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Posted Date: 1 August 2023

doi: 10.20944/preprints202307.2124.v1

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Article

Eco-Engineering Technologies and Achievements of Landscape Water Reconstructed from Aquaculture Ponds in Shanghai

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Abstract: Post-evaluation of ecological redevelopment is a good method for 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 for landscape water reconstructed 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 by adopting the single and Nemero comprehensive pollution index method. The results demonstrated that nutrients including organic matter, organic nitrogen and their ratio of sediments were confirmed to be in a state of moderate pollution, while their ecological risks of heavy metals were relatively low. Although the concentrations of total nitrogen and total phosphorus were really higher than those of other indexes, ammonia nitrogen, total nitrogen and total phosphorus all presented obvious downward trends over time and a majority of water were exhibited mild to moderate pollution levels. In general, this study provides certain reference value for redevelopment of water ecosystems from aquaculture ponds using eco-engineering technologies.

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

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 expanse of aquaculture ponds has attained a span of 26,450 m³, constituting 51.7% of the nation's overall freshwater aquaculture region [1]. Notably, the aggregate territory of aquaculture ponds within the Yangtze River Basin has encompassed an extensive area of 14,567 m³ [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 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 reconstruction of water ecosystems [4,5]. These methods not only have been applied in ecological restoration of large lakes and wetlands including Taihu Lake, Chaohu Lake, Dianchi Lake, West Lake, but also used to control and maintain the water quality of large artificial lakes, streams and pools in urban open space [6]. The effect of ecological redevelopment on water ecosystems mainly are conducted in eutrophic lakes and constructed wetlands [7,8]. In aquaculture ponds, terrain modification has been carried out by dismantlement of pond dikes, drainage treatment, sediment replacement, and sun exposure at the bottom of pond in Yilong Lake in Yunnan [5]. Also, the implementation of vegetative buffer zones, including reintroduction of aquatic plants and construction of ecological floating islands has been completed

in Qiachuan Town within the Yellow River Nature Reserve [4]. Indeed, there are a few reports on reconstruction of water ecosystems from aquaculture ponds [9–11].

It is practical and effective to perform post-evaluation of ecological redevelopment on its achievements [12,13]. Two aspects for water environmental quality evaluation need to be mentioned, namely, using the water quality index to evaluate the ecosystems redevelopment and conducting comprehensive evaluation including water quality and sediment index [14]. However, the existing assessment studies are carried out immediately after engineering completion with few indicators and short cycle [15,16]. For example, water quality chemical indicators 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 after 6 months 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, BOD₅, ammonia nitrogen, total nitrogen, total phosphorus, chloride, and total suspended solids was conducted for the ecological restoration demonstration project in 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 body is full of nutrients and heavy metals, which becomes the primary source of pollution [23,24]. Specially, most nitrogen and phosphorus that are the primary load of water body nutrients and participate in the circulation of water ecosystems undergo 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 evolution characteristics but also enables the identification of key pollution factors and the implementation of effective preventive and control measures. Furthermore, it 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 of landscape water reconstructed 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 redevelopment of water ecosystems from aquacultural bonds using ecological engineering technologies.

2. Materials and Methods

2.1. Study Area

The research site with geographical coordinates of the central position (31°04'48.10"N, 121°11'5.76" E) was located on 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. 60% of rainfall is concentrated in the rainy season from May to September. The soil in Shanghai previously described is a silty clay loam with an elevated pH of 8.



Figure 1. Location of this study area.

The total area was 207,000 m², with Chenshan hill, village, rivers, farmlands and aquaculture ponds covered. In this region, the area of surface water was 90,774 m², of which aquaculture ponds accounted for 34.5% [28] (Figure 2). The maximum value on nitrogen content of surface water in aquaculture ponds was 13.54 mg/L, leading to frequent outbreak of eutrophication and fertile sediments. Moreover, there were excessive heavy metals in ponds 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 design within Shanghai Chenshan Botanical Garden, which was composed of hills, water and plants. Its surface water area has been expanded to 200,000m² by terrain consolidation and reshaping from rice farmlands and aquaculture ponds (Figure 3). During the initial phase of construction, 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 as water flow direction, which was sequenced by Shenjing River (19,041 m²), West Lake (104,296 m²), Aquatic Garden (25,823 m²) and East Lake (49,684 m²). To improve the water quality, a water treatment plant with a total area of 10000 m² including the 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 landscape water system.

A cycle purification system was designed and established in landscape water (Figure 4). The landscape water which mainly relies on natural precipitation replenishment is circulated through methods such as groundwater replenishment and outside river supplement. There were 40,000 m³ volumes in all surface water estimated by the designed mean depth of 2 m water. The designed hydrodynamic cycle was almost one month. A total of 10,000 m³ waters were pumped from East Lake to water treatment plant through a pipeline each day, with maximum daily supplement amount of 3000 m³ from river in outside.

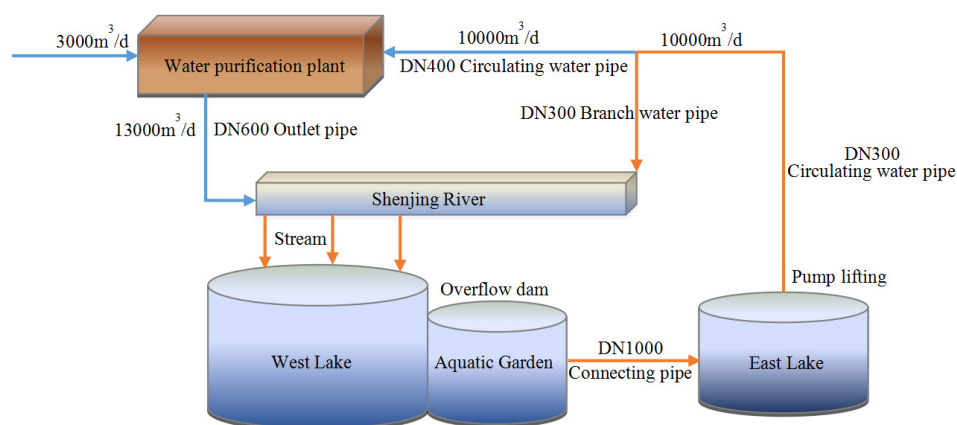


Figure 4. Schematic diagram of water cycle purification for landscape water. The total amount of green irrigation and evaporation in West Lake, Aquatic Garden and East Lake is 3000m³/d.

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 undergoing filtration and percolation through the soil prior to entering the landscape water.

The circulation water and supplement water of river in outside were first subjected to artificial reinforcement treatment such as coagulation and sedimentation in the semi-buried sewage treatment plant to remove most of the suspended substances, total phosphorus and organic matter. Only 3,000 m³ water flowed into 3,000 m² surface flow constructed wetlands and 56 parallel independent 65m² subsurface flow constructed wetlands to remove substances such as organic matter, ammonia nitrogen, and total phosphorus [30,31] (Figure 5).

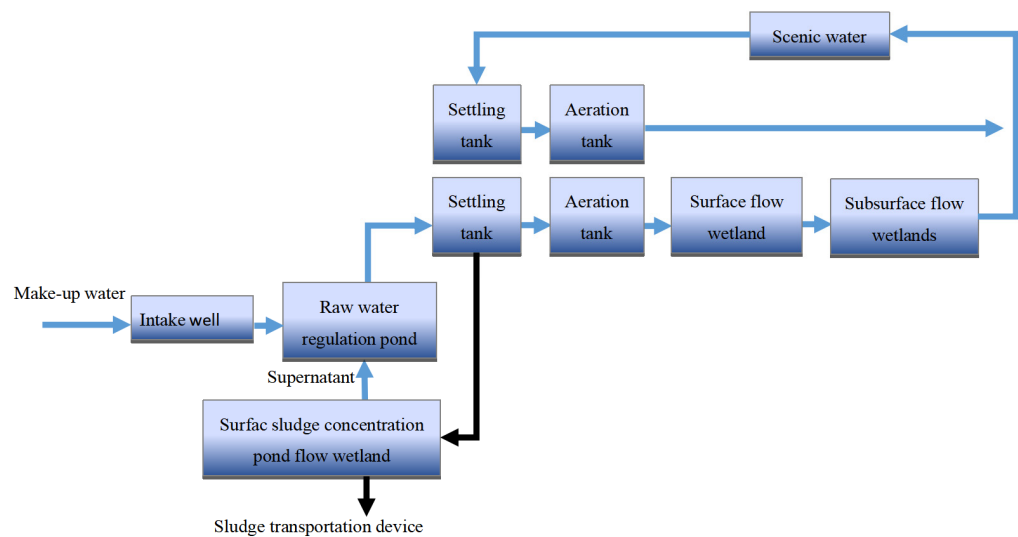


Figure 5. Process flow diagram of water treatment plant.

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 erects revetments. The length of natural revetments accounted for 74.4% of the entire waterfront space while erect revetments was only 12.3%[32].

The selection of aquatic species should prioritize their ecological functions and water purification abilities, especially the native species. In natural and near-nature waterfront spaces, vegetation zones with hygrophytes, emergent plants, floating-leaf plants or submerged plants were replanted gradually. In waterfront space above normal water level, water-tolerant hygrophytes such as *Taxodium mucronatum*, *Salix babylonica*, *Pterocarya stenoptera*, *Metasequoia glyptostroboides*, *Glyptostrobos pensilis*, *Triadica sebifera*, and *Cephalanthus tetrandrus* were replanted. Around normal water level, 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.

Table 1. List of aquatic plant in the garden.

Life form	Species	Area (m ²)	Planting density (individuals/m ²)
Emergent plant	<i>Cortaderia selloana</i> 'Pumila'	244	8
	<i>Sagittaria trifolia</i>	494	25
	<i>Juncus effusus</i>	270	48
	<i>Cyperus involucratus</i>	1188	25
	<i>Typha latifolia</i> 'Variegata'	425	25
	<i>Iris pseudacorus</i>	1296	30

Floating-leaf plant	<i>Typha latifolia</i>	232	25
	<i>Canna indica</i>	195	25
	<i>Lythrum salicaria</i>	1283	20
	<i>Cyperus papyrus</i>	952	30
	<i>Acorus gramineus</i>	1084	25
	<i>Schoenoplectus tabernaemontani</i>	656	30
	<i>Pontederia cordata</i>	443	16
	<i>Nelumbo nucifera</i>	1335	3~4
	<i>Thalia dealbata</i>	1486	8~12
	<i>Alisma plantago-aquatica</i>	866	20
	<i>Nymphaea tetragona</i>	2940	1~2
	<i>Nymphoides peltata</i>	983	10~20
	<i>Ceratophyllum demersum</i>	4177	60~80
	<i>Vallisneria natans</i>	12119	60~80
	<i>Hydrilla verticillata</i>	7791	60~80
Submerged plant	<i>Potamogeton wrightii</i>	7006	60~80
	<i>Batrachium trichophyllum</i>	3806	60~80
	<i>Elodea canadensis</i>	7039	60~80
	<i>Potamogeton crispus</i>	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 have been reintroduced to improve the purification ability and stability of the aquatic ecosystem (Table 2).

Table 2. Biomass of aquatic animal released.

No	Species	Size (cm)	Total mass (kg)
1	<i>Hypophthalmichthys molitrix</i>	8~12	16680
2	<i>Aristichthys nobilis</i>	3~7	3336
3	<i>Xenocypris microlepis</i>	3~4	112
4	<i>Ctenopharyngodon idellus</i>	5~8	28.8
5	<i>Caridina zhejiangensis</i>	2~3	1900
6	<i>Macrobrachium nipponense</i>	2~3	1300
7	<i>Cristaria plicata</i>	4~5	1800
8	<i>Cipangopaludina chinensis</i>	0.8~1	7400

2.3. Sampling and testing

A total of 12 sampling points were set up for water quality monitoring and sediments testing. According to the surface water area, points 1~3 were located in Shenjing River, points 4~7 in West Lake, points 8~9 in Aquatic Garden and points 10~12 in East Lake. During 2015-2017, samples were collected once every month to detect the dissolved oxygen (DO), pH, conductivity (EC), BOD₅, COD_{cr}, total nitrogen, ammonia nitrogen, and total phosphorus. In August 2016, 0-10 cm top sediments were collected by a grab-type sampler and placed into 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}, NH₃-N, TN and TP were measured according to APHA (2005). BOD₅ was determined by first 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 sediments 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, TP was determined using the HClO₄-H₂SO₄ method, and organic matter was determined by virtue of the potassium dichromate volumetric method. Heavy metals were determined using the HNO₃-H₂O₂-HCl digestion method. The digested solutions of samples were analyzed using inductively coupled plasma atomic absorption spectrometry (Agilent ICPMS 7700®).

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 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
	0.20~0.50	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 following [34,35]:
Organic nitrogen (%) = total nitrogen (%) × 0.95
Organic carbon (%) = organic matter (%) / 1.724
Organic index = organic carbon (%) × organic nitrogen (%)

2.4.2. Nemero comprehensive pollution index

The nemero comprehensive pollution index was an evaluation method based on the single-factor pollution index, which was required, the establishment of environmental indicator quantity standards. The calculation method was as following:

$$P_i = \frac{C_i}{S_i}$$

(1)

$$P_z = \sqrt{\frac{(\bar{P}_i)^2 + (P_{max})^2}{2}}$$

(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; $\bar{P}_i$ represents the number of evaluation indexes, and P_{max} represents the maximum value of the single-factor evaluation index [36–38].

The grade standards for the comprehensive pollution index were shown in Table 5. When evaluation on the comprehensive pollution of sediment nutrients, the background values of TN and

TP in the Taihu Basin sediment were selected as the 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	$0.7 < P_i \leq 1.0$	$0.7 < P_z \leq 1.0$	Slightly pollution (cautionary level)
3	$1.0 < P_i \leq 2.0$	$1.0 < P_z \leq 2.0$	Moderately pollution
4	$2.0 < P_i \leq 3.0$	$2.0 < P_z \leq 3.0$	Heavily pollution
5	$P_i > 3.0$	$P_z > 3.0$	Extremely pollution

When evaluation on the comprehensive pollution of heavy metals in sediments, the soil background values of Shanghai were used as the 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 evaluation on 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 BOD₅ 4 mg/L.

3. Results

3.1. Water quality

The dissolved oxygen, COD_{cr}, TN, ammonia nitrogen, TP and BOD₅ were evaluated by the Nemero comprehensive pollution index method and level classification in spring (March to May), summer (June to August), autumn (September to November), and winter (December to February)(Table 5). The values of Nemero comprehensive pollution index of Shenjing River, West Lake, Aquatic Garden, and East Lake were ranged from 0.83 to 1.62. It was showed that a moderate level of pollution. The level of water quality presented as : autumn > winter > spring > summer.

Table 5. Values and grade of Nemero comprehensive pollution index in seasons.

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

Note: C represents the clean (safe), M represents the moderately pollution.

Besides dissolved oxygen, COD_{cr}, ammonia nitrogen, and BOD₅, 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 were ranged from 1.58 to 1.86, with relatively lower values in East Lake and West Lake, suggesting a state of moderate pollution. The Nemero pollution index values for TP were 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 pollutant index value and its classification for water quality.

Location	P_i					
	DO	COD _{Cr}	TN	NH ₃ -N	TP	BOD ₅
Shenjing River	0.64	0.70	1.86	0.28	1.22	0.53
	C	C	M	C	M	C
West Lake	0.63	0.67	1.58	0.23	0.90	0.50
	C	C	M	C	S	C
Aquatic Garden	0.66	0.69	1.81	0.26	0.89	0.50
	C	C	M	C	S	C
East Lake	0.60	0.77	1.60	0.22	1.13	0.56
	C	S	M	C	M	C

Note: C represents the clean (safe), S represents the slightly pollution (cautionary level), M represents the moderately pollution.

3.2. Nutrient in sediments

Table 7 summarizes the results of nutrient determination in sediments. The organic matter value of top sediments in landscape water body was ranged from 0.06 to 0.45, revealing an overall state of 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 in clean conditions despite its organic pollution. All fairly clean and still clean conditions were tested in West Lake, 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 Shenjing River was heavy while other three water bodies were moderately polluted according to the TN, TP and comprehensive pollution evaluation standards (Table 8). This indicated that the endogenous load of nutrients, especially nitrogen sources should not be ignored in these water bodies.

Table 8. Comprehensive pollution evaluation of sediments.

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

The C/N ratio in sediments can reflect the source of nutrients. The C/N ratio of fiber-bundle plant debris is greater than 20, while that of non-fiber-bundle plants is ranged from 4 to 12. The C/N ratio of planktonic animals is less than 7, while that of planktonic plants is ranged from 6 to 14 and that of algae from 4 to 10. In general, organic matter is mainly from land when C/N ratio is greater than 10,

while it mainly comes from within the water body when C/N ratio is less than 10. When C/N ratio is approximately 10, the organic matter from within and outside of water body is in balance. 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, it was found that 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, excepting for a small amount from higher plants and planktonic organisms. The average C/P ratio was 22.82, with the highest value in Shenjing River and the lowest in West Lake. Therefore, continuous efforts should be made to strengthen the control of external nutrient pollution.

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). Besides, a clean or slightly conditions were observed from other heavy metals. The range of As was from 0.52 to 0.76, with an average of 0.67. The range of Cr was from 0.70 to 0.84, with an average of 0.78. The range of Zn was from 0.70 to 0.86, with an average of 0.78. The range of Pb was from 0.81 to 0.97, with an average of 0.88. The range of Cd was from 0.39 to 0.97, with an average of 0.68. The range of Ni was from 0.78 to 0.99, with an average of 0.88. The range of Cu was from 0.79 to 1.06, with an average of 0.95. The range of Hg was from 0.69 to 1.25, with an average of 0.96. The range of Nemero comprehensive pollution index was from 0.81 to 1.07, suggesting that heavy metal pollution in this region was within the cautionary range. However, sediments in Aquatic Garden should be monitored as a priority due to being the affected by 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	0.74	0.70	0.87	0.62	0.78	0.79	0.69	0.81
	S	S	C	S	C	S	S	C	S
West Lake	0.60	0.79	0.79	0.87	0.80	0.92	1.00	1.02	0.94
	C	S	S	S	S	S	S	M	S
Aquatic Garden	0.52	0.70	0.77	0.81	0.97	0.81	0.90	1.25	1.07
	C	C	S	S	S	S	S	M	M
East Lake	0.76	0.84	0.86	0.97	0.39	0.99	1.06	0.97	0.96
	S	S	S	S	C	S	M	S	S
Mean	0.67	0.78	0.78	0.88	0.68	0.88	0.95	0.96	0.95
	C	S	S	S	C	S	S	S	S

Note: C represents the clean (safe), S represents the slightly pollution (cautionary level), M represents the moderately 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 reached a certain achievements [6]. Notable changes of the composition and quality of water and sediments were observed in this study. The levels of ammonia nitrogen, TN, and TP in the water have shown a consistent decrease over time [43]. Continuous quantitative assessments were conducted over a two-year, a majority of water were exhibited mild to moderate pollution levels. The high input of fertilizers in Aquatic Garden required for plant maintenance which would result in non-point source pollution pressure, consistent with findings by P.A. Vadas et al. [44]. According to assessment results of the single pollution index and Nemero comprehensive pollution index for sediments, TN content of this study was lower compared to 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 those in Dalian Lake [48], Dianshan Lake [50], Dishui Lake [51] and other public park water in Shanghai [52], while Hg, As, Ni, and Cr was showed differences. These results can be attributed to the following eco-engineering techniques in hydrodynamic circulation reconstruction, water purification treatment and aquatic ecosystem restoration along with plant harvesting management.

Firstly, two common approaches for shallow lake restoration nowadays need to be mentioned, namely, decreasing the total nutrient load by pollution sources control [53,54] and increasing the hydrodynamic circulation [55]. Although organic matter and nutrients in the water primarily originate from surface runoff with only a minimal contribution from higher plants and planktonic organisms, as was indicated by the C/N ratio of sediments, with an average value of 11.98. The improvement of hydraulic conditions increases the oxygenation capacity of the water, promoting the dilution capacity and self-purification ability of the water ecosystems [56,57], as was demonstrated by the evaluation of DO, COD_{Cr} and BOD_5 of water in this study. This closed landscape water could reach a better performance in comparison with outside rivers [6]. Moreover, the operation of hydrodynamic circulation systems with ecological measures over a period of 30 days has more cost-effectively than tap water replenishment planned every 10 days [58]. Thus, closed hydrodynamic circulation systems with approximately 30 day's period can ensure the water quality healthy and operational economically in regional area.

Secondly, approximately 10,000 m^3 of water were pumped into the water purification treatment per day, sometimes, 3000 m^3/day were pumped from outside river when the landscape water needs to be replenished. Coagulation-sedimentation is one of the considerable techniques for pretreating the waste water. The total suspended solids are effectively reduced or eradicated in raw water regulation ponds and coagulation sedimentation tank, which are subsequently eliminated through the sludge removal system. Other pollutions such as COD_{Cr} , BOD_5 , TN, $\text{NH}_4\text{-N}$, 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 [63,64]. Meanwhile, wetland plants not only directly assimilate heavy metals from wastewater through their own growth, but also eliminate heavy metals through the secretion of metabolites and their influence on rhizosphere microorganisms. For instance, plant roots secrete metal-binding proteins that can form complexes or chelate heavy metals in wastewater, rendering them less reactive [65]. In this case study, the combination of coagulation-sedimentation, surface and subsurface flow treatment wetlands are contributed the comprehensive of different pollution in water of circulation or replenishment.

Thirdly, aquatic ecosystem restoration and its effectively management play the final barrier for water quality and ecosystem health. During the process of aquatic ecosystems 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 [66,67]. The nitrogen and phosphorus removal efficiency of submerged plants such as *Hydrilla verticillata* and *Vallisneria spiralis* is greater than that of emergent plants like *Typha orientalis* and *Phragmites australis* [68,69]. By introducing appropriate filter-feeding fish species, the eutrophication of the water body can be suppressed, and snails and mussels also contribute to the purification of water quality [70,71]. In this case study, the plantation area of submerged plants is 2.67 times larger than that of other aquatic plants, 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. This result in submerged plants should be harvested within one week after their death [72]. The optimal harvesting time for *Canna indica* and *Juncus effusus*, based on nitrogen and phosphorus uptake, is determined to be in April, May, and June, respectively [73]. In this case study, submerged plants are harvested every month from April to November, while emergent plants and floating are harvested at the end of 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 the levels of nutrients in the water environment.

5. Conclusions

It is practical and effective to perform 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 been demonstrated the achievements of water quality maintenances. The ecological redevelopment of landscape water reconstructed from aquaculture ponds was evaluated by adopting the single and Nemero comprehensive pollution index method. The nutrients including organic matter, organic nitrogen and their ratio of sediments were confirmed to be in a state of moderate pollution, while their ecological risks of heavy metals were relatively low. Although the concentrations of total nitrogen and total phosphorus of water were really higher than those of other indexes, ammonia nitrogen, total nitrogen and total phosphorus all presented obvious downward trends over time and a majority of water were exhibited mild to moderate pollution levels. In general, this study provides certain reference value for redevelopment of water ecosystems from aquaculture ponds using eco-engineering technologies.

Author Contributions: Conceptualization, Guowei Zhang, Kankan Shang and Qian Zhang; Data curation, Guowei Zhang and Kankan Shang; Funding acquisition, Kankan Shang; Methodology, Guowei Zhang and Kankan Shang; Supervision, Kankan Shang and Qian Zhang; Visualization, Guowei Zhang; Writing - original draft, Guowei Zhang, Kankan Shang; Writing - review & editing, Kankan Shang.

Funding: This research was supported by Project of Shanghai Municipal Commission of Science and Technology (22dz1209603); Shanghai Talent Development Fund Project (2021050).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the restriction policy of the co-authors' affiliations.

Acknowledgments: The authors would like to thank Jingsha Zhang for their technical assistance.

Conflicts of Interest: The authors declare no conflict of interest.

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