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Eco-Engineering Technologies and Achievements of Projects for Reconstructing Landscape Water from Aquaculture Ponds in Shanghai

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Abstract: The post-evaluation of ecological redevelopment is a good way of describing its achievements. In this paper, eco-engineering techniques, including hydrodynamic circulation reconstruction, water purification treatment, and aquatic ecosystem restoration, along with plant harvesting management, have been applied to reconstruct landscape water from aquaculture ponds. Both sediments and water quality were sampled and tested for basic physicochemical parameters and heavy metals. The ecological redevelopment of landscape water reconstructed from aquaculture ponds was evaluated using the single and Nemero comprehensive pollution index methods. The results demonstrate that nutrients, including organic matter and organic nitrogen and their ratio to sediments, were confirmed to be in a state of moderate pollution, while the ecological risk of heavy metal pollution was relatively low. Although the concentrations of total nitrogen and total phosphorus were significantly higher than those of other indexes, ammonia nitrogen, total nitrogen and total phosphorus, all presented obvious downward trends over time, and a majority of the water samples exhibited mild-to-moderate pollution levels. In general, this study provides a set of reference values for redeveloping water ecosystems from aquaculture ponds using eco-engineering technologies.

Keywords: wetland restoration; biodiversity; post-evaluation; ecological monitoring

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1. Introduction

In recent years, the aquaculture industry has experienced rapid growth, leading to an expansion in the size of aquaculture ponds. In 2021, within China, the cumulative area of aquaculture ponds reached 26,450 m^3, constituting 51.7% of the nation's overall freshwater aquaculture region [1]. Notably, the aggregate territory of aquaculture ponds within the Yangtze River Basin encompasses an extensive area of 14,567 m^3 [1]. However, aquaculture ponds are currently confronted with water degradation issues, primarily including water pollution, eutrophication and sediment contamination [2,3]. The aquaculture industry has faced challenges in terms of ecological benefits and the sustainable development of the environment.

To improve the water quality, eco-engineering measures encompassing ecosystem reconstruction and population control techniques for aquatic plants, benthic organisms and microorganisms have been implemented in the reconstruction of water ecosystems [4,5]. These methods have not only been applied in the ecological restoration of large lakes and wetlands, including Taihu Lake, Chaohu Lake, Dianchi Lake and West Lake, but are also used to control and maintain the water quality of large artificial lakes, streams and pools in urban open spaces [6]. The effect of ecological redevelopment on water ecosystems is mainly evident in eutrophic lakes and constructed wetlands [7,8]. In aquaculture ponds, terrain modification has been carried out through the dismantlement of pond dikes, drainage treatment, sediment replacement, and sun exposure at the bottom of Yilong Lake in Yunnan [5]. In addition, the implementation of vegetative buffer zones, including the reintroduction of aquatic plants and the construction of ecological floating islands, has been achieved in Qiachuan within the Yellow River Nature Reserve [4]. Indeed, there are a few reports on the reconstruction of water ecosystems from aquaculture ponds [9–11].

The post-evaluation of ecological redevelopment is a practical and effective method for evaluating recent achievements in this area [12,13]. Two aspects required for water environmental quality evaluation need to be mentioned, namely, using the water quality index to evaluate ecosystem redevelopment and conducting a comprehensive evaluation considering both water quality and sediment index [14]. However, the existing assessment studies were carried out immediately after engineering completion with few indicators and a short cycle [15,16]. For example, chemical indicators of water quality, such as transparency, total nitrogen, total phosphorus, permanganate index, suspended solids and chlorophyll A, were selected to evaluate the effectiveness of the water environmental pollution control project in Xuanwu Lake, Nanjing [17]. Related indicators, such as total nitrogen, total phosphorus, nitrate nitrogen, nitrite nitrogen and chlorophyll A, were chosen to evaluate the water quality changes 6 months after the initiation of the water ecological restoration project in Dalian Lake, Shanghai [18]. A comprehensive evaluation of 12 physical and chemical indicators of water quality, including pH, dissolved oxygen, conductivity, total dissolved solids, salinity, COD, BOD_5, ammonia nitrogen, total nitrogen, total phosphorus, chloride and total suspended solids, was conducted for the ecological restoration demonstration project in the Dagupai River in Tianjin [19]. Additionally, long-term and stable biological restoration measures have been predominantly qualitative, lacking quantitative data [20–22].

The quality of sediments is also an important aspect of water environmental quality evaluation. The runoff inflow into water bodies is full of nutrients and heavy metals, which become the primary source of pollution [23,24]. Specifically, nitrogen and phosphorus represent the primary load of water body nutrients and participate in the circulation of water ecosystems undergoing physical, chemical and biological processes. Heavy metals are deposited into sediments [25]. The assessment of sediments not only facilitates the recognition of water quality status and its evolutionary characteristics but also enables the identification of key pollution factors and the implementation of effective preventive and control measures; it also provides a scientific basis for the formulation of water pollution control and water environment restoration plans [26,27].

In this study, both eco-engineering technologies and achievements in projects reconstructing landscape water from aquaculture ponds in Shanghai Chenshan Botanical Garden were investigated. The objectives of this study were: (1) to introduce a comprehensive restoration approach that combines fast-acting, short-term engineering measures with long-term, stable biological restoration measures for transforming aquaculture ponds into landscape water; (2) to establish a scientific and effective long-term evaluation method for assessing the ecological outcomes of ecosystem reconstruction; (3) to provide a valuable reference for the redevelopment of water ecosystems from aquacultural bonds using ecological engineering technologies.

2. Materials and Methods

2.1. Study Area

The research site, the central position of which had the geographical coordinates (31°04′48.10″ N, 121°11′5.76″ E), was located in Songjiang District in Shanghai, China (Figure 1). Shanghai has a subtropical monsoon climate, with an annual temperature of 15.4 °C and an annual rainfall of 1103.2 mm. Of the total rainfall, 60% is concentrated in the rainy season from May to September. The soil in Shanghai has previously been described as a silty clay loam with an elevated pH of 8.

Figure 1. Location of the study area.

The total area was 207,000 m^2, covering Chenshan Hill, village, rivers, farmlands and aquaculture ponds. The surface water area in this region was 90,774 m^2, of which aquaculture ponds accounted for 34.5% [28] (Figure 2). The maximum nitrogen content of surface water in aquaculture ponds was 13.54 mg/L, leading to frequent eutrophication outbreaks and fertile sediments. Moreover, the ponds had excessive heavy metals, such as As, Cd and Zn [29].

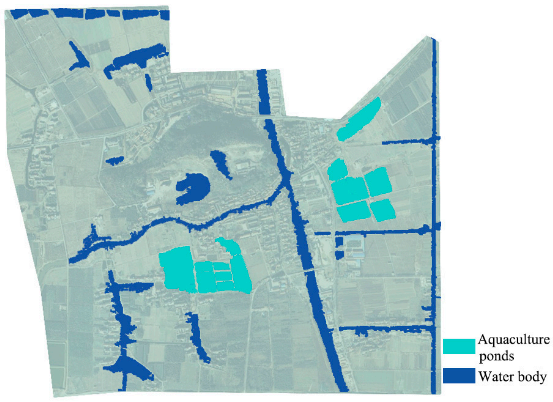

Figure 2. The area and distribution of surface water and aquaculture ponds.

2.2. Eco-Engineering Treatments

2.2.1. Hydrodynamic Reconstruction

The research site was designed within the Shanghai Chenshan Botanical Garden, composed of hills, water and plants. Its surface water area has expanded to 200,000 m^2 due to terrain consolidation and reshaping from rice farmlands and aquaculture ponds (Figure 3). During the initial construction phase, the removal and replacement of heavily contaminated sediments in rice fields and aquaculture ponds were accomplished, effectively reducing the levels of nutrients and heavy metals in existing sediments. The landscape water system was divided into four subareas following a water flow direction. These subareas were sequenced by Shenjing River (19,041 m^2), West Lake (104,296 m^2), Aquatic Garden (25,823 m^2) and East Lake (49,684 m^2). To improve water quality, a water treatment plant with a total area of 10,000 m^2, including a semi-buried sewage treatment plant, surface flow and subsurface flow constructed wetlands, was constructed in the western part of the garden.

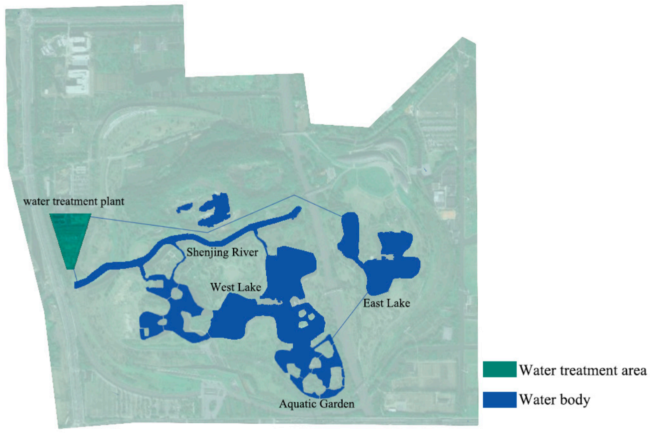

Figure 3. The area and distribution of the landscape water system.

A landscape water cycle purification system was designed and established (Figure 4). Landscape water mainly relies on natural precipitation replenishment and circulates through groundwater replenishment and outside river supplementation. A total of 40,000 m^3 volumes of all surface water was estimated at the designed mean depth of 2 m. It took almost a month to complete the hydrodynamic cycle. A total of 10,000 m^3 of water was pumped from East Lake to the water treatment plant through a pipeline each day, with a maximum daily supplement amount of 3000 m^3 from the river outside.

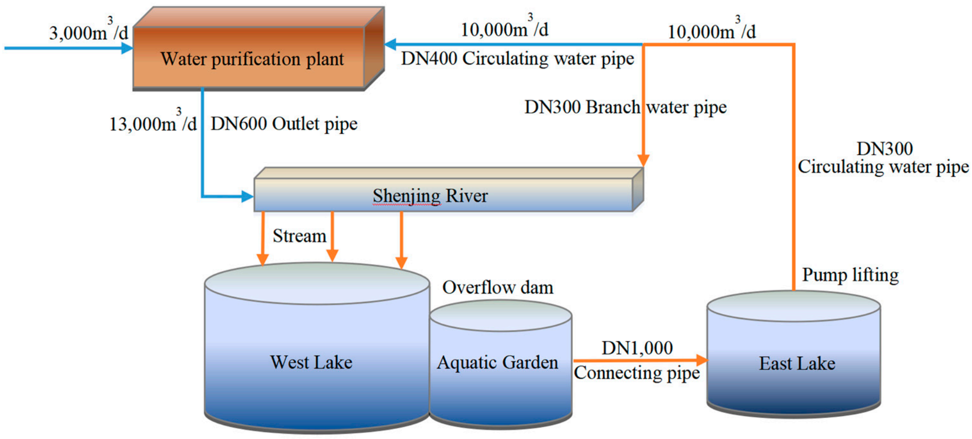

Figure 4. Schematic diagram of water cycle purification for landscape water. The total amount of green irrigation and evaporation in West Lake, Aquatic Garden and East Lake is 3000 m^3/d.

2.2.2. Water Purification Treatment

In order to avoid directly polluting the water in the landscape, rainwater storage and infiltration systems were implemented at the terminus of the drainage channels. The rainwater required filtration and percolation through the soil before entering landscape water.

The circulation and supplement water of the river outside were first subjected to artificial reinforcement treatment such as coagulation and sedimentation in the semi-buried sewage treatment plant. This aimed to remove most of the suspended substances, total phosphorus and organic matter. Only 3000 m^3 water flowed into 3000 m^2 surface flow constructed wetlands and 56 parallel independent 65 m^2 subsurface flow constructed wetlands to remove organic matter, ammonia nitrogen, and total phosphorus [30,31] (Figure 5).

2.2.3. Aquatic Ecosystem Restoration

The sediments of aquaculture ponds were replaced with river sands and absorbent substrates such as vermiculite. The waterfront space was reconstructed into natural, near-natural and erect revetments. The length of natural revetments accounted for 74.4% of the entire waterfront space, while erect revetments were only 12.3% [32].

Water purification abilities and ecological functions should be prioritized when selecting aquatic species, especially native species. In natural and near-natural waterfront spaces, vegetation zones with hygrophytes, emergent plants, floating-leaf plants or submerged plants were gradually replanted. In waterfront spaces above normal water level, water-tolerant hygrophytes such as *Taxodium mucronatum*, *Salix babylonica*, *Pterocarya stenoptera*, *Metasequoia glyptostroboides*, *Glyptostrobus pensilis*, *Triadica sebifera*, and *Cephalanthus tetrandrus* were replanted. Around normal water levels, emergent aquatic plants such as *Sagittaria trifolia subsp. leucopetala*, *Juncus effusus*, *Cyperus involucratus*, and *Typha orientalis* were replanted. Floating-leaf aquatic plants such as *Nymphaea tetragona* and *Nymphoides peltata* and submerged plants such as *Ceratophyllum demersum*, *Vallisneria natans*, and *Hydrilla verticillata* were replanted (Table 1). The planting area of different types of aquatic plants follows the order submerged plants > emergent plants > floating-leaf plants. The planting area of floating-leaf plants is 2.67 times larger than that of other types of aquatic plants.

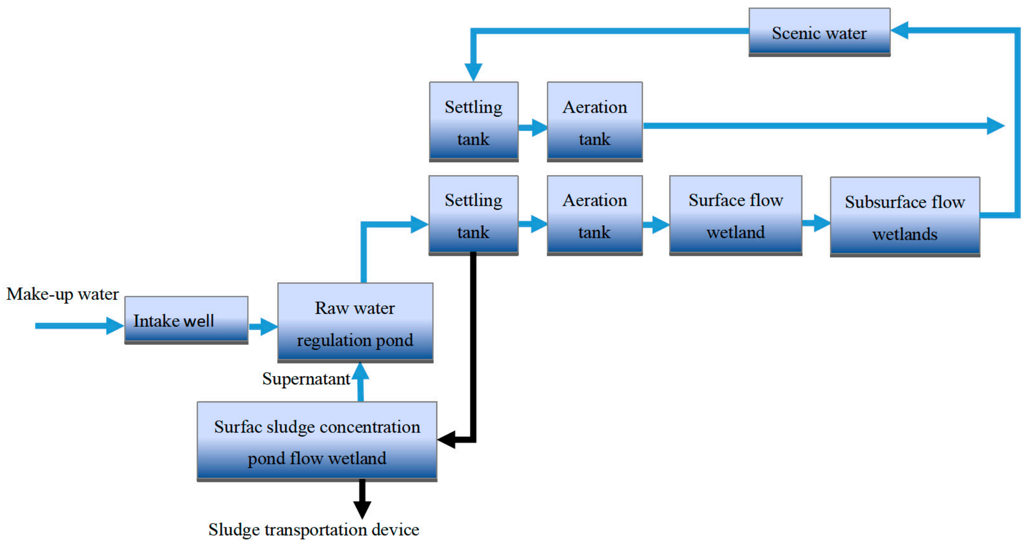

Figure 5. Process flow diagram of the water treatment plant.

Table 1. List of aquatic plants in the garden.

Life Form	Species	Area (m^2)	Planting Density (Individuals/m^2)
Emergent plant	*Cortaderia selloana* 'Pumila'	244	8
	Sagittaria trifolia	494	25
	Juncus effusus	270	48
	Cyperus involucratus	1188	25
	Typha latifolia 'Variegata'	425	25
	Iris pseudacorus	1296	30
	Typha latifolia	232	25
	Canna indica	195	25
	Lythrum salicaria	1283	20
	Cyperus papyrus	952	30
	Acorus gramineus	1084	25
	Schoenoplectus tabernaemontani	656	30
	Pontederia cordata	443	16
	Nelumbo nucifera	1335	3~4
	Thalia dealbata	1486	8~12
	Alisma plantago-aquatica	866	20

Table 1. *Cont.*

Life Form	Species	Area (m^2)	Planting Density (Individuals/m^2)
Floating-leaf plant	*Nymphaea tetragona*	2940	1~2
	Nymphoides peltata	983	10~20
Submerged plant	*Ceratophyllum demersum*	4177	60~80
	Vallisneria natans	12,119	60~80
	Hydrilla verticillata	7791	60~80
	Potamogeton wrightii	7006	60~80
	Batrachium trichophyllum	3806	60~80
	Elodea canadensis	7039	60~80
	Potamogeton crispus	1835	60~80

Aquatic animals should be selected based on their ability to effectively remove suspended particles, such as algae and debris, with a focus on short food chains. A certain number and variety of filter-feeding fish, carnivorous fish, and benthic animals was reintroduced to improve the purification ability and stability of the aquatic ecosystem (Table 2).

Table 2. Biomass of aquatic animals released.

No	Species	Size (cm)	Total Mass (kg)
1	*Hypophthalmichthys molitrix*	8~12	16,680
2	*Aristichthys nobilis*	3~7	3336
3	*Xenocypris microlepis*	3~4	112
4	*Ctenopharyngodon idellus*	5~8	28.8
5	*Caridina zhejiangensis*	2~3	1900
6	*Macrobrachium nipponense*	2~3	1300
7	*Cristaria plicata*	4~5	1800
8	*Cipangopaludina chinensis*	0.8~1	7400

2.3. Sampling and Testing

A total of 12 sampling points were set up for water quality monitoring and sediment testing. According to the surface water area, points 1~3 were located in Shenjing River, 4~7 in West Lake, 8~9 in Aquatic Garden and 10~12 in East Lake. During 2015–2017, samples were collected once every month to detect the dissolved oxygen (DO), pH, conductivity (EC), BOD_5, COD_{cr}, total nitrogen, ammonia nitrogen, and total phosphorus. In August 2016, 0–10 cm top sediments were collected with a grab-type sampler and placed in a clean polyethylene self-sealing bag.

The following parameters of water quality were measured in the laboratory immediately after sampling: dissolved oxygen and temperature (Hach HQ30d, USA), pH (Hach HQ411d, USA), turbidity (Hach 2100Q, USA), and electrical conductivity (Leici Company, China). Samples of COD, TN and TP were kept frozen and analyzed the day after sampling. Moreover, parameters of COD_{cr}, NH_3-N, TN and TP were measured according to APHA (2005). BOD_5 was determined by measuring the dissolved oxygen value immediately. These samples were then incubated for 5 days at 20 °C and measured again. The D-value (mg/L) was calculated as the 5-day biochemical oxygen demand.

The sediment samples were air-dried naturally in a cool and ventilated environment and then processed by removing gravel, shells, and weeds before being sieved through a 100-mesh (0.154 mm) nylon sieve. TN of sediments was determined using the Kjeldahl method (Sinopharm Chemical Reagent Co., Ltd., Shanghai, China), TP was determined using the $HClO_4$-H_2SO_4 method (Sinopharm Chemical Reagent Co., Ltd., Shanghai, China), and organic matter was determined by virtue of the potassium dichromate volumetric method (Sinopharm Chemical Reagent Co., Ltd., Shanghai, China). Heavy metals were determined using the HNO_3-H_2O_2-HCl digestion method (Sinopharm Chemical Reagent Co., Ltd., Shanghai, China). The digested solutions of samples were analyzed using inductively coupled plasma atomic absorption spectrometry (Agilent ICPMS 7700® USA).

2.4. Data Analysis

2.4.1. Organic Matter and Nitrogen

The classification standards for sediment organic nitrogen and organic indexes are displayed in Table 3. The organic matter consisting of organic nitrogen and organic carbon was an important indicator of the environmental status of the sediment.

Table 3. Evaluation standard for organic matter and organic nitrogen [33].

Parameters	Value	Description	Level
Organic matter	<0.05	Clean	I
	0.05~0.20	Fairly clean	II
	0.20~0.05	Still clean	III
	≥0.50	Organic pollution	IV
Organic nitrogen (%)	<0.033	Clean	I
	0.033~0.066	Fairly clean	II
	0.066~0.133	Still clean	III
	≥0.133	Organic nitrogen pollution	IV

Their calculation formulas were as follows [34,35]:

$$\text{Organic nitrogen (\%)} = \text{total nitrogen (\%)} \times 0.95$$

$$\text{Organic carbon (\%)} = \text{organic matter (\%)}/1.724$$

$$\text{Organic index} = \text{organic carbon (\%)} \times \text{organic nitrogen (\%)}$$

2.4.2. Nemero Comprehensive Pollution Index

The Nemero comprehensive pollution index is an evaluation method based on the single-factor pollution index, which was required to establish environmental indicator quantity standards. The calculation method was as follows:

$$P_{\text{i}} = \frac{C_{\text{i}}}{S_{\text{i}}} \quad (1)$$

$$P_Z = \sqrt{\frac{(P_{\text{i}})^2 + (P_{\max})^2}{2}} \quad (2)$$

In the formula, P_{i} represents the single-factor evaluation index; C_{i} represents the measured content of the i-th environmental indicator quantity; S_{i} represents the evaluation standard of the environmental indicator quantity. P_Z represents the Nemero comprehensive index; P_{i} represents the number of evaluation indexes; $P_{\max}$ represents the maximum value of the single-factor evaluation index [36–38].

The grade standards for the comprehensive pollution index are shown in Table 4. When evaluating the comprehensive pollution of sediment nutrients, the background values of TN and TP in the Taihu Basin sediment were selected as regional background values [39], i.e., C_s = 0.67 g/kg for TN and C_s = 0.44 g/kg for TP.

Table 4. Standards for single- and Nemero comprehensive pollution index.

Level	Single Pollution Index P_i	Nemero Comprehensive P_Z	Index Pollution Degree
1	$P_i \leq 0.7$	$P_Z \leq 0.7$	Clean (safe)
2	$0.7 < P_i \leq 1.0$	$0.7 < P_Z \leq 1.0$	Slight pollution (cautionary level)
3	$1.0 < P_i \leq 2.0$	$1.0 < P_Z \leq 2.0$	Moderate pollution
4	$2.0 < P_i \leq 3.0$	$2.0 < P_Z \leq 3.0$	Heavy pollution
5	$P_i > 3.0$	$P_Z > 3.0$	Extreme pollution

When evaluating the comprehensive pollution of heavy metals in sediments, the soil background values of Shanghai were used as regional background values [40], i.e., As 9.1 mg/kg, Cr 75 mg/kg, Zn 86.1 mg/kg, Pb 25.47 mg/kg, Cd 0.132 mg/kg, Ni 31.9 mg/kg, Cu 28.59 mg/kg, and Hg 0.101 mg/kg.

When evaluating the comprehensive pollution of water quality, the Class III water standard in the Surface Water Environmental Quality Standards (GB 3838-2002) was used as the background value in this region, i.e., DO 5 mg/L, COD_{cr} 20 mg/L, TN 1 mg/L, ammonia nitrogen 1 mg/L, TP 0.05 mg/L, and BOD_5 4 mg/L.

3. Results

3.1. Water Quality

Dissolved oxygen, COD_{cr}, TN, ammonia nitrogen, TP and BOD_5 were evaluated by the Nemero comprehensive pollution index method and level classification in spring (March–May), summer (June–August), autumn (September–November), and winter (December–February) (Table 5). The Nemero comprehensive pollution index values of Shenjing River, West Lake, Aquatic Garden, and East Lake ranged from 0.83 to 1.62. It was shown that there was a moderate level of pollution. The level of water quality presented as autumn > winter > spring > summer.

Table 5. Values and grades of the Nemero comprehensive pollution index in all seasons.

Location	Spring	Summer	Autumn	Winter	Mean
Shenjing River	1.51 M	1.47 M	1.59 M	1.46 M	1.46 M
West Lake	1.14 M	1.33 M	1.53 M	1.20 M	1.24 M
Aquatic Garden	1.54 M	1.34 M	1.57 M	1.15 M	1.40 M
East Lake	0.83 S	1.26 M	1.62 M	1.45 M	1.27 M

Note: C represents clean (safe) pollution levels, S represents slight pollution (cautionary level), and M represents moderate pollution.

In addition to dissolved oxygen, COD_{cr}, ammonia nitrogen, and BOD_5, the individual pollution index values of TN and TP were also relatively higher in redevelopment landscape water (Table 6). The Nemero pollution index values for TN ranged from 1.58 to 1.86, with relatively lower values in the East Lake and West Lake, suggesting a state of moderate pollution. The Nemero pollution index values for TP ranged from 0.89 to 1.22, with relatively lower values in Aquatic Garden and West Lake, which indicated a moderate or slight pollution state.

Table 6. Single pollution index value and water quality classification.

Location	P_i					
	DO	COD_{cr}	TN	NH_3-N	TP	BOD_5
Shenjing River	0.64 C	0.70 C	1.86 M	0.28 C	1.22 M	0.53 C
West Lake	0.63 C	0.67 C	1.58 M	0.23 C	0.90 S	0.50 C
Aquatic Garden	0.66 C	0.69 C	1.81 M	0.26 C	0.89 S	0.50 C
East Lake	0.60 C	0.77 S	1.60 M	0.22 C	1.13 M	0.56 C

Note: C represents clean (safe) pollution levels, S represents slight pollution (cautionary level), and M represents moderate pollution.

3.2. Nutrients in Sediments

Table 7 summarizes the results of nutrient determination in sediments. The organic matter value of top sediments in landscape waters ranged from 0.06 to 0.45, revealing relatively clean conditions. The range of organic nitrogen was between 0.07% and 0.16%, which implied that the overall state was still relatively clean. For sampling points, the organic matter in the Shenjing River was still clean despite its organic pollution. All fairly clean conditions were determined in West Lake, the Aquatic Garden and East Lake.

Table 7. Assessment of sediment pollution.

Sampling Location	Organic Matter			Organic Nitrogen (%)		
	Average Value	Type	Level	Average Value	Type	Level
Shenjing River	0.45 ± 0.38	Still clean	III	0.16 ± 0.06	Organic pollution	IV
West Lake	0.06 ± 0.03	Fairly clean	II	0.07 ± 0.02	Still clean	III
Aquatic Garden	0.10 ± 0.01	Fairly clean	II	0.10 ± 0.01	Still clean	III
East Lake	0.13 ± 0.04	Fairly clean	II	0.11 ± 0.02	Still clean	III
Average value	0.11 ± 0.05	Fairly clean	II	0.11 ± 0.05	Still clean	III

The pollution degree of the Shenjing River was heavy, while the other three water bodies were moderately polluted according to TN, TP and comprehensive pollution evaluation standards (Table 8). This indicates that the endogenous load of nutrients, especially nitrogen sources, should not be ignored in these waters.

Table 8. Comprehensive sediment pollution evaluation.

Location	P_{TN}	P_{TP}	P_Z	Pollution Degree
Shenjing River	1.84	2.53	2.21	Heavy
West Lake	1.21	1.33	1.27	Moderate
Aquatic Garden	1.54	1.56	1.55	Moderate
East Lake	1.54	1.68	1.61	Moderate
Average value	1.51	1.68	1.60	Moderate

The C/N ratio in sediments reflects the source of nutrients. The C/N ratio of fiber-bundle plant debris is greater than 20, while that of non-fiber-bundle plants ranges from 4 to 12. The C/N ratio of planktonic animals is less than 7, while that of planktonic plants ranges from 6 to 14 and that of algae from 4 to 10. In general, organic matter is mainly from land when the C/N ratio is greater than 10, while it mainly comes from within the water body when the C/N ratio is less than 10. When the C/N ratio is approximately 10, the organic matter from within and outside the water body is balanced. Clearly, the C/P ratio can reflect the decomposition rate of organic carbon and phosphorus compounds in sediments, as well as the form of phosphorus. A higher C/P ratio indicates that the material source primarily derives from terrestrial biomass, with phosphorus being rapidly released after biological death and organic matter being released more slowly.

In the sediments of the Chenshan Botanical Garden, the C/N ratio was mostly between 10 and 15, with an average value of 11.98 (Table 9). It indicated that organic matter and nutrients in water mostly came from external sources, except for a small amount from higher plants and planktonic organisms. The average C/P ratio was 22.82, with the highest value in the Shenjing River and the lowest in West Lake. Therefore, continuous efforts should be made to strengthen external nutrient pollution control.

Table 9. Ratios of C, N, and P in sediments.

Location	C/N	N/P	C/P
Shenjing River	14.89	3.33	49.59
West Lake	10.39	1.25	13.00
Aquatic Garden	9.84	1.56	15.32
East Lake	10.28	1.81	18.60
Average Value	11.98	1.91	22.82

3.3. Heavy Metal in Sediments

Based on the single pollution index and the Nemero comprehensive pollution index for heavy metals in sediments, it was indicated that Hg pollution was moderate in West Lake and Aquatic Garden, while Cu pollution was moderate in East Lake (Table 10). However, clean or slightly contaminated conditions were observed with other heavy metals. The range of As was 0.52 to 0.76, with an average of 0.67. The range of Cr was 0.70 to 0.84, with an average of 0.78. The range of Zn was 0.70 to 0.86, with an average of 0.78. The range of Pb was 0.81 to 0.97, with an average of 0.88. The range of Cd was 0.39 to 0.97, with an average of 0.68. The range of Ni was 0.78 to 0.99, with an average of 0.88. The range of Cu was 0.79 to 1.06, with an average of 0.95. The range of Hg was 0.81 to 1.07, with an average of 0.95. The Nemero comprehensive pollution index range was 0.81 to 1.07, suggesting that heavy metal pollution in this region was within the cautionary range. However, sediments in the Aquatic Garden should be monitored as a priority due to heavy metal pollution.

Table 10. Nemero comprehensive pollution index and grades of heavy metal pollution in sediments.

Location	P_i								P_Z
	As	Cr	Zn	Pb	Cd	Ni	Cu	Hg	
Shenjing River	0.75 S	0.74 S	0.70 C	0.87 S	0.62 C	0.78 S	0.79 S	0.69 C	0.81 S
West Lake	0.60 C	0.79 S	0.79 S	0.87 S	0.80 S	0.92 S	1.00 S	1.02 M	0.94 S
Aquatic Garden	0.52 C	0.70 C	0.77 S	0.81 S	0.97 S	0.81 S	0.90 S	1.25 M	1.07 M
East Lake	0.76 S	0.84 S	0.86 S	0.97 S	0.39 C	0.99 S	1.06 M	0.97 S	0.96 S
Mean	0.67 C	0.78 S	0.78 S	0.88 S	0.68 C	0.88 S	0.95 S	0.96 S	0.95 S

Note: C represents clean (safe) pollution levels, S represents slight pollution (cautionary level), and M represents moderate pollution.

4. Discussions

Since 1950, more than 1.3 million hm^2 of lakes have been lost in China due to land reclamation for agriculture, aquaculture and infrastructure development [41,42]. Many cases of ecological restoration engineering have been implemented in degraded or disturbed lake wetlands and have achieved some success [6]. Notable changes in water and sediment composition were observed in this study. Ammonia nitrogen, TN, and TP levels in the water have consistently decreased over time [43]. Continuous quantitative assessments were conducted over a two-year period, and the majority of water exhibited mild to moderate pollution levels. The high input of fertilizers required for plant maintenance in the Aquatic Garden would result in non-point source pollution pressure, consistent with the findings of Vadas et al. [44]. According to the assessment results of the single pollution index and Nemero comprehensive pollution index for sediments, the TN content in this study was lower than Poyang Lake [45], Chaohu Lake [46], Dongting Lake [47], and Dalian Lake [48]. TP content was also lower than that of Dalian Lake [48], Dianshan Lake [49] and Chaohu Lake [46]. The Cu, Zn, Cd, and Pb content in sediment in this study was significantly lower than that in Dalian Lake [48], Dianshan Lake [50], Dishui Lake [51] and other public park water in Shanghai [52], while Hg, As, Ni, and Cr showed differences. These results can be attributed to eco-engineering techniques in hydrodynamic circulation reconstruction, water purification treatment, aquatic ecosystem restoration, and plant harvesting management.

A few common approaches to shallow lake restoration at presnet are the reduction of total nutrient loads by controlling pollution sources [53,54] and increasing hydrodynamic circulation [55]. Organic matter and nutrients in the water primarily originate from surface runoff, with only a minimal contribution from higher plants and planktonic organisms. This was indicated by the C/N ratio of sediments, with an average value of 11.98. The improvement in hydraulic conditions increases the oxygenation capacity of the water, promoting the dilution capacity and self-purification ability of water ecosystems [56,57], as was demonstrated by the evaluation of DO, COD_{Cr} and BOD5 of water in this study. This closed landscape water could achieve a better performance in comparison with outside rivers [6]. Moreover, the operation of hydrodynamic circulation systems with ecological measures over 30 days is more cost-effective than tap water replenishment planned every 10 days [58]. Therefore, closed hydrodynamic circulation systems with a period of around 30 days are beneficial for ensuring the health and efficiency of water quality in regional areas.

Secondly, approximately 10,000 m^3 of water was pumped into the water purification treatment per day; sometimes, 3000 m^3/day was pumped from the river outside when the landscape water needed to be replenished. Coagulation–sedimentation is a considerable technique for pretreating wastewater. The total suspended solids are effectively reduced or eradicated in raw water regulation ponds and coagulation sedimentation tanks. These solids are subsequently eliminated through the sludge removal system. Other pollutions such as COD_{Cr}, BOD_5, TN, NH_4-N, and TP were reduced by surface and subsurface flow treatment wetlands [59,60]. Surface flow treatment wetlands are the favored option for stormwater wetlands as well as tertiary treatment wetlands designed to polish minimally polluted effluents [61,62]. Subsurface flow treatment wetlands may be more efficient at removing nutrients because the media contribute to phosphorus absorption or serve as a substrate for microbial development [30,63]. Meanwhile, wetland plants not only directly assimilate heavy metals from wastewater through their own growth, they also eliminate heavy metals through the secretion of metabolites and their influence on the rhizosphere microorganisms. For instance, plant roots secrete metal-binding proteins that can form complexes or chelate heavy metals in wastewater, rendering them less reactive [64]. In this case study, combined coagulation–sedimentation, surface and subsurface flow treatment wetlands contributed to the comprehensive treatment of different levels of pollution in circulation or replenishment waters.

Thirdly, aquatic ecosystem restoration and its effective management plays a crucial role in ensuring water quality and ecosystem health. During the process of aquatic ecosystem restoration, plants are chosen based on their ecological functionality and water purification capabilities. Studies have shown that submerged aquatic plants have significantly higher nitrogen and phosphorus content and heavy metal accumulation compared to floating and emergent plants [65,66]. The nitrogen- and phosphorus-removal efficiency of submerged plants such as *Hydrilla verticillata* and *Vallisneria natans* is more efficient than that of emergent plants such as *Typha orientalis* and *Phragmites australis* [67,68]. By introducing appropriate filter-feeding fish species, the eutrophication of the water body can be suppressed, and snails and mussels can also contribute to the purification of water quality [69,70]. In this case study, the plantation area of submerged plants is 2.67 times larger than that of other aquatic plants. This includes filter-feeding fish species such as *Hypophthalmichthys molitrix*, *Ctenopharyngodon idellus*, and *Cristaria plicata*, as well as benthic organisms, which effectively decrease the concentration of nutrients in the water. It has been reported that submerged plants typically require around 10 days for phosphorus release and 28–30 days for total nitrogen release. As a result, submerged plants should be harvested within one week after death [71]. The optimal harvesting time for *Canna indica* and *Juncus effusus*, based on nitrogen and phosphorus uptake, is April, May, and June, respectively [72]. In this case study, submerged plants were harvested every month from April to November, while emergent plants and floating plants were harvested at the end of the growth season as part of a management strategy to efficiently remove nitrogen and phosphorus. The presence of aquatic organisms in the aquatic ecosystem can effectively reduce nutrient levels in the water environment.

5. Conclusions

It is practical and effective to perform a post-evaluation of ecological redevelopment on its achievements. In this paper, these eco-engineering techniques, including hydrodynamic circulation reconstruction, water purification treatment, and aquatic ecosystem restoration, along with plant harvesting management, have demonstrated water quality maintenance achievements. The ecological redevelopment of landscape water reconstructed from aquaculture ponds was evaluated using the single and Nemero comprehensive pollution index methods. The nutrients, including organic matter, organic nitrogen and their ratio to sediments, were confirmed to be in a state of moderate pollution, while the ecological risks of heavy metals were relatively low. Although the concentrations of total nitrogen and total phosphorus in water were higher than those of other indexes, ammonia nitrogen, total nitrogen and total phosphorus all presented obvious downward trends over time, and the majority of water exhibited mild to moderate pollution levels. In general, this study provides a set of reference values for redeveloping water ecosystems from aquaculture ponds using eco-engineering technologies.

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