat[3], fundamentally altering the natural attributes of the wetlands and almost completely losing their ecological service functions. The typical issues affecting the restoration area's ecological environment are analyzed as follows:

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2.2.1. The area of natural wetlands shrinks, the habitat function decreases, and the biodiversity decreases

After on-site investigation of the Luan River Estuary Wetland in Leting County, it was found that the area is facing human interference such as aquaculture, agricultural development, environmental pollution, and overfishing. These activities have become significant threats to the biodiversity of the wetland. As pointed out in the biodiversity assessment report of the Luan River Estuary Wetland in Hebei Province, these human disturbances have led to the degradation of the wetland environment and the loss of biological habitats. There are large areas of existing fish ponds and temporary structures within the Luan River Estuary Wetland, occupying extensive marine and coastal resources, disrupting the original estuarine coastal wetland habitat, and severely damaging the integrity of the estuarine marine ecosystem. At the same time, abandoned fish ponds have not been effectively restored, and construction waste, household garbage, and spoil are piled up randomly within the wetland, seriously affecting the ecological and living conditions of the wetland.[4]

2.2.2. Low connectivity of wetlands, decreased water purification capacity and reduced carbon sequestration and oxygen release function

The barriers of pond embankments lead to sedimentation in the water body, making it difficult for effective circulation. Coupled with the uncontrolled discharge of aquaculture effluent and the arbitrary accumulation of surface production and household waste, this results in a surge of suspended solids and nutrients such as nitrogen and phosphorus, further exacerbating the deterioration of water quality. Meanwhile, lagoons and estuarine wetlands occupied by ponds, due to the lack of mutual water exchange, experience reduced water exchange capacity, which in turn leads to a decline in water purification capabilities within the wetlands. In recent years, as natural coastal wetlands have continuously shrunk, the scope of aquaculture ponds has gradually expanded, reducing vegetation coverage and causing long-term disturbance to the wetland substrate. These factors collectively alter the microbial community structure in the wetlands, significantly diminishing the role of the biotic carbon pump and weakening the wetlands' carbon sequestration and oxygen release functions. Especially when aquaculture ponds are abandoned, the water circulation mechanism completely collapses, rendering the wetland functions virtually non-existent. [5]

3. Restoration objectives and principles of Luanhekou Wetland

(1) Follow the laws of nature, carry out ecosystem protection and restoration in line with the natural attributes of coastal zones, ensure the integrity and stability of ecosystems, maintain ecological security, coordinate land and sea, and enhance synergistic effects.

(2) Follow the principle of giving priority to conservation, protection and natural restoration, and realize the restoration of Marine ecological functions in accordance with the requirements of overall protection, systematic restoration and comprehensive management.

(3) Clean up abandoned aquaculture ponds around the project, restore wetland habitat and vegetation in key areas, improve the coastal environment, and solve the problems of ecological environment and economic development with systematic thinking.

(4) Adhere to the principle of adapting measures to local conditions and being practical. The restoration plan makes rational use of the topography, geology and meteorological conditions of the proposed restoration site, combines long and short distances, rationally divides the area, and saves the cost of restoration.

4. Restore the overall layout and measures of the design

Currently, the technical measures for wetland ecological restoration can be categorized into coastal wetland habitat restoration technology and coastal wetland biological resource restoration technology based on the intended restoration targets. Coastal wetland habitat restoration technology can be further divided into substrate restoration technology and hydrological restoration technology; while coastal wetland biological resource restoration technology can be divided into wetland vegetation restoration technology and other biological resource restoration technologies[6]. Considering the natural conditions and existing ecological issues in different areas of the Luan River estuary in Leting County, as well as the restoration objectives, this project primarily adopts hydrological restoration technology and wetland vegetation restoration technology, specifically: micro-terrain shaping, hydrodynamic recovery, and

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vegetation restoration.

4.1. Micro-terrain management

In response to the primary ecological issues at the Luan River Estuary Wetland, such as declining ecological quality and reduced ecosystem service functions, micro-terrain restoration measures have been implemented to convert aquaculture areas back into wetlands. Using earthwork techniques, the nearshore tidal flats have been reshaped to restore wetland ecology; the planting zones' elevations have also been adjusted to optimize the seawater inundation cycle, creating more suitable conditions for various vegetation types and accelerating the natural succession process of salt-tolerant plants within the project area. In the design of micro-terrain restoration, appropriate habitats have been considered to support bird conservation and animal survival.

4.1.1. Ecological slope protection

The coastal side of the existing earthen embankment should be appropriately organized and preserved, with the slope gradient adjusted and modified to ensure that the earthwork for terrain improvement is balanced locally as much as possible. The outer side of the slope should be treated with geotextiles for filtration, and protective structures for both the face and base should be installed to effectively resist wave and water erosion. To ensure the ecological effects of wetland restoration, the face and base should preferably use natural and eco-friendly materials. Therefore, in this project, the face and base can adopt a vegetated cage stone structure or a natural stone structure. The vegetated cage stone face structure, due to its overall load-bearing capacity, can use smaller stones, resulting in less engineering work, lower costs, and easier construction. Thus, the vegetated cage stone face and base are selected for protection to prevent wave and water erosion, ensuring the stability of the slope and the toe of the embankment.

4.1.2. Beach surface construction

Under the existing topographical conditions, engineers should fully utilize water dynamics to restore the embankment, remove accumulated spoil, and implement earthwork operations for shaping the high-tide beach position. These measures aim to minimize substrate disturbance and reduce overall construction volume. Adhering to the principle of minimal intervention, the design shall leverage existing terrain features to preserve the site's natural texture while creating a functional beach surface. Transitional zones must be established between vegetation, shallow water, and open water areas to enhance the ecological heterogeneity and habitat quality of wetland ecosystems. The designed slope gradients and elevation profiles of the beach surface should accommodate the temporal needs of diverse bird species, providing tailored habitats and foraging resources aligned with their specific migratory behaviors. For migratory birds in particular, the design priorities include comfortable roosting sites and abundant food supplies to support their seasonal stopover requirements.

4.1.2.1. Wetland restoration

The dredged soil from the breeding embankments and tidal channels is pushed into the breeding ponds and leveled to the designed elevation, followed by micro-terrain shaping to restore the tidal wetland. According to the "Luan River Estuary Flood Obstruction Issues Remediation Plan" and the conclusions of numerical simulation tests, the average elevation of the tidal flats in the western ecological restoration area is 1.0 m; the eastern side of the eastern tidal flat in the eastern ecological restoration area has an elevation of-0.15 m, while the western tidal flat has an elevation of 0.2 m. This data reflects the specific achievements of the Luan River Estuary remediation work, aiming to ensure smooth flood discharge in the river, in line with the guidelines set by the Hebei Provincial Water Resources Department for addressing key and difficult issues in water conservancy.

4.1.2.2. Construction of high tide beach habitat

To create suitable conditions for coastal vegetation growth, a continuous and extensive intertidal habitat unit is set up at a certain distance from the shore. This primarily involves dismantling existing crisscrossing aquaculture ponds and using the earth from tidal channels to reshape the surrounding terrain, adhering to the principle of local soil balance to minimize the introduction of external soil. The goal is to construct an undulating intertidal habitat, forming a large-scale salt marsh landscape with red seaweed and green reeds. The elevation on the seaward side is 0.5m, roughly consistent with the average high tide level, gradually increasing from sea to land. The elevation on the landward side is around 1.0m. The main technique for terrain shaping is rotary tillage, which involves rotating and breaking up the topsoil layer, 10-15cm deep, to loosen the surface soil, increase its roughness, enhance

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water retention capacity, and ensure vegetation growth.

4.1.2.3. Bird habitat safety needs

By constructing undulating tidal flats, the habitat layout of tidal flats is enhanced with water surface isolation, providing an isolation buffer zone. This not only increases the safety distance from human activity areas but also creates various habitat patterns for birds, such as water activity zones and offshore wetland tidal flats. Secondly, increasing and enriching the morphology of offshore tidal flats can effectively resist tidal erosion, while also providing better shelter for waterfowl. Additionally, a corresponding analysis has been conducted on the slope of tidal flat habitats. Studies show that the slope should not be too steep, ideally below 1:15, with special habitats requiring slopes between 1:50 and 1:100, and the water depth should preferably be 1—1.5m above the designed low water level.

4.2. Hydrodynamic recovery

To improve the regional hydrodynamic conditions and enhance the flood discharge capacity at the Luan River estuary, hydrodynamic restoration has been carried out on the west and south sides of the sandbar at the Luan River estuary, as well as on the south side of the Luan River estuary. The main contents include the removal of fish farming embankments and the cleaning of tidal channels. Implementing these measures to remove fish farming embankments and clean tidal channels can free up tidal channel passages, thereby enhancing hydrological connectivity and achieving effective restoration of regional hydrodynamics.

4.2.1. Removal of embankments for river aquaculture

The current crest elevation of the wetland aquaculture embankment is approximately 2.5m, and it is a soil embankment that severely disrupts the water exchange between the wetland and its surroundings. Moreover, the existing embankment is in a relatively poor condition, necessitating its renovation. Most of the embankment will be broken up and leveled to balance the earthwork within the wetland, maintaining its zoning and creating diverse habitat conditions. According to the "Luan River Estuary Flood Obstruction Remediation Plan" and the conclusions of numerical simulation tests, the Changli County People's Government has decided to clear and rectify the aquaculture facilities and other obstacles at the Luan River Estuary that obstruct flood flow. The ecological restoration area in the western zone will have the aquaculture embankment removed to 1.0m; in the eastern zone, the eastern side of the aquaculture embankment will be removed to-0.15m, and the western side to 0.2m.

4.2.2. Tidal ditch cleaning

To enhance the hydrodynamic conditions of the estuary and improve its ecological functions, tidal channel cleaning has been carried out on the southwest side of the sandbar at the mouth of the Luan River, ensuring smooth connectivity with the existing river channel. At the same time, tidal channel cleaning has also been conducted in the micro-terrain modification area south of the Luan River estuary. Adhering to the principle of minimal disturbance, the excavation volume is minimized based on the existing topography.

According to the "Luan River Estuary Flood Obstruction Outstanding Issues Rectification Work Plan" and the conclusions of numerical simulation tests, the width of the tidal channel in the western ecological restoration area is 30-50m, with a dredged bottom elevation of-1.0m and a total length of approximately 2787m, with an estimated excavation volume of 152,000 m^3 and a hydrodynamic recovery area of 18.7hm2; the width of the tidal channel in the eastern ecological restoration area is 40-90m, with a dredged bottom elevation of-0.5m and a total length of approximately 2313m, with an estimated excavation volume of 48,000 m^3 and a hydrodynamic recovery area of 6.9 hm^2. In total, the dredging excavation volume for the tidal channels is 200,000 m^3, and the hydrodynamic recovery length is 5.1 km. All excavated soil is fully utilized in the creation of micro-topography and beach surface construction, achieving local utilization of soil resources without external transportation. Based on the needs of beach surface construction, considering the particle size of the soil and the stability of the designed beach surface, the use of soil from the western and eastern restoration areas is coordinated to achieve soil balance.

4.3. Vegetation restoration

Based on the principle of prioritizing natural restoration with artificial management as a supplement, vegetation for salt marsh restoration is selected according to the local natural environment and in

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conjunction with wetland vegetation in surrounding areas. Native salt-tolerant plants are chosen for their salt tolerance. In terms of plant configuration, reeds, Suaeda, and other herbaceous plants, as well as tamarisk and other shrubs, are selected, complemented by wildflower combinations. This provides rich habitats for birds, benthic organisms, and others, effectively promoting the recovery of biodiversity.

4.3.1. Wetland vegetation selection

According to the "Investigation and Evaluation Report on the Wetland Resources and Environment of the Luan River Estuary," it was found that in the outer edge or along both banks of the Luan River estuary, as well as on the floodplains, there are clusters of Suaeda salsa and reeds growing on meadowy saline soils. These areas are typically low-lying with standing water, often moist or muddy, and have a high salt content, usually around 1%. Suaeda salsa and reeds form a dominant species combination, with a total coverage of 90%. Suaeda salsa has strong vitality and high density, easily forming a background layer, constituting the lower part of the community, with a coverage of 70%. Reeds, with their robust underground stems, invade these areas, either scattered or in clusters or patches, occupying the upper part of the community. Due to the high soil salinity, their growth is inhibited, making the plants shorter, about 20-80cm tall, with a coverage of 20%. The community has a simple species composition, including not only the dominant species but also Suaeda salsa and Spartina alterniflora as companions.

4.3.2. Determination of vegetation planting elevation

The threshold of the growth environment of reeds, alkali grass and tamarisk in the region and its surrounding areas was analyzed. According to the measured tidal level curve, the suitable flooding time of reeds and alkali grass was guaranteed, and the elevation of the beach surface in the planting area was determined.

5. Economic and social impact assessment of the project study

The Lueting Luan River Estuary Wetland Ecological Protection and Restoration Project in Tangshan City, as part of the city's marine ecological protection and restoration project, aims to further optimize the marine ecosystem structure through measures such as returning farmland to tidal flats, restoring tidal flats, and rehabilitating salt marsh vegetation. This will enhance the quality of the marine environment, increase the carbon sequestration capacity of ecosystems, thereby promoting coordinated social and natural development in coastal areas and ensuring the healthy economic growth of the region.

5.1. Ecological benefits

This project can effectively restore the damaged marine ecosystem at the river mouth, improving the ecological environment of the estuarine waters. It reduces the degree of water quality deterioration in surrounding seas, effectively protecting the ecology of the river mouth and promoting sustainable development of resources and the economy. Moreover, in the long term, the implementation of restoration projects will foster positive self-regulation and self-repair capabilities, building a solid ecological safety barrier for the steady progress of the marine economy.

5.2. Social benefits

This project holds significant potential to enhance the regional environment, production capacity, and living standards, while elevating public approval of government service delivery. By fostering a positive social environment and orderly community development, it contributes to mitigating social risks and instability factors. These outcomes reflect the government's people-centered governance philosophy and its dedication to building social harmony. The initiative strengthens social stability and generates substantial positive societal impacts through: 1) Environmental and livelihood improvements that directly benefit local populations; 2) Strengthened public trust in governance systems through effective service provision; 3) Proactive social risk management that maintains community equilibrium; and 4) A holistic approach to sustainable development that aligns with national strategies for inclusive progress. Such integrated benefits demonstrate the project's alignment with contemporary governance objectives focused on balanced socio-economic advancement and public welfare enhancement.

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5.3. Economic benefits

The implementation of this project has effectively protected the ecology and resources of the Luan River estuary and its surrounding waters. It can mitigate economic losses caused by ecological damage and environmental pollution in the estuary wetlands and waters, offering direct economic benefits. The significant improvement in the estuary's ecological environment not only provides strong support for the protection of marine resources and biodiversity but also promotes long-term stability and prosperity of the local environment. Its role in driving sustainable economic development is self-evident.

6. Conclusion

In the Lueting Luan River Estuary Wetland Restoration Project in Tangshan City, micro-terrain modification measures, hydrodynamic restoration measures, and vegetation restoration measures were primarily adopted. In future wetland restoration design plans, base soil remediation techniques and other biological resource restoration technologies (such as microbial remediation measures and bivalve restoration measures) can be added, with more suitable methods and means selected based on specific project conditions. Given that each wetland has unique natural environments and ecological issues, ecological restoration work must follow the principle of adapting to local conditions, tailoring ecological restoration plans according to local natural conditions and construction technical requirements.

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