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Original Paper

Application Research of Fish-Plant Symbiosis Technology in a Urban Lake: A Case Study of the Environment Remediation Project with Machine Learning Application

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Abstract

This research examines the Jiefang Park Water Environment Remediation Project, a pioneering initiative in urban lake rehabilitation. The project is anchored in a fish-plant symbiosis system, which has significantly improved water quality, upgrading it from Category V to Category III, and in certain zones, achieving the commendable Category II. This enhancement is quantitatively marked by a notable reduction in nitrogen and phosphorus levels, and a marked increase in water transparency, with submerged plants covering over 70% of the lakebed.

A key innovation is the utilization of a machine learning model to predict chlorophyll-a concentration, a vital water quality metric. The model's accuracy is underscored by its R^2 values, ranging from 0.23 to 0.99, and RMSE values between 6.921 and 0.237, with the best performance at point 1. Additionally, comprehensive measurement data highlight the project's effectiveness. Water transparency significantly improved from baseline levels, as evidenced by increased dissolved oxygen levels at various sampling sites, indicative of restored ecological equilibrium in the lake. This study represents an exemplary fusion of ecological restoration and advanced data analytics, signifying a substantial advancement in urban lake restoration. It underscores the potential of combining synergistic ecological approaches with technological innovation to further sustainable urban environmental management.

Keywords

fish-plant symbiosis, water quality, food web construction, nitrogen, phosphorus

1. Introduction

To address the pervasive challenges in aquatic ecosystem restoration, our study introduces a novel approach leveraging the symbiosis between fish species and submerged plants. Unlike traditional methods that often exacerbate issues like rapid ecosafystem collapse and economic burdens due to high management costs, our methodology offers a sustainable, cost-effective solution. By integrating fish species that regulate aquatic plant populations naturally and submerged plants that enhance water quality, we establish a self-regulating ecosystem. This innovative approach not only mitigates the effects of external pollution but also promotes the long-term health and stability of aquatic environments, showcasing a significant advancement in the field. To address these challenges, a scientifically sound approach involving the cultivation of submerged plants and the introduction of fish species can be employed to restore the aquatic ecosystem. By reinstating the key components of producers, consumers, and decomposers within the ecosystem, the material cycling and energy flow in the water can be reinstated. Through the utilization of plant absorption and animal predation, the forms of nutrients in the water can be transformed, ultimately leading to a reduction in water pollutants, purification of water quality, and restoration of the aquatic ecosystem. This approach not only aims to mitigate the adverse effects of external pollution but also strives to establish a sustainable and self-regulating system that promotes the long-term health and stability of the aquatic environment. Our approach is particularly innovative due to its use of a machine learning model to predict and manage the interactions within this symbiotic system. By accurately predicting the impact of various species on water quality, our model allows for precise adjustments to the ecosystem, enhancing its resilience and sustainability. This integration of technology sets our work apart, offering a novel contribution to the methods of ecological restoration and management.

2. Materials and Methods

Identify suitable water bodies for the aquatic ecosystem restoration project based on factors such as pollution levels, ecological importance, and feasibility. Implement measures to intercept and reduce external pollution sources, such as constructing sedimentation ponds, wetlands, or artificial barriers to trap sediment and pollutants before they enter the water body.

Determine the appropriate design and construction plan for the aquatic ecosystem, taking into account factors such as water depth, substrate type, and hydrological conditions. Construct submerged habitats, including planting beds or structures, to support the growth of submerged plants and provide suitable habitats for aquatic organisms. Select native or suitable submerged plant species based on their ability to absorb nutrients and their ecological functions. Propagate the selected plant species in a nursery or obtain them from reliable sources. Plant the submerged vegetation in the designated areas of the water body, following appropriate spacing and planting techniques. Identify fish species that are compatible with the restored aquatic ecosystem and can contribute to its ecological balance.

Select fish species that are herbivorous or omnivorous to control the growth of aquatic plants while maintaining a balanced food web. Introduce the selected fish species into the water body, considering factors such as stocking density, acclimatization, and monitoring their impact on the ecosystem. Implement a monitoring program to assess the progress and effectiveness of the restoration project. Regularly monitor water quality parameters, including nutrient levels, dissolved oxygen, and turbidity, to evaluate the success of the restoration efforts. Conduct surveys to assess the abundance and diversity of submerged plants, fish species, and other aquatic organisms. Evaluate the overall ecological health and functionality of the restored aquatic ecosystem. Based on the monitoring and evaluation results, make necessary adjustments to the management strategies to optimize the restoration outcomes. Continuously assess and address any challenges or issues that arise during the operation and management of the restored aquatic ecosystem.

By following these materials and methods, it is possible to implement a scientifically informed and comprehensive approach to restore and maintain the ecological integrity of aquatic ecosystems, promoting their resilience and sustainability.

2.1 Study Area

The study area is located within Jiefang Park in the northwest corner of Hankou, Wuhan City. It has a catchment area of approximately 44.8 hectares and a total water surface area of about 10 hectares. Within the park, the lake area surrounding the park is approximately 4.69 hectares, with Lake No.1 covering an area of 0.55 hectares, Lake No.2 covering an area of approximately 0.22 hectares, and Lake No.3 covering an area of about 0.17 hectares. The interconnected canal between the lakes has a water area of approximately 0.58 hectares. The total water surface area within the project scope is approximately 6.20 hectares.

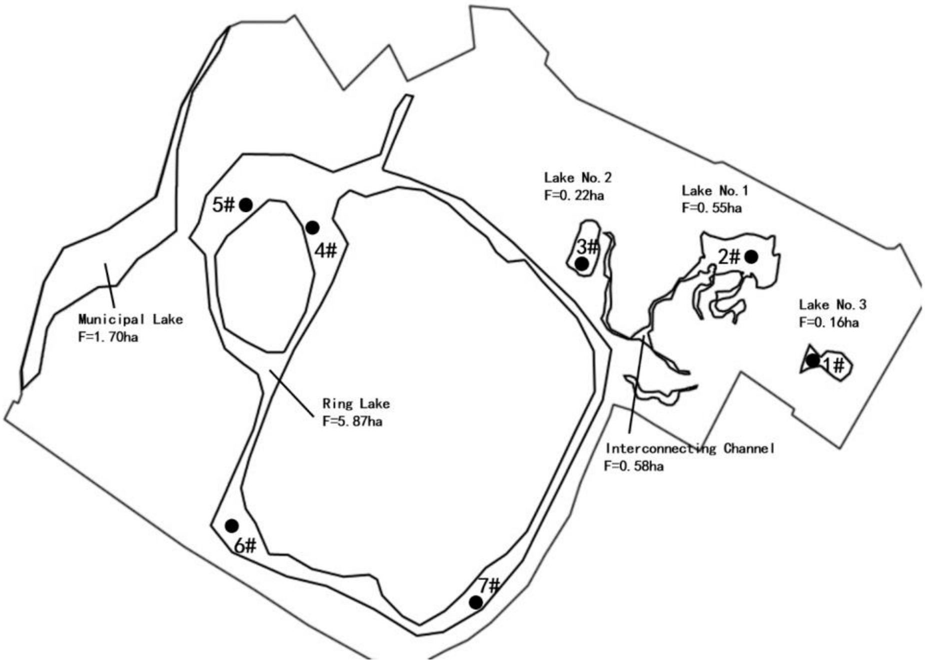


Figure 1. Jiefang Park Water Area Plan

2.2 Sampling Methods

2.2.1 Water Quality Sampling

This study outlines a water quality sampling plan for multiple sampling points using a multi-functional water sampler. The sampling will be conducted during June 2021 and at intervals of 1-2 months from March 2022 to January 2023. The aim is to collect water samples from seven designated sampling points (No.1 to No.7) for subsequent laboratory analysis. The samples will be stored in 50 mL centrifuge tubes, appropriately labeled with sampling time and weather conditions. This document provides a detailed description of the sampling methodology, including equipment, sampling procedures, sample preservation, and transportation to the laboratory. The collected data will contribute to the assessment of water quality in the study area.

2.2.2 Fish Community Sampling

On July 18, 2023, a fish community sampling was conducted at Sampling Point No.5 in Jiefang Park. The sampling methodology involved enclosure netting followed by seine netting with a mesh size of 5 cm along one side of the water bank. This approach was employed to capture and collect the organisms present within the designated sampling area.

During the sampling process, the eastern and western sides of Sampling Point No.5 were first blocked using an enclosure net. This step effectively confined the target area, allowing for a more focused sampling effort. Subsequently, a seine net with a 5 cm mesh size was deployed along one side of the water bank. The seine net was carefully maneuvered through the water, capturing a wide range of organisms inhabiting the sampling point.

All the collected organisms were then carefully examined, identified, and classified based on their taxonomic groups. Taxonomic keys or expert assistance were utilized to ensure accurate identification. The classification process involved assigning each organism to the appropriate species or higher taxonomic level.

Following the classification, the data collected from the sampling effort will be subjected to statistical analysis. This analysis will involve calculating various parameters to assess the fish community composition and abundance at Sampling Point No.5. Species richness, diversity indices, and other relevant metrics will be calculated to provide a comprehensive understanding of the sampled fish community.

The results obtained from this study will contribute to the existing knowledge of the fish community dynamics at Sampling Point No.5 in Jiefang Park. This information will be valuable for ecosystem management and conservation efforts, as it provides insights into the composition and structure of the fish populations in the studied aquatic environment.

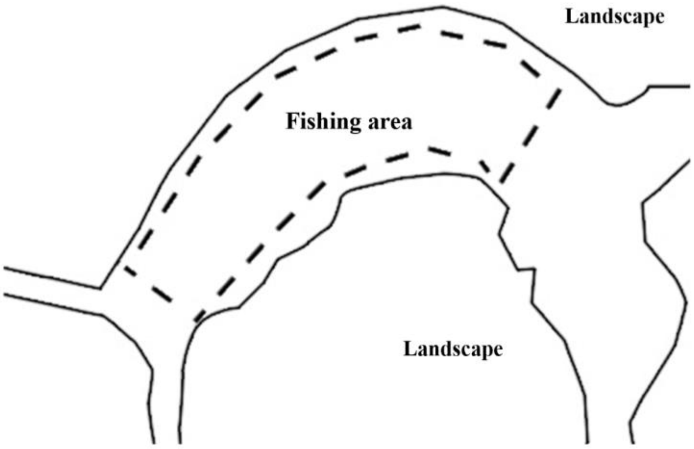


Figure 2. The Sampling Area of Sampling Point No.5 in Jiefang Park

2.3 Sample Processing

2.3.1 Water Quality Sample

After obtaining water quality samples, the samples were brought back to the laboratory for further analysis. Upon arrival, the samples were allowed to settle naturally for 30 minutes, during which time the non-settled upper portion was extracted for subsequent analysis according to the prescribed methodology.

To begin, a clean and sterile container, such as a glass or polyethylene bottle, was prepared for each sample, ensuring the absence of any residual contaminants. The size of the container was selected based on the required sample volume for analysis.

The water samples were carefully poured into the containers, and the containers were placed on a stable surface to allow for natural sedimentation for a period of 30 minutes. This step aimed to facilitate the settling of suspended solid particles to the bottom of the containers.

Following the sedimentation period, the upper portion of the water samples, which did not undergo settlement, was collected using a clean glass rod or plastic pipette. Care was taken to avoid disturbing or aspirating any solid matter that had settled at the bottom.

The collected upper portion of the water samples was then subjected to further analysis in accordance with the specified methodology. This involved the utilization of specific reagents, instruments, or equipment to measure various water quality parameters, such as pH, dissolved oxygen, turbidity, total suspended solids, or concentrations of specific pollutants.

2.3.2 Fish Community Samples

On-site identification, species-level classification, and measurement of length and weight for the collected fish specimens were conducted. The length was measured with an accuracy of 0.1 cm, and the weight was measured with an accuracy of 50 g. After the measurements were completed, live carnivorous fish were released back into their natural habitat whenever possible, while herbivorous fish and deceased individuals were subjected to harmless disposal methods.

2.4 Sample Testing

According to the reference GB3838-2002, the sample testing methods are based on various detection parameters and corresponding analysis techniques, as presented in Table 1. This standard, titled "Ambient Quality Standards," was issued by the Ministry of Environmental Protection of China. The table provides a comprehensive overview of the detection parameters and analysis methods specified in the standard.

Table 1. The Sample Testing Projects and Analysis Methods

Index	Parameter	Analysis Method	Method Source
1	pH Value	Glass Electrode Method	GB 6920-86
2	Water Transparency	Turbidity Meter Method	SL 87-1994
3	Water Temperature	Thermometer Method	GB 13195-91
4	Dissolved Oxygen	Electrochemical Probe Method	GB 11913-89
5	Chemical Oxygen Demand (COD)	Dichromate Method	GB 11914-89
6	Total Nitrogen	Ultraviolet Spectrophotometry	GB 11894-89
7	Total Phosphorus	Ammonium Molybdate Spectrophotometry	GB 11893-89
8	Biochemical Oxygen Demand (BOD5)	Dilution and Seeding Method	GB 7488-87
9	Suspended Solids (SS)	Gravimetric Method	GB 11901-89
10	Chlorophyll-a	Spectrophotometric Method	HJ 897-2017

2.5 Data Analysis

To describe the fish community diversity in Jiefang Park using the Shannon-Wiener diversity index (H), the following formula is used:

$$H = -\sum P_i * \ln P_i \tag{1}$$

Where P_i represents the proportion of the i-th fish species in the total number of individuals in the community. A higher Shannon index indicates greater uncertainty and a higher level of unknown factors in the community, thus indicating higher diversity.

By applying the Shannon-Wiener diversity index to the fish community in Jiefang Park, it becomes possible to assess and describe the extent of diversity present in the park's aquatic ecosystem. The resulting index value provides valuable insights into the complexity and richness of the fish community, highlighting the importance of preserving and managing the park's aquatic resources to maintain biodiversity and ecosystem health.

3. Results and Discussion

3.1 Water Quality Before Remediation

Before the remediation efforts, the overall water quality in Jiefang Park was poor, exhibiting several indicators of degradation. The key observations regarding the water quality were as follows:

Turbidity: The water was turbid, indicating a high concentration of suspended particles. This resulted in low transparency and reduced water clarity. The turbidity may have been caused by sediment runoff, organic matter, or other pollutants.

Aquatic Vegetation: The predominant aquatic vegetation consisted mainly of algae, indicating excessive nutrient levels in the water. The absence of submerged plants suggested poor water quality, as these plants play a crucial role in oxygen production and habitat provision for aquatic organisms.

Fish Composition: The fish population was dominated by small-sized filter-feeding species. This suggests a lack of suitable habitat and limited food sources for larger fish species. The imbalance in the fish community composition could be attributed to the poor water quality and limited availability of prey organisms.

The study conducted by Li et al. revealed that disturbances caused by benthic fish can lead to an increase in the concentrations of nutrients such as nitrogen and phosphorus in the water column, thereby enhancing the biomass of algae in the surrounding area. Overall, the water quality in Jiefang Park before remediation was compromised, characterized by turbidity, low transparency, an abundance of algae, and a fish community dominated by small filter-feeding species. These issues indicated an imbalance in the aquatic ecosystem and the need for remediation measures to improve water quality and restore a healthier and more diverse aquatic environment. Detailed water quality testing data is presented in Table 2.

Table 2. The Water Quality Testing Data for Jiefang Park

Parameters	1#	2#	3#	4#	5#	6#	7#	Class IV Standard (mg/L)
pH	6.72	6.73	6.28	7.04	6.99	7.13	6.97	6--9

Parameters	1#	2#	3#	4#	5#	6#	7#	Class IV Standard (mg/L)
(dimensionless)								
Transparency (m)	0.60	0.71	0.46	0.59	0.56	0.96	0.71	--
Water Temperature (℃)	23.2	23.4	23.3	23.1	23.2	23.5	23.7	--
Dissolved Oxygen (mg/L)	9.70	8.58	7.03	8.63	8.44	8.77	9.05	≥3
COD (mg/L)	7	7	4	9	5	10	5	≤30
Ammonia Nitrogen (mg/L)	0.319	0.237	0.778	0.227	0.283	0.218	0.222	≤1.5
Total Nitrogen (mg/L)	0.49	0.48	0.94	0.67	0.70	0.52	0.40	≤1.5
Total Phosphorus (mg/L)	0.11	0.11	0.12	0.14	0.12	0.07	0.12	≤0.1
BOD5 (mg/L)	1.8	1.9	1.2	2.3	1.3	2.8	1.2	≤6.0
Suspended Solids (mg/L)	14	12	27	15	11	13	18	--
Chlorophyll-a (ug/L)	4	12	6	19	15	6	10	--

The transposed table above presents the water quality testing data for Jiefang Park. Each row represents a specific parameter, and the columns denote the corresponding values for different sampling points. The last column indicates the Class IV standard values for the respective parameters.

3.2 Impact of the Fish-Plant Symbiosis System on Water Quality

The fish-plant symbiosis system has shown a significant improvement in water quality, as evidenced by the specific water quality improvement data presented in Table 3.

Table 3. Water Quality Monitoring Data for Jiefang Park after Remediation

Indicator (Average)	2022.3	2022.5	2022.6	2022.7	2022.9	2022.10	2023.1
pH (dimensionless)	6.78	7.96	7.89	7.82	6.94	7.97	8.18
Water Temperature (°C)	14.36	21.04	28.93	33.74	28.24	18.78	6.63
Dissolved Oxygen (mg/L)	10.48	9.34	10.33	9.24	6.10	3.36	9.11
Transparency (m)	0.63	0.86	0.99	1.54	1.17	1.22	1.05
Chemical Oxygen Demand (COD) (mg/L)	8.60	7.06	8.17	8.37	11.79	6.06	22.19
Ammonia Nitrogen (mg/L)	0.39	0.38	0.21	0.63	0.27	0.22	0.20
Total Nitrogen (mg/L)	1.04	1.11	1.40	1.18	1.17	0.60	0.79
Total Phosphorus (mg/L)	0.08	0.07	0.07	0.09	0.08	0.05	0.05
Biochemical Oxygen Demand (BOD_5) (mg/L)	2.30	1.86	1.93	2.00	2.63	1.00	3.89
Suspended Solids (SS) (mg/L)	14.60	17.29	20.00	17.11	3.44	14.11	13.11
Chlorophyll-a (ug/L)	12.00	12.57	6.71	5.75	7.44	8.78	7.11

The Table presents the average values of various indicators measured at Jiefang Park from March 2022 to January 2023. The indicators include pH, water temperature, dissolved oxygen, transparency, chemical oxygen demand (COD), ammonia nitrogen, total nitrogen, total phosphorus, biochemical oxygen demand (BOD5), suspended solids (SS), and chlorophyll-a.

After remediation efforts, the transparency of the water body has improved from 60 centimeters to 150 centimeters. The ammonia nitrogen content remains stable around the standards of Class II water quality. The total phosphorus content is below 0.1 mg/L, maintaining the standards of Class II water quality, while the total nitrogen content remains within the standards of Class IV water quality. The BOD_5 falls within the range of Class II to Class III water quality standards. Most sampling points indicate that the COD levels are within the range of Class I to Class II water quality standards. The coverage of submerged plants has reached over 70%. The common species in the Yangtze River Basin, Vallisneria denseserrulata, is often used for the restoration of eutrophic lakes in the region0. The presence of submerged vegetation in restored eutrophic lakes can effectively reduce nutrient concentrations and phytoplankton biomass in the water. Furthermore, the leaf blades of submerged plants provide suitable habitats for microbial growth and influence microbial community structures0, thus enhancing wetland microbial diversity and stability.

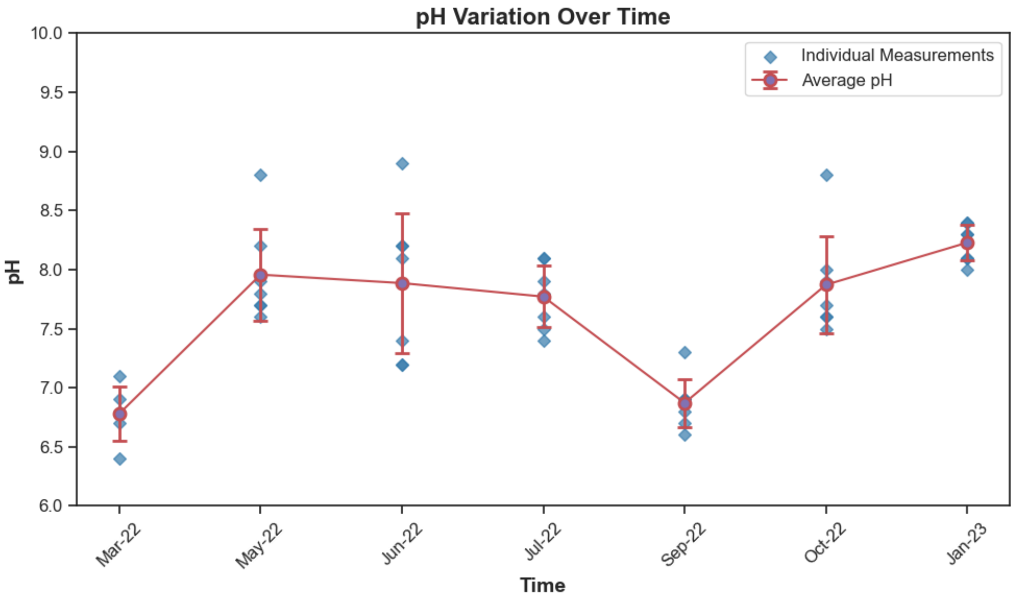


Figure 3. Trend Analysis of pH Variation in Aquatic Systems

According to the data, the growth of dense spikerush (Eleocharis acicularis) is associated with an upward trend in water pH. Initially starting at 6.78, the pH value rises to approximately 8.18 and stabilizes around 8 in the long term, indicating a weak alkaline nature of the water body. The primary reason for this trend is the strong photosynthetic activity of spikerush, which surpasses its respiratory activity and consumes CO_2 in the water, leading to an increase in pH. In January 2023, the decrease in water temperature inhibits microbial activity, resulting in a reduced release of CO_2 during organic matter decomposition, further intensifying the pH increase. At this time, the pH reaches its maximum level. According to the research findings of Szabo, the low nitrogen concentration and alkaline pH environment created by dense submerged plant communities are crucial factors that contribute to the competitive advantage of submerged plants over phytoplankton populations. Furthermore, an increase in pH effectively inhibits the growth of phytoplankton.

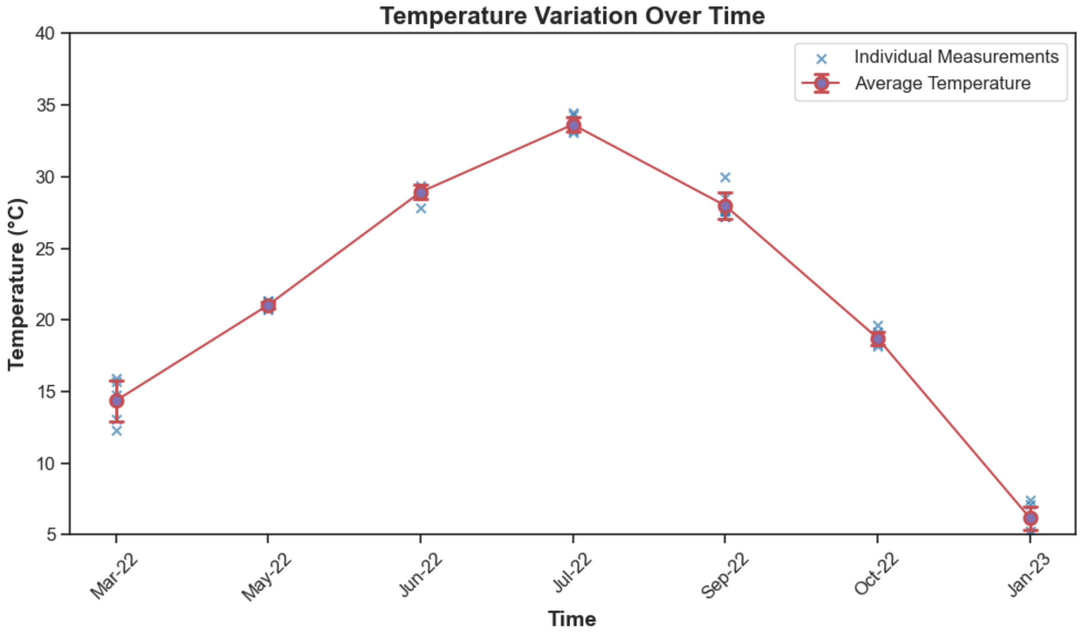


Figure 4. Trend Analysis of Water Temperature Variation in Aquatic Systems

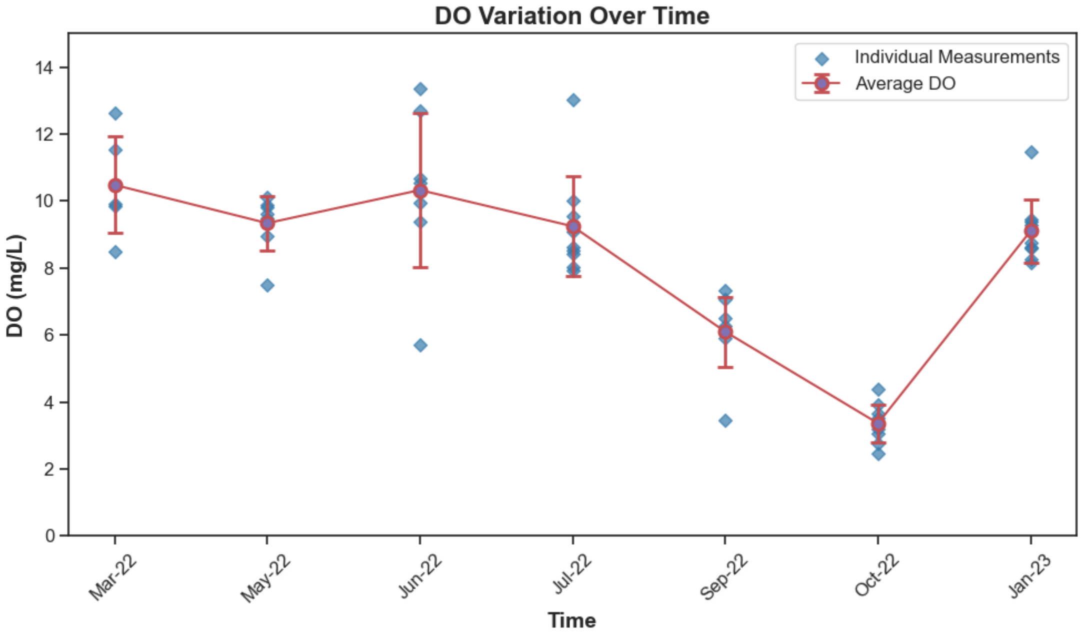


Figure 5. Trend Analysis of Dissolved Oxygen Variation in Aquatic Systems

Existing literature indicates that the absorption rate of nutrients by submerged plants is closely related to temperature. Under high-temperature conditions, the aerobic respiration of aquatic plants intensifies, leading to a slowdown or inhibition of their growth rate. Under low-temperature conditions, although submerged plants can still grow, their growth rate is inhibited. The membrane fluidity and membrane proteins on the cell membrane are affected, resulting in a decreased capacity for active transport of ammonia nitrogen by the cells, subsequently reducing the electrochemical potential for H+ transmembrane transport, which directly affects the transmembrane transportation of ammonia nitrogen.

According to the data, the dissolved oxygen in the water body exhibited an overall decreasing trend followed by an increasing trend during the experimental period. The main reason for this is the growth and reproduction of the aquatic plant, leading to an increase in population density and a lack of water flow at the bottom of the water body, resulting in hypoxia at the bottom. The research findings of Woodward and Hofstra suggest that if photosynthesis decreases or the oxygen demand of sediment increases, plants may no longer be able to oxygenate the sediment surrounding their roots, which could potentially lead to the death of submerged plants. In autumn, the aquatic plant deteriorates, and the decomposition of the accumulated plant residues by microorganisms leads to a decrease in dissolved oxygen at the bottom of the water body. In winter, the lower water temperature reduces microbial activity and oxygen consumption, resulting in an increase in dissolved oxygen in the water body.

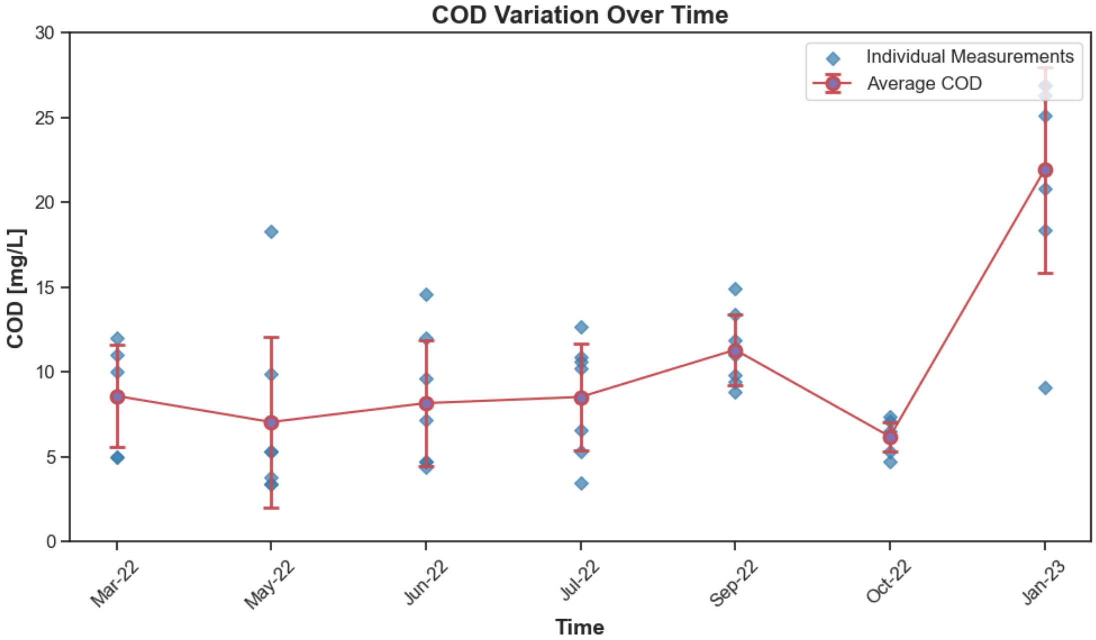


Figure 6. Trend Analysis of Chemical Oxygen Demand (COD) Variation in Aquatic Systems

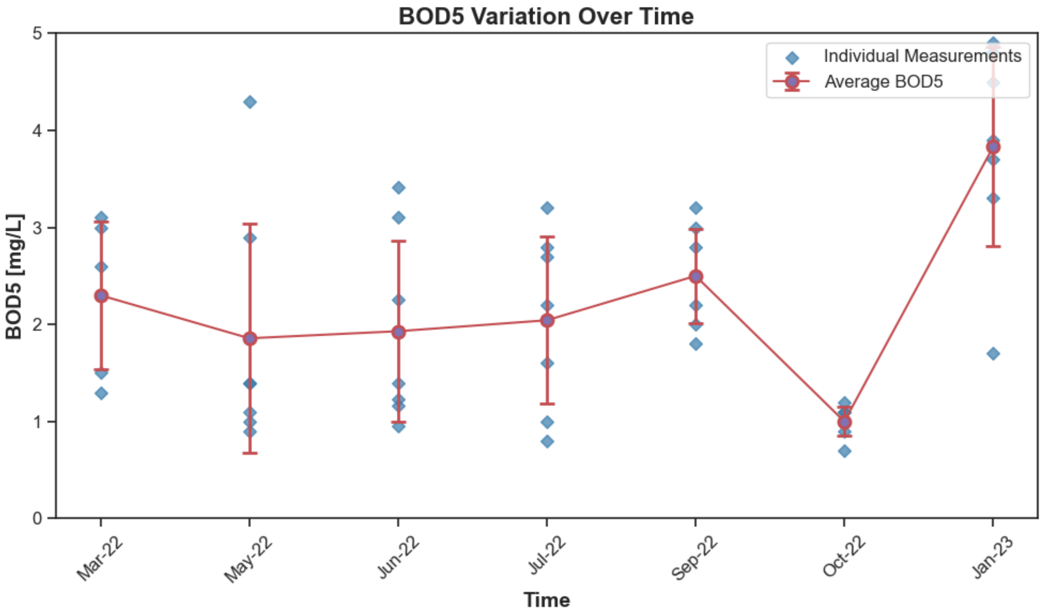


Figure 7. Trend Analysis of Biochemical Oxygen Demand (BOD5) Variation in Aquatic Systems

According to the data, the overall concentrations of COD and BOD_5 in the water body are relatively low. The lowest levels were observed in October, which can be attributed to the significant decomposition of organic matter by microorganisms. In January 2023, there was an increase in the concentrations of COD and BOD_5 in the water body. The primary reason for this increase is the higher COD content in the replenishment water source. Additionally, the low water temperature during winter inhibited microbial activity, resulting in incomplete degradation of organic matter at the bottom.

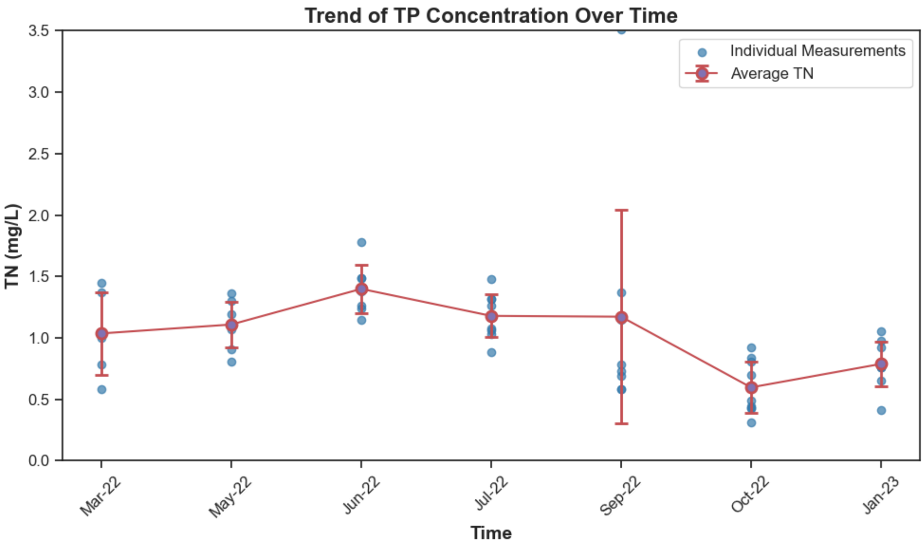


Figure 8. Trend Analysis of Total Nitrogen content in Aquatic Systems

The data shows that from March to September, which is the growth period of bittergrass (a kind of aquatic plant), the concentrations of ammonia nitrogen and total nitrogen in the water are relatively high. This indicates that bittergrass is unable to effectively reduce the nitrogen content in the aquatic systems. The possible reason for this could be the inhibitory effect of higher pH levels in the water on the nitrogen absorption capacity of bittergrass leaves. Previous literature indicates that, apart from certain marine plants that establish an ion gradient through Na^+/K^+ pumps for nutrient ion absorption0, most plants still rely on proton pumps to absorb surrounding anions and cations. Moreover, a decrease in pH weakens the nitrification of ammonia nitrogen. Therefore, appropriately lowering the pH facilitates the transmembrane transport of ammonia nitrogen.

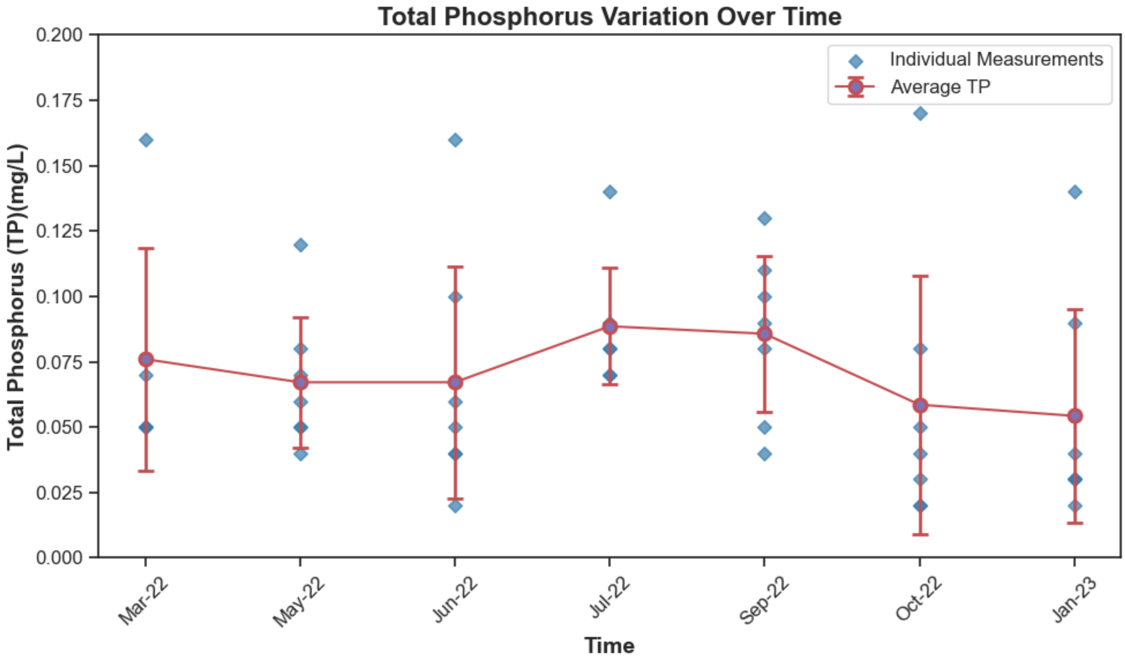


Figure 9. Trend Analysis of Total Phosphorus content in Aquatic Systems

The data reveals that the overall concentration of total phosphorus in water bodies is relatively low and exhibits significant seasonal fluctuations. The implementation of dredging, lanthanum-based phosphorus-locking agents, and the cultivation of submerged aquatic plants has proven to be effective. Submerged aquatic plants reduce the release of phosphorus from sediments by influencing the sediment-water interface phosphorus exchange mechanism0. Experimental results by Zhang et al. demonstrate that the combined use of submerged aquatic plants and phosphorus-locking agents can effectively decrease phosphorus levels in eutrophic lakes. Application of phosphorus-locking agents with Vallisneria sp. during the low-temperature season has been successful in reducing nitrogen and phosphorus concentrations in water bodies0. Even in the presence of small benthic fish, significant purification effects can be achieved. This can be attributed to the combined effects of varying growth cycles of aquatic vegetation and water temperature fluctuations. From March to June, there is a decreasing trend in total phosphorus concentration, indicating the significant absorption capacity of aquatic vegetation towards total phosphorus. From June to September, with increasing temperatures, there is an upward trend in total phosphorus concentration, suggesting that the absorption capacity of aquatic vegetation is weaker than the release rate of phosphorus from the bottom sediment. From September to January 2023, the total phosphorus concentration in the water bodies decreases again, with an overall level lower than that of March to June. This is due to the decrease in water temperature, reduction in phosphorus release from the bottom sediment, and slower growth rate of aquatic vegetation, leading to a decline in phosphorus absorption efficiency.

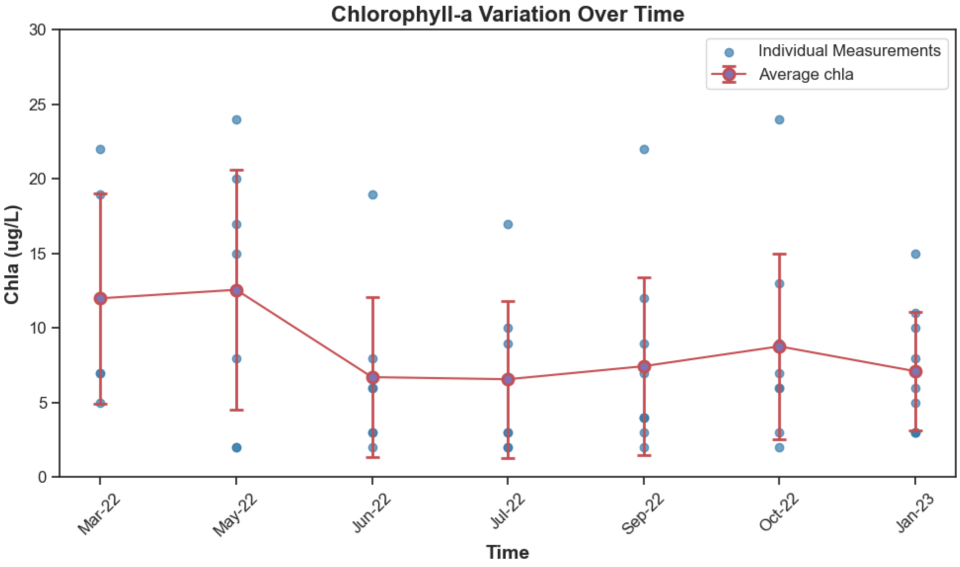


Figure 10. Trend Analysis of Chlorophyll-a (chla) in Aquatic Systems

According to the data, the overall trend of chlorophyll concentration in the water exhibited a decline followed by an increase. Combining this trend with the growth data of bittergrass during its vigorous growth phase, it indicates that during this phase, there is a competitive advantage of submerged plants over phytoplankton. This advantage can partially inhibit the growth of phytoplankton, thereby maintaining water clarity and preserving water transparency.

Table 4. Growth Status of Bittergrass

Growth Date	Number of Plants	Weight (kg)	Length (cm)
May 2022	150 plants	2.3	50.2
June 2022	150 plants	2.7	56.4

Growth Date	Number of Plants	Weight (kg)	Length (cm)
July 2022	150 plants	3.2	68.3
October 2022	150 plants	3.4	72.0
January 2023	150 plants	3.3	70.1

The Table above presents the growth status of bittergrass, including the growth date, number of plants, weight (in kilograms), and length (in centimeters) for each month from May 2022 to January 2023.

The growth status of bittergrass plays a significant role in this process. As bittergrass thrives, it competes effectively with phytoplankton for available nutrients and light resources. The vigorous growth of bittergrass leads to increased shading of the water column, reducing the amount of light available for phytoplankton photosynthesis. Additionally, bittergrass extracts nutrients from the water, further limiting the nutrient availability for phytoplankton growth.

The competition between bittergrass and phytoplankton during the peak growth phase of bittergrass results in a suppression of phytoplankton growth. This suppression contributes to the maintenance of clear water and the preservation of water transparency. The presence of bittergrass in the water ecosystem acts as a natural regulator, promoting a balanced and healthy aquatic environment.

In conclusion, the observed trend of chlorophyll concentration, combined with the growth data of bittergrass, suggests that during the vigorous growth phase of bittergrass, there is a competitive advantage of submerged plants over phytoplankton. This advantage leads to the suppression of phytoplankton growth, ensuring clear water and maintaining water transparency in the ecosystem. Increasing water transparency contributes to the recovery of submerged aquatic plant populations. Additionally, high light conditions can accelerate the decomposition of decaying submerged plants, as the components of tyrosine and tryptophan in the decomposition products of submerged plants can be rapidly and directly degraded by light.

3.3 Impact of the Fish-Plant Symbiosis System on Fish Populations

In July 2023, a recapture of fish that were stocked in 2022 was conducted, and their weight and length were measured. Some of the results are presented in Table 5.

Table 5. Fish Data from Jiefang Park, July 2023 (Partial)

No.	Species	Length (cm)	Weight (g)
1	Crucian	40	900
2	Crucian	47	1550
3	Crucian	37	1050

No.	Species	Length (cm)	Weight (g)
4	Crucian	23	300
5	Crucian	36	800
6	Crucian	43	1100
7	Catfish	82	5600
8	Catfish	80	3750
9	Grass Carp	90	11300
10	Common Carp	62	3650
11	Carp	17	100
12	Silver Carp	64	5100

The Table above presents the captured fish data from Jiefang Park in July 2023. The table includes the species, length (in centimeters), and weight (in grams) of the fish.

In June 2022, common carp with an initial weight of 200g per fish were stocked, and after 13 months of growth, the average weight per fish was 2525g. In June 2022, grass carp with an initial weight of 200g per fish were stocked, and after 13 months of growth, the average weight per fish was 9050g. In December 2022, crucian carp with an initial weight of 200g per fish were stocked, and after 7 months of growth, the average weight per fish was 917g, with an average weight gain of 717g. In December 2022, predatory catfish (large-mouthed catfish) with an initial weight of 400g per fish were stocked, and after 7 months of growth, the average weight per fish was 2764g, with an average weight gain of 2364g. The growth trajectory was positive for all species.

3.3.1 Weight Comparison

Further Analysis of Weight Comparison between Released and Captured Fish

In this section, we delve deeper into the academic investigation of the weight comparison between fish released and those captured, as depicted in Figure 11 and Figure 12. The obtained results shed light on the distribution of weight percentages for different fish species during the release and capture processes.

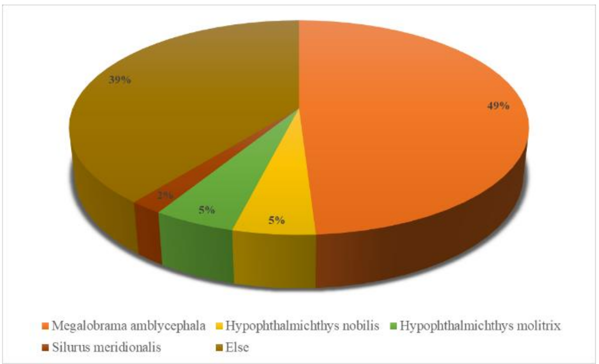


Figure 11. Weight Proportion of Released Fish Species

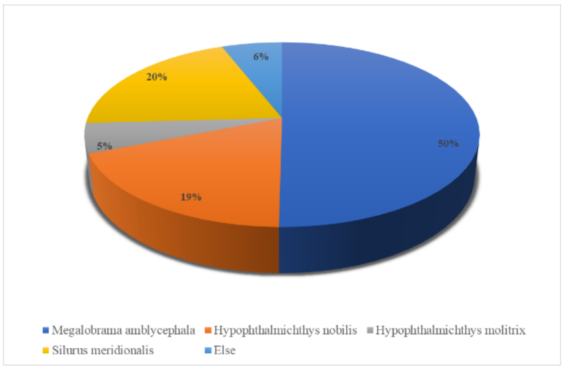


Figure 12. Weight Proportion of Captured Fish Species

During the release phase, the weight distribution of the released fish species exhibited certain patterns. Specifically, the Crucian and Silver Carp accounted for 49% and 5% of the total weight, respectively. These proportions remained relatively stable when the fish were subsequently captured, with percentages of 50% and 5% for Crucian and Silver Carp, respectively. This indicates that the weight distribution of these two species remained largely unchanged throughout the release and capture stages.

In contrast, the weight distribution of Catfish and Grass Carp displayed notable variations between the release and capture phases. During release, Catfish and Grass Carp accounted for only 2% and 5% of the total weight, respectively. However, upon capture, their weight proportions increased significantly to 20% and 18%, respectively. This suggests that Catfish and Grass Carp experienced substantial weight gain during the capture process.

Furthermore, the weight percentage of other fish species released initially constituted 39% of the total weight. However, upon capture, this proportion decreased significantly to 6%. This decline indicates that the weight distribution of other fish species underwent a considerable reduction during the capture phase.

Overall, the weight comparison analysis demonstrates that while the weight proportions of Crucian and Silver Carp remained relatively consistent throughout the release and capture processes, significant weight changes were observed for Catfish, Grass Carp, and other fish species. These findings contribute to a comprehensive understanding of the weight dynamics in fish populations during the release and capture operations.

Common carp and grass carp were the first batch of filter-feeding fish species released in June 2022. After one year of growth, the growth rate of grass carp was significantly higher than that of common carp. This difference may be attributed to the fact that the common carp and grass carp of the same weight were in different growth stages. During this year, the grass carp happened to be in a rapid growth phase, which led to the competition for feeding space and slower growth of the common carp compared to the fast-growing grass carp.

In December 2022, the herbivorous silver carp and the carnivorous largemouth catfish were released simultaneously. After 7 months of growth, the largemouth catfish exhibited a higher growth rate compared to the silver carp. Firstly, the largemouth catfish is a carnivorous fish species that primarily feeds on small fish, shrimp, and other aquatic animals, which are rich in nutrients and can meet the rapid growth requirements of the largemouth catfish. On the other hand, the silver carp is a herbivorous fish species that primarily feeds on aquatic plants and filamentous algae, which have relatively lower nutritional value and cannot sustain the rapid growth of silver carp.

Secondly, the two fish species have different growth rates. The largemouth catfish possesses strong predatory abilities and growth potential, allowing it to acquire more food and nutrients in a shorter period, thereby promoting its rapid growth. The largemouth catfish can gain 1 to 4 pounds in a year, with faster growth rates observed in the first three years. By the age of three, the largemouth catfish weighs approximately 3500 g. On the other hand, the silver carp has relatively weaker predatory abilities and growth potential, resulting in slower growth rates. The silver carp exhibits rapid growth in the first and second years, with a weight of around 500 g at the age of two. Subsequently, its growth rate slows down.

Furthermore, the largemouth catfish’s body size and physiological characteristics provide favorable conditions for its rapid growth. It has a longer body, well-developed muscles, and strong swimming abilities, enabling it to better adapt to the aquatic environment and acquire food and nutrients more easily.

In conclusion, the higher growth rate of the largemouth catfish compared to the silver carp is the result of multiple factors, including its carnivorous diet, strong predatory abilities and growth potential, as well as its favorable body size and physiological characteristics.

3.3.2 Species Diversity

According to the Shannon-Weaver index, the theoretical value of species diversity within Jiefang Park was calculated as 1.67 in December 2022, immediately after the fish stocking event. Subsequently, in July 2023, the Simpson index was used to calculate species diversity based on fishing results, yielding a value of 0.91. From a numerical perspective, the species diversity in December 2022, following the fish stocking, was higher than the species diversity recorded in July 2023, indicating a decline in species diversity.

Furthermore, during the fish capture, additional fish species were found that were not part of the stocking event. These fish species may have originated from the existing water bodies or were released by nearby residents, thereby increasing the species diversity within Jiefang Park's water bodies. However, after a period of 7 months, there has been a decline in species diversity. This decline can be attributed to several factors. Firstly, the fishing nets used had a mesh size of 5 cm, which prevented the capture of individuals with a body length below 5 cm, such as minnows and slender mandarin fish. Secondly, predatory fish species like large catfish and mandarin fish may have preyed upon smaller fish, resulting in a decrease in species diversity within the water bodies of Jiefang Park. These factors likely contributed to the observed decline in species diversity based on the collected data.

The findings of Su et al. indicate that the disturbance activities of benthic fish increase the concentrations of total nitrogen, total phosphorus, total dissolved phosphorus, and ammonia nitrogen in the overlying water, thereby altering the survival strategy of submerged aquatic plants. Elevated levels of ammonia nitrogen can damage the chlorophyll structure of submerged plants and reduce photosynthetic efficiency0. When small fish species such as Crucian carp are abundant, it may decrease the resistance of submerged plants to external nitrogen loading, thus reducing the success of biological manipulation for restoration. Therefore, the method of introducing large carnivorous fish to control small benthic fish can effectively improve the survival rate and growth rate of submerged plants.

Megalobrama amblycephala, a native herbivorous fish species in China, has a moderate body size with small mouth and pharyngeal teeth, and consumes a smaller amount of food. The grazing behavior of Megalobrama amblycephala is milder compared to grass carp (Ctenopharyngodon idella) and can serve as an ideal alternative species for the management of submerged plant communities. The grazing activity of Megalobrama amblycephala stimulates the growth of Vallisneria spiralis, resulting in increased plant density and leaf numbers, denser meadows, and tougher leaves0.

Although the fish-vegetation balance system in Liberation Park has been established through biological manipulation, it remains unstable. In eutrophic shallow lakes, there exists an unstable equilibrium between submerged and planktonic plants that can maintain clear water conditions. Hilt's research suggests the existence of an intermediate recovery state under reduced external nutrient loading, characterized by clear water in spring and turbidity in summer, while internal lake restoration measures typically result in clear water conditions in both spring and summer, followed by a return to turbidity after several years. This is primarily because, towards the end of the growth cycle of submerged plants, their pioneer species' dominance is replaced by other species, leading to a massive proliferation of phytoplankton by late summer. To maintain a stable clear water state, in addition to continuously reducing the input of external nutrients, it is necessary to establish a stable submerged plant community composed of multifunctional species0. Liu and Chen's research found that the combination of Vallisneria spiralis and Potamogeton maackianus has the highest nutrient removal efficiency.

3.4 Machine Learning Tool for Monitoring Environmental Health

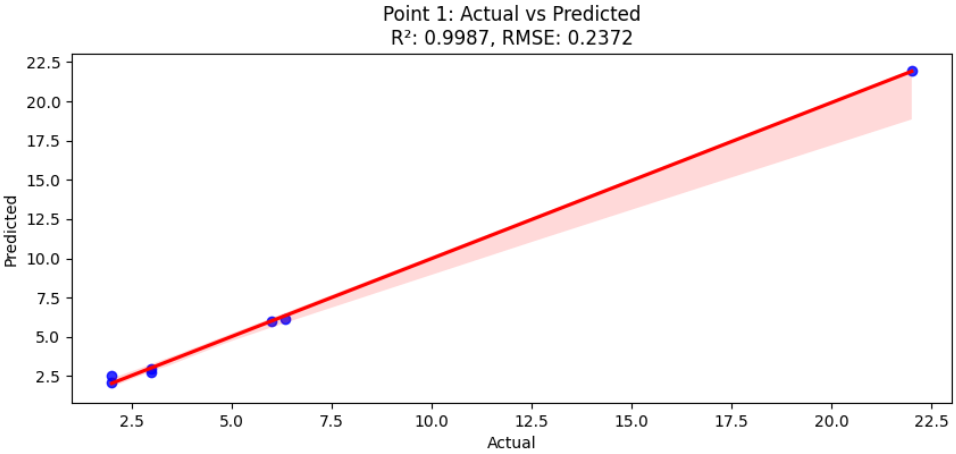
In this section, we developed a machine learning model, specifically aimed to predict chlorophyll-a concentration in aquatic environments. Our model, developed using PyTorch, exhibits a architecture comprising an input layer, two hidden layers, and an output layer, each featuring five nodes. This architecture adeptly processes a range of environmental parameters including pH, temperature, dissolved oxygen, transparency, COD, ammonia nitrogen, TN, TP, and BOD5.

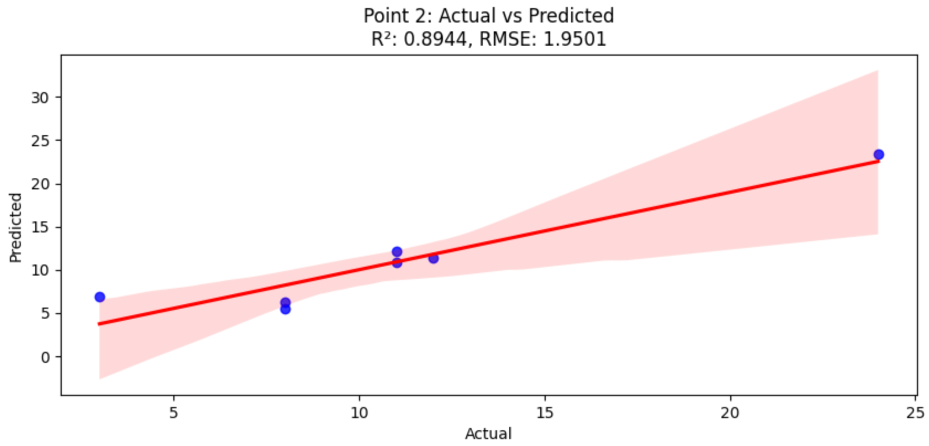
The model's efficacy is underscored by Figure 15 in our study, which illustrates its performance across seven distinct measuring points. These results, obtained after rigorous training over 400 epochs with a learning rate of 0.005, demonstrate the model's ability to capture the complex relationships between the forementioned environmental factors and chlorophyll-a concentration.

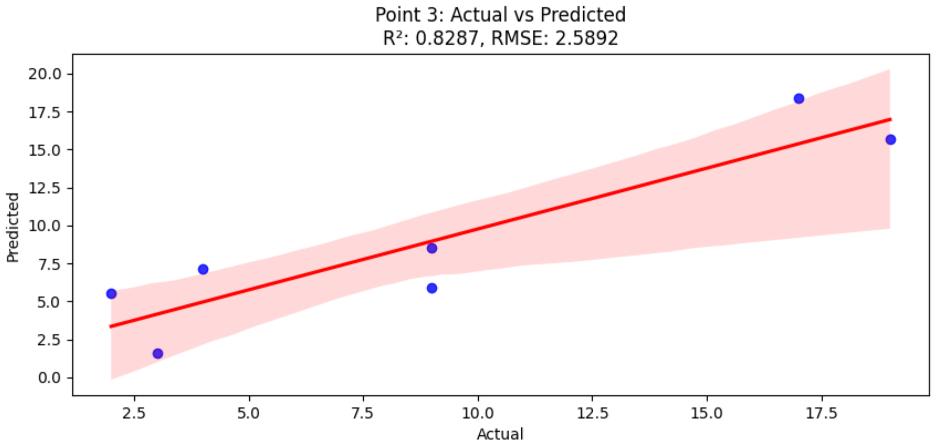
Through a series of preprocessing steps, including normalization and handling of missing values, the model ensures robustness and accuracy in its predictions. The use of MinMaxScaler for normalization, in particular, aids in maintaining data integrity.

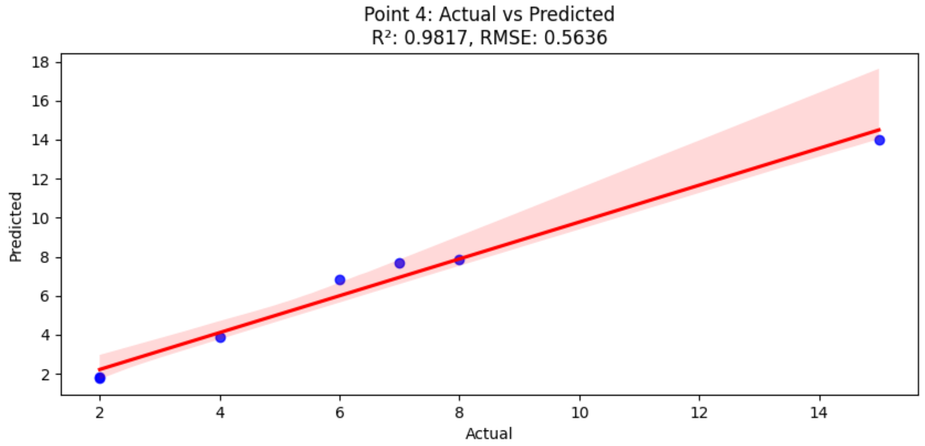
The evaluation of our model reveals its proficiency, as indicated by the R^2 and RMSE values calculated for each measuring point (R2 range from0.23 to 0.99 and RMSE range from 6.921 to 0.237). The point 1 prediction results showed the best performance of our machine learning model. This evaluation not only attests to the model's precision but also highlights its potential applicability in real-world scenarios for environmental monitoring and management.

In conclusion, our enhanced machine learning tool, as depicted in Figure 15 and detailed in this section, represents a significant tool in predicting chlorophyll-a concentration, leveraging advanced neural network capabilities within the PyTorch framework. This advancement paves the way for more effective and accurate environmental health monitoring.




Point 2: Actual vs Predicted
R²: 0.8944, RMSE: 1.9501
Predicted
30
25
20
15
10
5
0
5
10
15
20
25
Actual


Point 3: Actual vs Predicted
R²: 0.8287, RMSE: 2.5892
Predicted
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
Actual


Point 4: Actual vs Predicted
R²: 0.9817, RMSE: 0.5636
Predicted
18
16
14
12
10
8
6
4
2
2
4
6
8
10
12
14
Actual

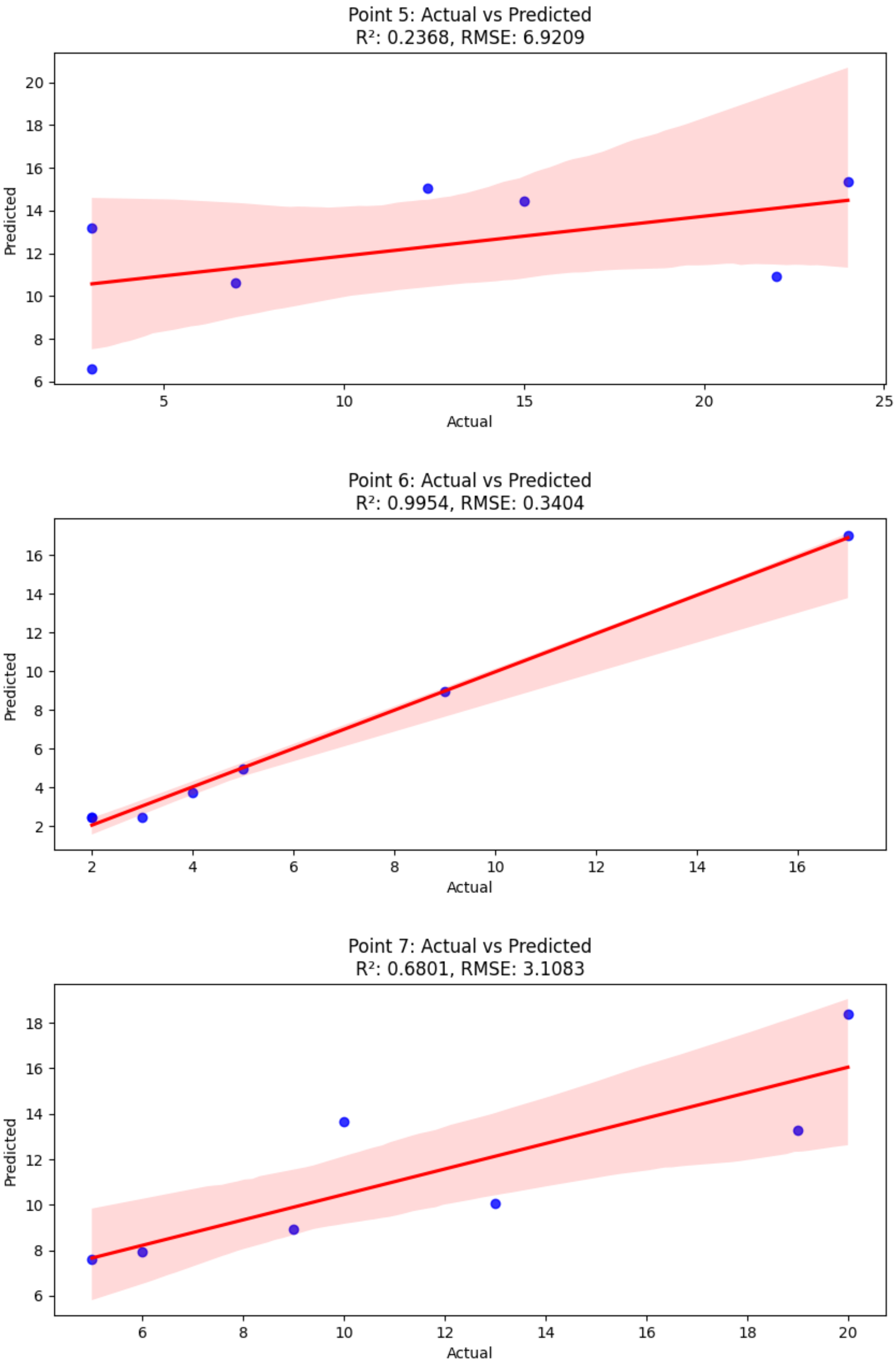


Figure 15. Machine Learning Results of Predicted Chlorophyll-a for Measured Points 1-7

4. Conclusion

Our study highlights the transformative potential of integrating fish-plant symbiosis with advanced machine learning technologies in urban lake restoration, illustrated by the Jiefang Park water environment remediation project. Our innovative approach not only markedly improved water quality from Class V to Class III, and in certain areas to Class II, but also adeptly navigated challenges including managing the delicate balance between fish and plant populations and mitigating the risk of rapid reversion to algae dominance.

Implementing our fish-plant symbiosis method, we addressed core issues in urban lake restoration while identifying specific challenges encountered during the process. These challenges encompassed effectively managing the population balance between fish and plants and reducing the risk of the ecosystem rapidly reverting to an algae-dominated state.

The outcomes of the project—significant improvements in water clarity, nutrient level reduction, and a transition to a macrophyte-dominated ecosystem—amply demonstrate the efficacy of our symbiotic system. Despite these achievements, we continue to face challenges such as ensuring the long-term sustainability of the restored ecosystem and adapting our management strategies to unforeseen ecological changes.

Our research’s application of a cutting-edge machine learning model, developed using the PyTorch framework, represents a pioneering step in utilizing technology for ecological restoration. The ability of this model to accurately predict chlorophyll-a concentrations underscores the critical role of technological integration in enhancing the precision and efficiency of environmental management.

The broader impact of our work transcends ecological restoration; it has revitalized urban spaces, fostering recreational and fitness opportunities for the community, and has set a new benchmark for future urban water management endeavors. Our project stands as a testament to the power of combining ecological knowledge with technological innovation to foster sustainable urban environments.

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