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Ecological Restoration of Coastal Wetlands Under Global Climate Change: A Case Study of Tianjin

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Abstract. The coastal zones of Tianjin, China, harbored vital ecosystems, including salt marshes and wetlands, which provided essential ecological services such as water purification, carbon sequestration, flood mitigation, and biodiversity conservation. However, increasing global climate change impacts, along with intensive human activities like land reclamation and industrial development, led to significant degradation of these ecosystems. This paper presented a detailed analysis of the "Retreat Ponds, Restore Wetlands" project in Qilihai Wetland, focusing on ecological interventions such as channel dredging, vegetation recovery, and habitat improvement. These efforts aimed to rehabilitate the degraded wetland, and their effectiveness was assessed in terms of ecological recovery, water quality improvement, and biodiversity enhancement, particularly in the return of migratory bird species and the regeneration of key plant species like reeds. Additionally, the study explored the resilience of the restored ecosystem in the face of rising sea levels, increasing soil salinity, and changes in hydrological cycles. The findings emphasized the limitations of traditional restoration approaches and highlighted the need for adaptive, innovative methods that integrate modern technologies, such as ecological monitoring and big data analysis, to ensure long-term ecosystem sustainability. The research also underscored the importance of interdisciplinary collaboration in restoration efforts, combining ecological science, climate adaptation strategies, policy reform, and public engagement to enhance the resilience of coastal ecosystems under future climate uncertainties.

Keywords: Wetland Restoration, Biodiversity, Tianjin, Qilihai Wetland.

1. Introduction

In recent years, global climate has undergone significant changes due to the impact of human activities. The increasing frequency of extreme weather events and natural disasters has had a profound effect on human life and posed unprecedented challenges to global ecosystems. Coastal zones, as ecological regions at the interface of land and sea, play a critical role in the global ecosystem. These zones encompass a range of ecosystems, including wetlands, salt marshes, mangroves, and coral reefs, which are characterized by complex dynamic balances. These ecosystems not only provide habitats for biodiversity but also play crucial roles in filtering pollutants, mitigating floods, and regulating carbon sequestration.

Tianjin, a key port city in the Bohai region, represents a typical sample of the Bohai coastal ecosystem, with salt marshes and wetlands constituting the largest portion. Due to the combined effects of human activities and climate change, these ecosystems have suffered severe degradation over time [1]. Since the early 20th century, as industrialization and urbanization accelerated, the growing issue of ecological degradation drove the development of ecological studies. From the 1970s onward, research on the protection and restoration of coastal ecosystems expanded globally. Howard et al. provided a theoretical foundation for understanding coastal ecosystem functions [2], and Eugene et al. laid the groundwork for ecological restoration. In China, ecologists such as Zhang et al. began investigating wetland restoration in the Yellow River Delta and the Yangtze River Estuary during the 1980s. By the early 1990s, Chen et al. conducted further research on wetland restoration in the Yangtze River Delta, proposing methods to restore natural hydrological processes, reduce human intervention, and use land sustainably [3]. This research provided scientific guidance for wetland restoration projects in China and achieved significant results in practice.

Entering the 21st century, global climate change has further accelerated the degradation of coastal ecosystems, making this a focal issue in international ecological restoration efforts. Carl Folke introduced the concept of ecosystem resilience in 2004, highlighting the ability of ecosystems to recover after disturbances [4]. In 2007, Robert et al. [5] proposed systematic ecological restoration measures to mitigate the threats posed by rising sea levels, such as restoring natural barriers like mangroves and wetlands. In Tianjin, Liu Changming's 2006 restoration plans for saline-alkali lands combined vegetation restoration with hydrological regulation [6], significantly improving the ecological conditions of the Binhai New Area.

However, despite the progress made, there remain limitations. Research has focused mainly on short-term restoration effects, with insufficient long-term data on carbon sequestration and ecosystem resilience. In the face of rapid climate change, restoration technologies and practices have yet to fully integrate, and adaptive research is still lacking. This paper examined the coastal ecosystems of Tianjin’s Binhai New Area, exploring how advanced scientific theories and restoration techniques can better protect coastal ecosystems under global climate change, providing insights applicable to similar regions worldwide.

2. Issues with the Tianjin Binhai Wetland Ecosystem

2.1. Current Status of the Tianjin Binhai Wetland

Tianjin is located in the eastern part of the North China Plain, adjacent to the Bohai Sea. The coastal region hosts a variety of ecosystems, among which wetlands cover the largest area and are the most widely distributed. The total area of Tianjin’s Binhai wetlands exceeds 340 square kilometers and consists of salt marshes, freshwater wetlands, and artificial wetlands. This area includes several important wetland reserves, such as Qilihai and Beidagang, which perform key ecological functions. Known as the "Kidneys of the Earth," coastal wetlands play crucial roles in regulating regional climate, flood prevention, water purification, and biodiversity conservation [7]. Key vegetation species like reeds (Phragmites australis) and seepweed (Suaeda salsa) in these wetlands not only purify water and sequester carbon efficiently but also provide habitats for wildlife, particularly migratory birds. Tianjin’s Binhai wetlands are vital stopovers along the East Asia-Australasian Flyway, supporting a wide range of bird species, including several endangered ones. However, due to climate change and extensive human activities, these wetlands have suffered severe ecological degradation.

2.2. Wetland Degradation and Ecological Issues

In recent years, as development in the coastal region has expanded, the Binhai wetlands have faced several critical issues, including:

(1) Wetland Shrinkage: Rapid urbanization and industrial development, especially large-scale land reclamation projects, have significantly reduced wetland areas [8].

(2) Water Resource Scarcity: Tianjin faces chronic water shortages, with water resources per capita far below the national average [9]. The region’s rivers are mostly seasonal, and pollution has worsened due to insufficient freshwater inflows.

(3) Biodiversity Decline: The degradation of wetlands has severely impacted native plant and animal species, with habitats shrinking and wildlife populations declining [10].

(4) Frequent Red Tides: Industrial wastewater and nutrient-rich effluents have exacerbated eutrophication in coastal waters, leading to more frequent occurrences of red tides [11].

These problems highlight the urgent need for restoration and sustainable management strategies to address the ongoing degradation of Tianjin’s Binhai wetland ecosystems.

3. Restoration of Tianjin's Binhai Wetland—A Case Study of Qilihai Wetland

The Qilihai Wetland is located in the southwestern part of Ninghe County, Tianjin, with an area of approximately 344 square kilometers. It is a critical ecological zone composed of mudflats and irregular semi-diurnal tides, typical of the Bohai coastal environment. The over-exploitation of the wetland, including pond farming and water overuse, was one of the main reasons for its severe ecological degradation. To address this, the "Retreat Ponds, Restore Wetlands" initiative became a crucial strategy for improving the ecological health of the Qilihai Wetland.

To halt the degradation of the Qilihai Wetland, the core area of the wetland was closed for restoration in 2017, with all human access prohibited (except for approved scientific research activities). Key restoration efforts focused on ecological water replenishment, channel dredging, vegetation recovery, and habitat improvement (as shown in Table 1).

Table 1. Specific Measures of the "Retreat Ponds, Restore Wetlands" Restoration Project for Qilihai Wetland

Category	Construction Project	Specific Measures
Channel Dredging	Ecological Water Replenishment	Five water routes planned, with eight engineering projects to achieve an annual replenishment of 80 million cubic meters. By May 2020, 12.5 million cubic meters had been replenished, expanding the wetland by 10 square kilometers
	Ring Canal	Excavated and dredged 21.8 kilometers of ring canals around the core areas, serving as water supply channels and natural barriers to prevent unauthorized access.
	Main Canal	7.7 kilometers of main canal laid in the West Sea core area and 7.6 kilometers in the East Sea to connect key water channels.
	Branch Canal	19 branch canals, totaling 14.8 kilometers, were excavated, spaced 200 meters apart in the southeastern area of the East Sea.
Vegetation Recovery	Aquatic Planting	Planted aquatic plants in shallow areas (0.2 to 0.5 meters deep) across 1.06 square kilometers in key regions.
	Reed Rejuvenation	Replanted 8 square kilometers of damaged reed fields in severely degraded areas.
Habitat Improvement	New Projects	Built 18 new habitat islands (15 in the West Sea and 3 in the East Sea).
	Renovation Projects	Renovated two habitat islands, creating smaller islands and shallow beaches for improved bird habitats.

Cadier et al. proposed that indicators of wetland restoration success include a range of comprehensive data, such as water transparency and biodiversity [12]. Based on this, the restoration results of the Qilihai Wetland can be evaluated using monitoring data. According to the monitoring data from 2020 [13], the water quality had significantly improved compared to 2017, showing positive trends in transparency, pH, dissolved oxygen, CODMn, and total nitrogen. Although total phosphorus levels increased, they remained below historical peaks. Levels of mercury, arsenic, lead, copper, and organic pollutants in the core area of the wetland all showed varying degrees of reduction, with only zinc levels slightly rising. The organic carbon content in sediments at all monitoring stations met the Class

I standards of GB 18668-2002, and the heavy metal indicators complied with the screening values of GB 15618-2018. From 2017 to 2019, the average density of phytoplankton in the core area increased during the flood season. Between 2017 and 2020, the diversity index of zooplankton in the core water area fluctuated but steadily rose, reaching its highest recorded value in 2020. Higher diversity index values indicate better water quality, suggesting that the ecological conditions of the monitored water areas are generally improving. Although the number of plant species remained relatively stable during the monitoring period, the vegetation coverage in the core area increased by 33.7%, and wild vegetation showed effective recovery. The number and diversity of bird species also significantly increased, indicating improvements in the overall ecological status of the habitat [14].

However, the recovery cycle for biological communities is long. It typically takes about five years to reach an initial stage of stability, while full recovery may require 10 to 50 years [15], necessitating ongoing monitoring and assessment.

Overall, the current environmental restoration measures have effectively promoted the functional and structural recovery of the wetland ecosystem, and the "Retreat Ponds, Restore Wetlands" initiative has proven to be highly effective [16]. Despite the positive progress made during this project's early stages, the restoration techniques employed are somewhat traditional and may not adequately address the challenges posed by current climate change impacts. The rising sea level is likely to expand the intertidal zone, and changes in seawater composition may affect soil quality, particularly its saline-alkali content, thereby impacting the plant communities within the habitat. Current vegetation restoration efforts primarily focus on supporting aquatic plants like reeds, while overlooking the adaptive capacity of plants and their ecological benefits in response to increased soil salinity. The invasion of Spartina alterniflora has also increased pressure on reed survival. Research by Wang et al. showed that the competition between Spartina alterniflora and other plants is closely related to abiotic factors on mudflats [17], with Spartina alterniflora having a competitive advantage over reeds in high-salinity and high-flooding environments, while reeds perform better in low-salinity, low-flooding conditions. Therefore, vegetation restoration plans must be continuously refined to account for the impacts of climate change. The innovative and effective approach of creating habitat islands in the habitat improvement project is worth further research and promotion. It is advisable to combine these efforts with emerging monitoring and restoration technologies to explore adaptive pathways in response to climate change.

4. Conclusion

The restoration efforts in Tianjin's Binhai wetlands have achieved certain success in addressing the impacts of global climate change and human activities. Through projects such as “Retreat Ponds, Restore Wetlands,” ecological water replenishment, vegetation recovery, and habitat improvement, the water quality in Qilihai Wetland has significantly improved, and the plant communities have gradually recovered. The biodiversity and habitat conditions of the wetlands have also shown marked improvements, with increases in both the number and diversity of bird species. These measures have laid a solid foundation for the recovery of the wetland's ecological functions, enhancing its ability to mitigate floods, purify water, and sequester carbon.

However, the intensification of global climate change presents more complex challenges for wetland ecosystems. Rising sea levels, temperature changes, and altered precipitation patterns will have profound impacts on the hydrology, soil, and biodiversity of wetlands. While the current restoration methods have yielded short-term results, their capacity to address future climate impacts is still limited, particularly in terms of long-term stability and adaptability.

Through studying the restoration experiences in Tianjin, broader lessons can be drawn for coastal ecosystem restoration. Restoration efforts must consider the uncertainties posed by global climate change, with a focus on enhancing ecosystem resilience and adaptability in the face of future extreme climate events. The restoration practices in Tianjin's Binhai wetlands provide valuable reference points and new perspectives for other coastal areas facing similar challenges around the world. Based on the above conclusions, there are still many areas in need of improvement in future restoration efforts. Current research and restoration methods are insufficient to keep up with the rapid progression of climate change. Therefore, strengthening research on climate change adaptation will be a priority in the future. The promotion of cutting-edge ecological restoration concepts and technologies, along with interdisciplinary collaboration, will bring new perspectives and development opportunities to this field. For example, combining ecological monitoring systems with big data analysis to conduct long-term monitoring and evaluation can help adjust restoration strategies in a timely manner, ensuring the efficiency and adaptability of restoration work.

Ecological restoration is a challenge faced by all of humanity, and it depends not only on scientific and technological advancements but also on policy support and public engagement. In the future, wetland protection policies should be further promoted, relevant laws and regulations should be improved, and public awareness and action in wetland ecosystem protection should be enhanced. Only in this way can we effectively promote the sustainable development of ecological restoration efforts.

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