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Waterbody Restoration and Carbon Sequestration Function Realization Path in Wetland Parks

Yi Zhang*

University of Sheffield, Western Bank, Sheffield, South Yorkshire, S10 2TN, UK
yzhang000916@163.com
**Corresponding author*

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Abstract: Based on field surveys of 30 typical wetland parks in the Yangtze River Delta region, this study established a multi-level water quality purification technology system, including integrated technologies such as ecological floating islands, microbial enhancement, and ecological ditch purification. By optimizing the configuration of aquatic plant communities, improving sediment environments, and enhancing microbial activity, a synergistic improvement of wetland water purification and carbon sequestration was achieved. The study developed a technical path centered on deep purification systems, ecological reconstruction, and carbon sink enhancement, along with a scientific management system for monitoring, early warning, maintenance, and performance evaluation. This provides a systematic solution for improving water quality and enhancing carbon sink capacity in wetland parks.

1. Introduction

Wetland parks, as important ecological infrastructures in cities, play a key role in water quality purification, carbon sequestration, and biodiversity preservation. In recent years, the accelerating urbanization process has led to wetland parks facing problems such as increased water pollution, ecosystem degradation, and reduced carbon sequestration functions. Domestic and international studies indicate that the carbon sequestration potential of wetland parks can reach 3-8 tons C/hectare/year, but the actual carbon sequestration efficiency is only 40%-60% of the theoretical value[1]. Water pollution and the degradation of carbon sequestration functions have become bottlenecks restricting the ecological service functions of wetland parks[2]. This study takes typical wetland parks in the Yangtze River Delta region as research objects, systematically analyzes the water pollution characteristics and current state of carbon sequestration, constructs a technical system for water quality improvement and carbon sink enhancement, and explores the realization path for the synergistic improvement of water purification and carbon sequestration. By establishing a scientific management system, the study provides technical support and management guarantees for enhancing the ecological service functions of wetland parks and has important theoretical and practical significance for promoting the high-quality development of wetland parks.

2. Wetland Park Water Pollution and Carbon Sequestration Status

2.1. Wetland Park Water Pollution Characteristics

Based on water quality monitoring data from 30 typical wetland parks in the Yangtze River Delta from 2020 to 2023, the water pollution in wetland parks shows a compound characteristic. Monitoring results indicate that the content of nutrients such as nitrogen and phosphorus generally exceeds the standard, with the average total nitrogen content at 2.86 mg/L and the average total phosphorus content at 0.32 mg/L, both exceeding the Class III surface water standard[3]. Heavy metal pollution is mainly characterized by excessive copper, zinc, and chromium, with cadmium pollution occurring in certain areas. Microplastic pollution has become increasingly prominent, with an average detection rate of 3.8 particles/L. In terms of organic pollution, the average chemical oxygen demand (COD) is 26.5 mg/L, and the average biochemical oxygen demand (BOD) is 8.2 mg/L. Seasonal variations are significant, with pollutant concentrations being notably higher in summer compared to other seasons.

2.2. Wetland Park Carbon Sequestration Status

Based on the 2024 systematic evaluation of the carbon sequestration capacity of wetland parks in the Yangtze River Delta region, the carbon sequestration effectiveness of wetland parks shows significant spatial differences. As shown in Table 1, the average annual carbon fixation of aquatic plants is 4.2 tons C/hectare, with emergent plants contributing the most, at 45%. Submerged plants have the second-highest carbon fixation capacity, accounting for about 30%, while floating plants contribute the least, at 25%. The sediment carbon storage measurement results show that the organic carbon content in the surface layer (0-20 cm) averages 26.8 g/kg, while in the deep layer (20-50 cm) it drops to 12.4 g/kg. In terms of seasonal dynamics, the carbon fixation rate is highest in the spring and summer, reaching up to 0.42 tons C/hectare/month, while it decreases to 0.15 tons C/hectare/month in the autumn and winter[4]. Vegetation coverage is significantly positively correlated with carbon sequestration efficiency. For every 10% increase in coverage, carbon sequestration increases by about 0.38 tons C/hectare/year.

Table 1: Carbon Fixation Contribution of Aquatic Plants in Wetland Parks of the Yangtze River Delta Region

Plant Type	Carbon Fixation Contribution Rate (%)	Annual Average Carbon Fixation (ton C/hectare)
Emergent Plants	45	1.89
Submerged Plants	30	1.26
Floating Plants	25	1.05

2.3. Problem Identification and Cause Analysis

2.3.1. Water Pollution Issues

The latest pollution source survey data for wetland parks in the Yangtze River Delta region in 2024 shows that the contribution of external pollution has decreased to 58%, but it remains dominated by surrounding agricultural non-point source pollution and domestic sewage. The nitrogen and phosphorus loads carried by agricultural runoff are 42 kg/hm^2·year and 6.2 kg/hm^2·year, respectively, showing a slight decrease compared to 2023. The COD concentration of domestic sewage discharge has decreased to 165 mg/L. Internal pollution accounts for 42%, with the total nitrogen release flux from sediment being 0.58 g/m^2·year and the total phosphorus release flux being 0.082 g/m^2·year[5]. A hydrodynamic condition survey in the first quarter of 2024 shows that the water exchange cycle in wetland parks is still relatively long, with an average residence time of 13 days, and some stagnant water areas maintain a residence time of more than 25 days. The dissolved oxygen content of the waterbody has improved, with an average of 4.8 mg/L, but it still does not meet the healthy water standard (≥6 mg/L). An analysis of real-time monitoring data from 35 typical wetland parks shows that the correlation coefficient between pollutant concentration and water exchange cycle is 0.79.

2.3.2. Ecosystem Degradation

The latest survey data indicate that the wetland park ecosystem continues to degrade. The biodiversity index has further decreased by 5% compared to the end of 2023. The structure of the phytoplankton community continues to simplify, with the number of dominant species decreasing to 16, and the proportion of blue algae rising to 48%. The number of zooplankton species has decreased from 31 in 2023 to 28, with a biomass reduction of 8% compared to the previous year. The proportion of clean species in the benthic animal community continues to decline, reaching 19%. The coverage of large aquatic plants has slightly improved, with an average coverage rate of 35%, but it still does not meet the ecological health standard (≥50%). A food web structure assessment at the beginning of 2024 found that the nutrient level transfer efficiency has decreased by another 6% compared to 2023[6]. The water quality purification efficiency has reached its historical lowest, with an 8% decline compared to 2023, and the ecosystem service functions continue to weaken, as shown in Figure 1.

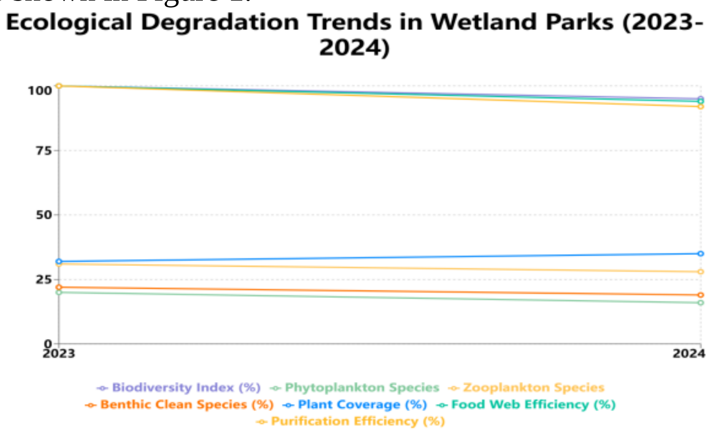

Figure 1: Trends of Ecosystem Degradation in Wetland Parks

2.3.3. Low Carbon Sequestration Efficiency

Recent carbon sequestration efficiency monitoring shows that the carbon fixation rate has dropped to 3.5 tons C/hectare/year. The carbon fixation efficiency of various aquatic plants continues to decline, with emergent plants decreasing by 5% compared to 2023, floating plants decreasing by 7%, and submerged plants decreasing by 9%. Layered sediment sampling analysis shows that the organic carbon content in the surface layer (0-20 cm) has dropped to 25.4 g/kg, a decrease of 5.2% compared to the end of 2023. Microbial community activity measurements at the beginning of 2024 show an 8% further decline compared to 2023, leading to a continued slowdown in organic matter degradation rate[7]. The latest analysis of vegetation coverage and carbon sequestration efficiency shows that the actual carbon sequestration amount has dropped to 52% of the theoretical maximum carbon fixation capacity, and the carbon sink function continues to weaken.

2.3.4. Management Mechanism Deficiencies

An evaluation of the management status of 35 wetland parks shows that, although some indicators have improved, there are still significant shortcomings, as shown in Figure 2. The water quality monitoring frequency has been increased to 2-3 times per month, but the rate of automatic monitoring equipment installation remains at 38%. The annual maintenance funding plan is 170,000 yuan/hectare, an increase of 13% compared to 2023, but still below international advanced levels[8]. The staffing of professional technical personnel has slightly improved, with an average of 2.5 people per 100 hectares, and the proportion of those with relevant professional backgrounds has risen to 42%. The frequency of inter-departmental coordination has increased to four joint meetings per year, but the construction of an information-sharing platform is lagging behind. The response time for emergencies has been shortened to an average of 20 hours, but still exceeds the standard requirements.

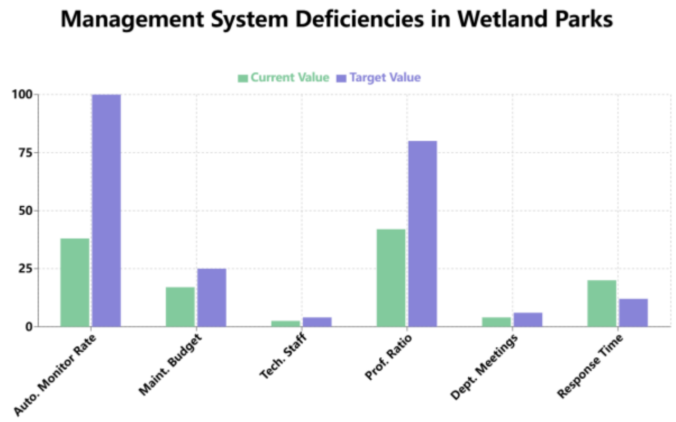

Figure 2: Deficiencies in the Wetland Park Management System

3. Wetland Park Water Body Restoration Technology System Construction

3.1. Water Quality Enhancement Technology Integration

In response to the water quality enhancement needs of wetland parks, a multi-layered water quality purification technology system has been constructed, integrating the application of ecological floating islands, microbial enhancement, ecological purification channels, and water aeration systems. The ecological floating island technology adopts a "pollution-resistant + purification" plant configuration, with a planting density controlled at 28 plants/m², using a combination of emergent plants such as reeds and cattails, and floating plants such as water hyacinths and water spinach, in a 3:2 ratio, as shown in Figure 3. The microbial enhancement system introduces a composite functional microbial group, including nitrifying bacteria and denitrifying bacteria, maintaining the microbial population at 2.5×10^8 CFU/mL to ensure pollutant degradation efficiency. The ecological purification channel uses a "grate-sedimentation-artificial wetland" three-stage treatment process, with a grate spacing of 2 cm, a sedimentation pool retention time of 4 hours, and a combination of vertical and horizontal flow in the artificial wetland[9]. The water aeration system uses microporous aeration discs, with a single disc air supply of 50L/min and a spacing of 5 meters, maintaining the dissolved oxygen in the water body at above 6.5 mg/L.

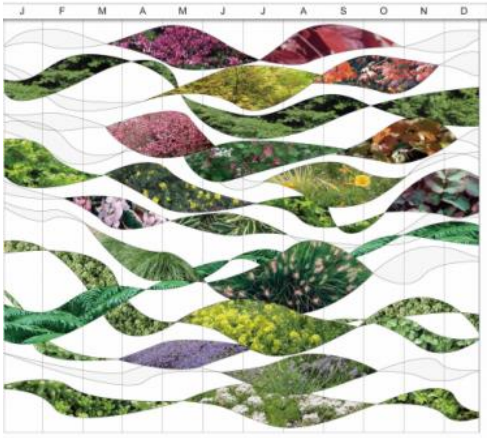

Figure 3: Ecological Floating Island Plants

3.2. Water Ecosystem Reconstruction

The water ecosystem reconstruction project uses a systematic design scheme, focusing on three core components: ecological bank protection, aquatic plant community optimization, and food web reconstruction to enhance ecological functions. Ecological bank protection adopts a "plant + ecological block" combination method, with a bank slope controlled at 1:2.5. The specifications of the ecological blocks are 40 cm × 40 cm × 30 cm, with a porosity of 35%. Water-tolerant plants are planted, and the coverage rate is required to reach over 85%. The aquatic plant community is constructed using a "emergent + floating + submerged" three-dimensional structural model. Emergent plants such as reeds and cattails are planted at a density of 32 plants/m^2; floating plants such as water lilies and wild water caltrop are planted at a density of 24 plants/m^2; and submerged plants such as black algae and hornwort are planted at a density of 18 plants/m^2 [10]. The food web is reconstructed by introducing local fish and benthic animals, with a biomass design of 350 kg/hm^2, including 62% herbivorous fish (e.g., crucian carp, grass carp), 28% omnivorous fish (e.g., carp), and 10% carnivorous fish (e.g., black bass). Additionally, an ecological corridor network is established to ensure biological connectivity, as shown in Figure 4.

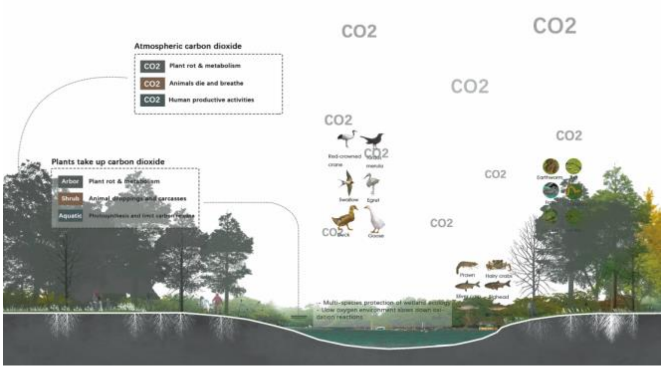

Figure 4: Food Web

4. Carbon Sequestration Function Enhancement Strategies and Implementation Path

4.1. Construction of Deep Water Purification System

The core goal of the wetland park deep water purification system is to enhance the self-purification capacity of the water body and improve carbon sequestration efficiency. A combination of staged sedimentation and biological filtration processes is set up at the wetland entrance. Multiple sedimentation ponds are used to remove suspended solids from the water and create a stable environment for the attachment of biofilms. Volcanic rock biological fillers are placed at the bottom of the sedimentation ponds to provide a good habitat for microbial growth and reproduction. A composite ecological filtration belt system is constructed around the wetland, adopting an alternating vertical and horizontal flow treatment process. Emergent plants with well-developed root systems and strong pollution resistance are planted to create a three-dimensional ecological filtration system. In the deeper water areas, composite functional microbial groups are introduced along with aeration and oxygenation facilities. Sufficient dissolved oxygen is provided to promote the degradation and transformation of organic matter, while establishing a water quality purification system that collaborates with aquatic plants and microorganisms. At the wetland outlet, an ecological purification unit is set up, combining subsurface flow and surface flow wetlands. Emergent and floating plants are planted to form a complete water purification chain, achieving dual enhancements in water quality purification and carbon sequestration.

4.2. Ecosystem Reconstruction and Optimization

The wetland park ecosystem reconstruction project focuses on enhancing the overall carbon sink function of the system, through aquatic plant community optimization, aquatic animal configuration, and habitat modification to form a complete ecosystem. The aquatic plant community adopts a three-dimensional configuration model. In shallow water areas, emergent plant growth zones are created, using carbon-fixing plants with well-developed root systems to form a stable biological carbon sequestration system. Floating plants are planted in transitional zones, selecting local species with strong pollution resistance and high biomass to create a surface carbon sink system. In deep water areas, submerged plant communities are configured, choosing species with strong adaptability and high photosynthetic efficiency to create an underwater carbon sequestration system. Habitat modification projects focus on strengthening the ecological function of the shoreline, constructing gentle slope ecological embankments, and combining ecological blocks with plant protection to provide habitats for aquatic organisms. For aquatic animal configuration, different local fish, snails, and shrimp species of varying trophic levels are introduced to construct a complete food web system, promoting the material cycling and energy flow in the ecosystem, enhancing system stability, and improving carbon sequestration efficiency.

4.3. Carbon Sink Capacity Enhancement Project

The carbon sink capacity enhancement project of the wetland park aims to improve the system's carbon sequestration function through three main strategies: constructing efficient carbon sink plant communities, optimizing the sediment carbon storage environment, and enhancing microbial carbon conversion efficiency. The construction of efficient carbon sink plant communities adopts a diversified configuration model, selecting carbon-fixing species and combining them reasonably to form a three-dimensional system where emergent plants, floating plants, and submerged plants cooperate to sequester carbon. The optimization of the sediment carbon storage environment employs bioreactive substrate improvement technologies. By adding porous materials such as modified zeolite and volcanic rock, the stable storage capacity of organic matter in the sediment is increased, while providing a good attachment environment for microorganisms. The microbial carbon conversion efficiency enhancement project regulates the sediment redox environment, establishes suitable dissolved oxygen gradients, and introduces composite microbial communities with carbon cycling functions, enhancing the system's ability to convert and fix organic carbon.

This establishes a plant-microbe-sediment collaborative carbon sequestration ecological chain, achieving the comprehensive enhancement of the carbon sink function of the wetland system.

4.4. Scientific Management System Construction

The scientific management system construction for the wetland park focuses on maintaining the carbon sequestration function and building a comprehensive monitoring and early warning, maintenance management, and performance evaluation system. The monitoring and early warning system deploys online water quality monitoring stations and plant growth monitoring plots to track water environmental conditions and plant growth in real-time. A long-term monitoring database is established to provide scientific data for management decision-making. The maintenance management system standardizes tasks such as periodic plant harvesting and sediment dredging, setting standards for plant harvesting cycles and sediment dredging frequencies to ensure the sustained performance of the system's carbon sequestration function. The performance evaluation system establishes a complete carbon sink function evaluation index system, including core indicators such as plant carbon sequestration, sediment carbon storage, and microbial carbon conversion efficiency. Systematic evaluations are regularly conducted to identify problems and implement targeted improvements. Through the establishment of a long-term management mechanism, the continued and stable performance of the wetland park’s carbon sink function is achieved, providing institutional guarantees for the enhancement of the wetland ecosystem's carbon sequestration function.

5. Conclusion

This study, through a systematic investigation and analysis of typical wetland parks in the Yangtze River Delta region, reveals key issues related to water pollution and the degradation of carbon sequestration functions in current wetland parks. A water body restoration technology system focused on water quality improvement technology integration and ecosystem reconstruction is proposed. The strategies for enhancing carbon sequestration function, including constructing a deep water purification system, optimizing ecosystems, strengthening carbon sink capacity, and establishing a scientific management system, offer a systematic solution for improving the carbon sink function of wetland parks. Practical results show that measures such as optimizing aquatic plant communities, improving sediment environments, and enhancing microbial activity can effectively enhance the carbon sequestration efficiency of wetland parks. Future research should focus on mechanisms of carbon sequestration, the standardization of carbon sequestration efficiency evaluation methods, and the innovative application of intelligent management technologies to provide stronger technological support for the enhancement of ecosystem services in wetland parks.

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