water

MDPI

Article

Jinluo Low-Density Lotus Pond Wetland Water Purification Practice Experiment—A Case of Limited Efficacy

Bo Liu [1], Yuan Gao [2,3,*], Jing Zhou [4], Yun Wang [2] and Junxia He [1]

[1] Shandong Linyi Station of Positioning Observation and Research for Forest Ecosystem, College of Resources and Environment, Linyi University, Linyi 276005, China; liubo@lyu.edu.cn (B.L.); hejunxia@lyu.edu.cn (J.H.)
[2] Shandong Provincial Key Laboratory of Water and Soil Conservation and Environmental Protection, College of Resources and Environment, Linyi University, Linyi 276005, China; wangyun@lyu.edu.cn
[3] Linyi Scientific Exploration Laboratory, Linyi 276037, China
[4] School of Life Sciences, Qufu Normal University, Jining 273165, China; jingzhou-2004@163.com
* Correspondence: 13589652495@163.com

Abstract

(1) Although lotus ponds exhibit ecological benefits in wetland restoration, their efficacy in water purification and eutrophication mitigation remains unclear. (2) This study utilized Jinluo lotus pond as the experimental group and the adjacent river as the control. Five sampling points were established in each area, with water samples collected in June 2022, April 2025, and May 2025. (3) The pH, BOD, COD, TN, and NH_3-N concentrations in Jinluo lotus pond water are higher than those in rivers, while the TP, NO_3-N, Chl-a, and algal cell density in rivers are higher. However, there was no significant difference in the nine parameters ($p > 0.05$) in June 2022. The pH, DO, algal cell density, and algal biomass of the Jinluo lotus pond were significantly higher ($p < 0.05$ for DO); the concentrations of BOD, COD, TN, TP, NH_3-N, NO_3-N, PI, and Chl-a in rivers are higher, with significant differences in Chl-a ($p < 0.05$) in April 2025. The BOD, COD, TP, NO_3-N, and PI of the Jinluo lotus pond were relatively high ($p < 0.05$ for PI); the pH, TN, NH_3-N, DO, Chl-a, algal cell density, and algal biomass of rivers are higher, with significant differences in Chl-a ($p < 0.05$) in May 2025. The results showed that there was no significant difference in the four diversity indicators in June 2022, April 2025, and May 2025. There was no significant difference in the algal diversity indices, including species richness (*S*), Shannon–Wiener diversity index (*H*), Simpson diversity index (*P*), and Pielou evenness index (*E*) between Jinluo lotus pond and rivers. (4) Conclusions and Recommendations: The Jinluo lotus pond and adjacent rivers suffer from severe nutrient overload, especially with BOD, COD, and TN all being classified as Class 5 water. Expanding natural and constructed reed communities is recommended to enhance nutrient removal. However, given the limited purification capacity of lotus ponds, maintaining or increasing their area may not be justified.

Keywords: lotus ponds; constructed wetland; water purification effect; water quality assessment; phytoplankton

check for updates

Academic Editor: Zizhang Guo

Received: 1 April 2025
Revised: 24 June 2025
Accepted: 30 June 2025
Published: 1 July 2025

Citation: Liu, B.; Gao, Y.; Zhou, J.; Wang, Y.; He, J. Jinluo Low-Density Lotus Pond Wetland Water Purification Practice Experiment—A Case of Limited Efficacy. *Water* **2025**, *17*, 1985. https://doi.org/10.3390/w17131985

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

With the rapid increase in global water demand, a series of water ecological issues caused by eutrophication, such as water quality deterioration and biodiversity loss, have become a global focus of concern [1]. Water eutrophication stands as one of the greatest challenges facing the global water environment, as it undermines the stability and functionality of aquatic ecosystems [2,3]. Water scarcity has emerged as a critical issue threatening

sustainability in many regions worldwide [4,5]. Water environment governance constitutes an essential component of the United Nations Sustainable Development Goals (SDGs), with the United Nations Environment Programme (UNEP) emphasizing the pivotal role of water governance in addressing sustainable development challenges [6,7].

Selecting appropriate restoration methods is essential for the recovery of aquatic ecosystems [1]. Among these, ecological approaches—known for their cost-effectiveness and efficiency—have emerged as a preferred solution for water quality improvement in diverse aquatic systems [8]. Specifically, aquatic macrophyte-based remediation is widely regarded as one of the most economical, efficient, and environmentally sustainable methods, offering distinct advantages [8]. For instance, constructed wetlands are increasingly utilized for sustainable wastewater treatment, effectively removing organic matter and nutrients while delivering ecosystem services and recreational benefits. Notably, hybrid constructed wetlands represent the most efficient approach for enhancing water quality and mitigating greenhouse gas emissions. Their performance depends on multiple factors, including plant species, substrate selection, and environmental/hydraulic conditions, with pollutant removal efficiency largely influenced by temperature, hydraulic retention time, and pollutant loading rates [9].

Constructed wetlands composed of diverse aquatic macrophyte species, acknowledged as a convenient, environmentally friendly, low-cost, and efficient phytoremediation technology, have been widely used globally for polluted water treatment [10–12]. Artificial water bodies are increasingly becoming prominent features in urban landscapes [13], serving as temporary sanctuaries and phased wetland reserves [14], though most landscape water bodies face risks of pollution and eutrophication.

As a rapidly developing economic powerhouse, China has confronted escalating water pollution challenges resulting from decades of intensive industrialization and urbanization. In response to these pressing environmental concerns, the Chinese government initiated the groundbreaking “Sponge City” program in 2015 as a comprehensive national infrastructure strategy. This innovative approach systematically addresses multiple urban water management challenges, including the following: (1) urban surface water flooding mitigation, (2) stormwater runoff purification, (3) peak flow regulation, and (4) sustainable water resource utilization [15]. Through coordinated efforts led by the State Council and implemented by various governmental departments, sponge city development has been vigorously promoted nationwide. By 2024, the cumulative investment in this initiative had surpassed 60 billion yuan (approximately 8.3 billion USD), facilitating the creation of urban ecosystems with enhanced natural hydrological functions including water retention, infiltration, and purification capacity. However, the effectiveness of natural wetlands in pollution control remains constrained by two fundamental limitations: (1) restricted spatial expansion potential within urban environments and (2) overburdened biogeochemical processing capacities [16]. In this context, constructed wetlands have emerged as strategically important engineered ecosystems, demonstrating a proven efficacy in water quality remediation through controlled biological and physical–chemical processes [17]. Nevertheless, their operational sustainability faces challenges from two primary environmental impacts: (1) greenhouse gas emissions associated with microbial metabolic processes and (2) potential secondary pollution from accumulated contaminants [18].

Constructed wetland systems consistently demonstrate high removal efficiencies (typically 70–90%) for organic pollutants including biochemical oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids, although nitrogen removal performance shows a greater variability (30–80%) depending on system configuration [19]. Typical designs incorporate extensive reed beds utilizing either single or mixed plant species to achieve multiple treatment objectives: the physical filtration of suspended solids,

biochemical transformation of nutrients, and enhanced sedimentation processes through rhizosphere interactions [20,21]. Selected macrophyte species such as reeds (*Phragmites australis*), sedges, and other emergent vegetation effectively assimilate nutrients and pollutants through their root systems before translocating them to aerial biomass [22,23]. Particularly high-performing species commonly employed in these systems include *Phragmites australis*, *Nelumbo nucifera*, *Typha domingensis*, *T. latifolia*, *Eichhornia crassipes*, *Pistia stratiotes*, and *Vallisneria natans*, which are specifically valued for their exceptional nutrient uptake capacities demonstrated in numerous studies [22–26].

Numerous case studies have demonstrated the remarkable treatment efficiency of constructed wetlands across various applications: in Xiantao, a constructed wetland system achieved removal rates of 94% for total nitrogen, 90% for total phosphorus, 68% for COD, and 95% for ammonia nitrogen in municipal wastewater treatment [27]; at Universiti Sains Malaysia, wetlands dominated by *Typha angustifolia* and *Eleocharis variegata* effectively reduced nitrites, nitrates, ammonia nitrogen, and phosphates [28]; reed floating beds showed removal efficiencies of 55–60% for total solids, 45–55% for NH_3-N, 33–45% for NO_3^--N, 45–50% for TKN, and 40–50% for BOD, proving particularly suitable for the in-situ treatment of shallow, slow-flowing water bodies [29]; the Lotus Lake National Wetland Park in Tieling City, featuring Phragmites and *Nelumbo nucifera*, significantly reduced total phosphorus and ammonia nitrogen concentrations [30]; while lotus pond wetlands demonstrated effectiveness in treating garlic processing wastewater through the substantial removal of organic pollutants and the reduction of COD_{60} and BOD_5 levels [31]. Comparative research has revealed distinct species-specific treatment efficiencies, with *Eichhornia crassipes* and *Phragmites australis* exhibiting superior nitrogen removal capabilities, whereas *Pistia stratiotes* and *Nelumbo nucifera* show an enhanced phosphorus removal performance [24,32]. Further studies conducted at Wuliangsuhai Lake and Baiyangdian Lake have elucidated *Nelumbo nucifera*'s dual effects on algal dynamics, demonstrating that low-density plantings can promote algal growth while high-density configurations effectively suppress it, underscoring the critical importance of optimal density management in wetland design [33–35].

The Yi River, a major watercourse in the Huai River Basin [36], is located in southern Shandong and northern Jiangsu, with geographical coordinates 34°23′–36°20′ N and 117°25′–118°42′ E. Spanning approximately 574 km, it originates from Yiyuan County in Shandong and flows into the Yellow Sea at Yanwei Port through the Xin-Yi River (Yi River Diversion Channel) from Wu Lou Village in Pi County, Jiangsu [37–39]. The Yi River has been listed as a key control and monitoring river in the Huai River Basin Water Pollution Prevention Plan. The Liuqing River, a tributary of the Yi River, suffers from severe excessive nutrient loads in its upper reaches.

Extensive research confirms that aquatic plants play a beneficial role in mitigating water eutrophication [4,10,40]. Common species employed in urban wetlands include reeds and reed ponds [4,41], as well as lotus and lotus ponds [10,32,33,42], all demonstrating ecological benefits for wetland restoration. The study site, Jinluo lotus pond, is situated on the north bank of the Liuqing River in Linyi City, Shandong Province, covering a total area of 7.109 km^2 with lotus ponds accounting for 5.5667 km^2. This project was designed to utilize lotus roots for regulating nutrient concentrations in wetland waters, alleviating eutrophication, and restoring polluted water bodies. Nevertheless, the actual efficacy of such systems in water quality purification remains questionable, particularly regarding their ability to achieve sustainable eutrophication control without causing secondary ecological impacts.

2. Materials and Methods

2.1. Site Description and Sampling Procedure

In this study, Jinluo lotus pond served as the experimental group, while the adjacent river outside the pond was designated as the control group, with five sampling areas established in each location. Sampling was performed in June 2022, April 2025, and May 2025 using sterilized 4 L sampling buckets to collect water samples for laboratory analysis in Figure 1.



Figure 1. The sampling point layout of Jinluo lotus pond and the river outside the pond. (**A**,**B**) show the exterior views of the lotus pond, (**C**) displays the distribution of sampling points in this study (The red line in the diagram represents the boundary of the lotus pond, yellow triangles indicate the lotus pond area, and pink triangles represent the river outside the lotus pond).

2.2. Analytical Methods

pH, Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen (TN), Total Phosphorus (TP), Ammonia Nitrogen (NH_3-N), Nitrate Nitrogen (NO_3^--N), Dissolved Oxygen (DO), Planktonic Index (PI), Chlorophyll-a (Chl-a), and algal cell density were studied. These selected parameters served dual purposes: (1) assessing the water purification efficacy of the lotus pond system, and (2) providing scientific basis for developing effective environmental management strategies for the Liuqing River watershed.

pH: Quantify using electrode method (HJ 1147-2020) and ST2100 pH meter (HLJC-243-2) [43]. BOD: Quantified using the standard Dilution and Inoculation Method (HJ 505-2009) with a 25 mL acid burette (Model B193) [44]. COD: Analyzed by the Potassium Dichromate Method (HJ 828-2017) employing a 50 mL acid burette (Model B192) [45]. TN: Determined through Ultraviolet Spectrophotometry (HJ 636-2012) using a UV-1750 UV-Vis Spectrophotometer (Model A11605031003CS) [46]. TP and NH_3-N: Measured, respectively, by Ammonium Molybdate Spectrophotometry (GB 11893-1989) and Nessler's Reagent Spectrophotometry (HJ 535-2009), with measurements conducted on a DR2008 Visible Spectrophotometer (Serial No. 1429121) [47,48]. NO_3^--N: Determined via ion chromatography (HJ 84-2016) using a DIONEX AQUION ion chromatograph (HLJC-231) [49]. DO: Detection using electrochemical probe method (HJ 506-2009) and JPB-607A portable dissolved oxygen analyzer (HLJC-285) [50]. PI: Determination of permanganate index (GB/T 11892-1989) and detection using a 25mL acid burette (B-S-25-2) [51]. Phytoplankton analysis: Species identification and quantification were performed under an optical microscope using standardized counting chambers, with results expressed as cell density (cells/L) and species diversity indices [52,53]. Chl-a: Quantified following Acetone Spectrophotometry (HJ 897-2017) [54].

2.3. Diversity Indices Calculation

Species Richness (S): Total number of identified phytoplankton species per sample.

$$\text{Shannon–Wiener Index } (H): H = -\sum(P_i \times \ln P_i)$$

$$\text{Simpson's Diversity Index } (P): D = 1 - \sum(P_i^2)$$

$$\text{Pielou's Evenness Index } (E): E = H/\ln S$$

where P_i denotes the proportion of individuals of the i-th species relative to the total phytoplankton count [55–57].

2.4. Statistical and Spatial Analysis

All data were processed using SPSS 19.0 for statistical analysis.

3. Results

3.1. Differences in Water Quality Factors

This study conducted a systematic comparison of water quality parameters between the Jinluo lotus pond and its adjacent river system in Figures 2 and 3. Results indicated that while the lotus pond exhibited elevated levels of water pH, BOD, COD, TN, and NH_3-N compared to the river, the adjacent river conversely showed higher concentrations of TP, NO_3^--N, Chl-a, and algal cell density. Statistical analysis revealed that none of the nine measured parameters demonstrated statistically significant differences ($p > 0.05$) in June 2022.

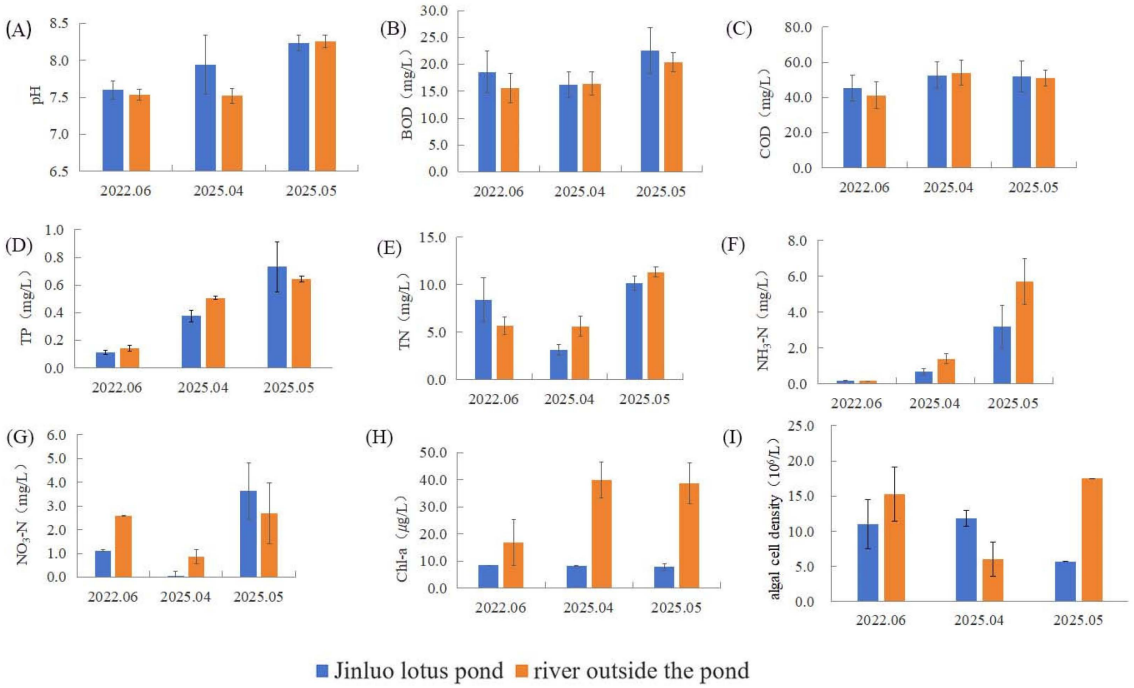


Figure 2. Differences of (**A**) pH, (**B**) BOD, (**C**) COD, (**D**) TP, (**E**) TN, (**F**) NH_3-N, (**G**) NO_3^--N, (**H**) Chl-a, and (**I**) algal cell density in the water quality factors of Jinluo lotus pond and the river outside the pond.

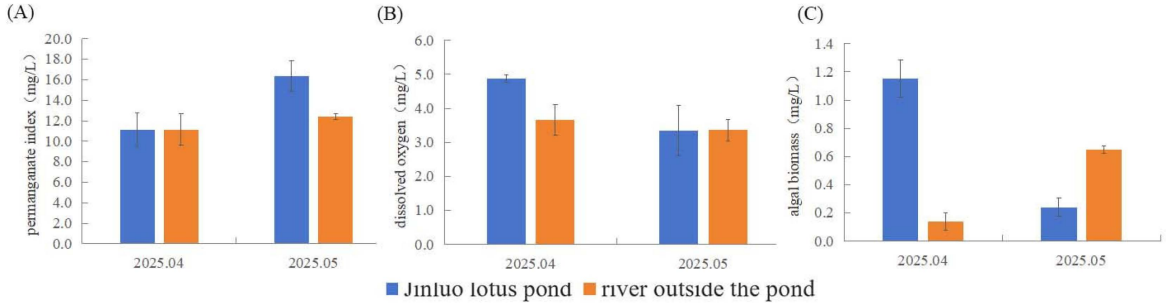


Figure 3. Differences of (**A**) PI, (**B**) DO, and (**C**) algal biomass in the water quality factors of Jinluo lotus pond and the river outside the pond.

Relative to adjacent rivers, the lotus pond exhibited a significantly higher pH, dissolved oxygen (DO), algal cell density, and algal biomass ($p < 0.05$ for DO). In contrast, river water showed elevated levels of BOD, COD, TN, TP, NH_3-N, NO_3^--N, planktonic index (PI), and Chl-a, with a statistically significant difference in Chl-a ($p < 0.05$) in April 2025.

Compared to rivers, the lotus pond had a higher BOD, COD, TP, NO_3^--N, and PI, with a significant difference in PI ($p < 0.05$). Conversely, river samples displayed a greater pH, TN, NH_3-N, DO, Chl-a, algal cell density, and algal biomass, with Chl-a showing a significant difference ($p < 0.05$) in May 2025.

3.2. Water Quality Assessment

In accordance with China's Surface Water Environmental Quality Standards (GB 3838-2002) [52], we evaluated the water quality of Jinluo lotus pond and its adjacent river using seven key parameters: BOD, COD, TN, TP, NH_3-N, PI, and DO (Table 1). The results demonstrated severe exceedances of national standards for BOD, COD, and TN in both systems, reflecting significant organic pollution and nutrient loading. All sampling sites consistently exceeded Class V water quality thresholds—the most polluted classification

under GB 3838-2002—indicating critically degraded water conditions throughout the study area.

Table 1. The water quality assessment of Jinluo lotus pond and the river outside the pond.

	Jinluo Lotus Pond	River Outside the Pond
BOD	Super Class V water (2022) Super Class V water (2025)	Super Class V water (2022) Super Class V water (2025)
COD	Super Class V water (2022) Super Class V water (2025)	Super Class V water (2022) Super Class V water (2025)
TN	Super Class V water (2022) Super Class V water (2025)	Super Class V water (2022) Super Class V water (2025)
TP	Class III water (2022) Super Class V water (2025)	Class III water (2022) Super Class V water (2025)
NH_3-N	Class II water (2022) Class III water (2025)	Class II water (2022) Class IV water (2025)
PI	Class V water (2025)	Class V water (2025)
DO	Class IV water (2025)	Class IV water (2025)

3.3. The Correlation of Water Quality Factors

As shown in Table 2, BOD and COD exhibited a strong positive correlation ($p < 0.01$), demonstrating a close relationship between these key organic pollution indicators. A significant positive correlation was also observed between COD and chlorophyll-a ($p < 0.05$). Among nitrogen components, TN and NH_3-N showed a particularly strong positive correlation ($p < 0.01$), implying shared sources or transformation processes.

Table 2. The correlation of water quality factors of Jinluo lotus pond and the river outside the pond (2022).

	pH	BOD	COD	TP	TN	NH_3-N	NO_3^--N	Chl-a	ACD
pH	1.000								
BOD	−0.240	1.000							
COD	−0.123	0.927 **	1.000						
TP	−0.452	−0.027	−0.104	1.000					
TN	−0.030	0.318	0.169	−0.105	1.000				
NH_3-N	−0.160	0.381	0.331	−0.206	0.775 **	1.000			
NO_3^--N	0.230	−0.431	−0.452	0.331	0.103	−0.292	1.000		
Chl-a	0.023	0.252	0.547 *	−0.066	−0.119	0.341	−0.293	1.000	
ACD	−0.035	0.176	0.245	0.231	0.224	0.584 *	−0.106	0.536 *	1.000

Note: ** $p < 0.01$; * $p < 0.05$; ACD, Algae cell density.

The analysis revealed significant linkages between algal dynamics and multiple water quality parameters. Notably, algal cell density showed positive correlations with both NH_3-N and Chl-a (all $p < 0.05$), suggesting a potential coupled biogeochemical cycling of these nutrients within the lotus pond ecosystem.

In Table 3, pH is significantly negatively correlated with COD ($p < 0.05$). BOD is significantly positively correlated with COD, TN, TP, NH_3-N, Permanganate index, and dissolved oxygen ($p < 0.01$). COD is significantly positively correlated with TP, NH_3-N, NO_3-N, Permanganate index, dissolved oxygen, Algae cell density, and Algal biomass ($p < 0.05$). TP is significantly positively correlated with TN and NH_3-N ($p < 0.01$), Permanganate index, and dissolved oxygen ($p < 0.05$). TN is significantly positively correlated with NH_3-N, Permanganate index, and dissolved oxygen ($p < 0.01$), NO_3-N ($p < 0.05$). NH_3-N is significantly positively correlated with dissolved oxygen ($p < 0.01$). Permanganate index is significantly positively correlated with dissolved oxygen ($p < 0.01$). Dissolved oxygen is

significantly positively correlated with Chl-a ($p < 0.05$). Algae cell density is significantly positively correlated with Algal biomass ($p < 0.01$).

Table 3. The correlation of water quality factors of Jinluo lotus pond and the river outside the pond (2025).

	pH	BOD	COD	TP	TN	NH_3-N	NO_3^--N	PI	DO	Chl-a	ACD	AB
pH	1.000											
BOD	−0.089	1.000										
COD	−0.428 *	0.835 **	1.000									
TP	0.181	0.642 **	0.452 *	1.000								
TN	0.179	0.536 **	0.179	0.526 **	1.000							
NH_3-N	0.235	0.647 **	0.384 *	0.518 **	0.685 **	1.000						
NO_3^--N	0.136	−0.181	−0.392 *	0.004	0.461 *	−0.243	1.000					
PI	−0.093	0.745 **	0.536 **	0.414 *	0.589 **	0.298	0.245	1.000				
DO	0.098	−0.603 **	−0.463 *	−0.492 *	−0.656 **	−0.622 **	−0.028	−0.529 **	1.000			
Chl-a	−0.366	0.124	0.266	0.052	0.290	0.124	0.227	0.040	−0.392 *	1.000		
ACD	−0.215	0.378 *	0.454 *	0.190	0.186	0.355	−0.273	0.342	−0.267	−0.094	1.000	
AB	−0.310	0.301	0.460 *	0.037	−0.004	0.076	−0.213	0.340	−0.033	−0.159	0.902 **	1.000

Note: ** $p < 0.01$; * $p < 0.05$; PI, Permanganate index; DO, dissolved oxygen; ACD, Algae cell density; AB, Algal biomass.

3.4. Phytoplankton Diversity

Phytoplankton diversity indices—including species richness (*S*), Shannon–Wiener diversity index (*H*), Simpson diversity index (*P*), and Pielou evenness index (*E*)—were analyzed for the lotus pond. The results showed that there was no significant difference in the four diversity indicators in June 2022, April 2025, and May 2025 in Figure 4.

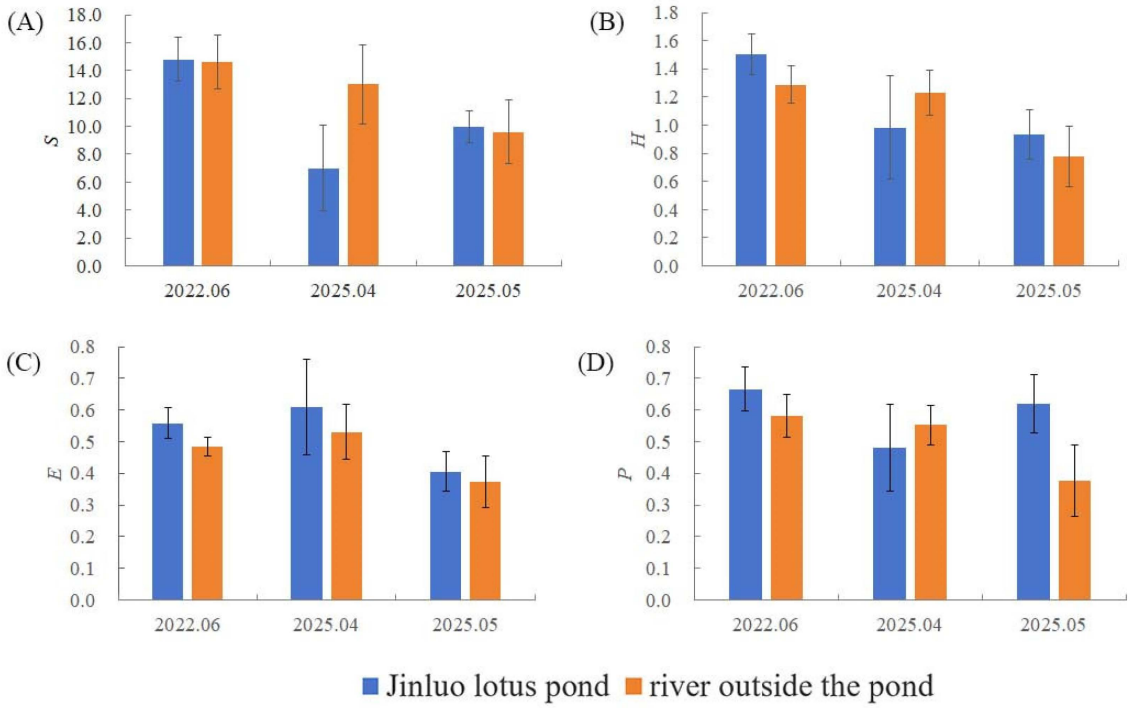


Figure 4. (**A**) The Phytoplankton richness index (*S*), (**B**) Shannon–Wiener diversity index (*H*), (**C**) Simpson diversity index (*P*), and (**D**) Pielou evenness index (*E*) of Jinluo lotus pond and the river outside the pond.

There is no significant difference between the Phytoplankton cell density of Jinluo lotus pond and the river outside the pond. In order of cell density, the phytoplankton in the Jinluo lotus pond water are *Cyclotella meneghiniana*, *Pseudanabaena* sp., and *Scenedesmus quadricauda*, but in the river outside the pond, the water has *P.* sp., *C. meneghiniana*, and *S. quadricauda* in 2022 in Table 4. The phytoplankton in the Jinluo lotus pond water is

Tetrastrum staurogeniaforme, but in the river outside the pond, the water has *Tetrastrum staurogeniaforme*, *Coelastrum microporum*, *Scenedesmus quadricauda*, and *Scenedesmus bicaudatus* in 2025 in Table 5.

Table 4. The Phytoplankton cell density of Jinluo lotus pond and the river outside the pond (2022).

	Jinluo Lotus Pond	River Outside the Pond
1	*Cyclotella meneghiniana*, 3,986,800, 36.30%	*Pseudanabaena* sp., 6,576,000, 43.13%
2	*Pseudanabaena* sp., 3,336,000, 30.37%	*Cyclotella meneghiniana*, 3,718,000, 24.39%
3	*Scenedesmus quadricauda*, 1,155,200, 10.52%	*Scenedesmus quadricauda*, 1,476,800, 9.69%
4	*Aphanocapsa delicatissima*, 560,000, 5.10%	*Trachelomonas superba*, 592,000, 3.88%
5	*Crucigenia tetrapedia*, 497,600, 4.53%	*Oscillatoria chlorine*, 560,000, 3.67%
6	*Coelastrum microporum*, 320,000, 2.91%	*Crucigenia tetrapedia*, 544,000, 3.57%
7	*Oscillatoria chlorine*, 280,000, 2.55%	*Coelastrum microporum*, 358,400, 2.35%
8		*Acanthosphaera* sp., 204,000, 1.34%
9		*Dictyosphaerium pulchellum*, 192,000, 1.26%
total	10,135,600/10,984,400, 92.27%	14,221,200/15,246,400, 93.28%

Note: This table only lists phytoplankton that account for over 1% of the total.

Table 5. The Phytoplankton cell density of Jinluo lotus pond and the river outside the pond (2025).

	Jinluo Lotus Pond	River Outside the Pond
1	*Tetrastrum staurogeniaforme*, 1,492,800, 17.04%	*Tetrastrum staurogeniaforme*, 2,964,000, 25.27%
2	*Anabaena* sp., 567,300, 6.47%	*Coelastrum microporum* 1,900,200, 16.20%
3	*Scenedesmus quadricauda*, 499,500, 5.70%	*Scenedesmus quadricauda*, 1,694,400, 14.45%
4	*Coelastrum microporum*, 377,700, 4.30%	*Scenedesmus bicaudatus*, 1,689,000, 14.40%
5	*Scenedesmus bicaudatus*, 176,100, 2.01%	*Scenedesmus dimorphus*, 641,100, 5.47%
6		*Scenedesmus denticulatus*, 175,800, 1.50%
7		*Actinastrum hantzschii*,168,600, 1.44%
8		*Pediastrum tetras*, 163,800, 1.40%
9		*Pediastrum biradiatum*, 157,300, 1.34%
10		*Scenedesmus acuminatus*, 150,300, 1.28%
11		*Microcystis* sp., 146,700, 1.25%
total	3,113,400/8,762,100, 35.53%	9,851,200/11,729,100, 83.99%

Note: This table only lists phytoplankton that account for over 1% of the total.

4. Discussion

Ecological restoration strategies frequently incorporate three principal phytoremediation approaches: riparian vegetation buffer zones, ecological floating beds, and constructed wetlands, each offering distinct advantages for water quality improvement [58–60]. The effectiveness of these phytoremediation systems is primarily determined by two critical design parameters: appropriate plant species selection and optimal planting density, which collectively govern nutrient uptake capacity and treatment performance [61–63]. As fundamental elements of ecological engineering solutions, aquatic plants demonstrate marked variations in removal efficiencies depending on pollutant composition, with species-specific responses to different contaminant mixtures [64,65]. Research indicates that under eutrophic conditions, superior nutrient removal performance correlates strongly with three key plant traits: (1) high biomass production capacity, (2) elevated leaf dry matter content (LDMC), and (3) reduced specific leaf area (SLA), suggesting that wetland species exhibiting this combination of characteristics—particularly those with high biomass and LDMC coupled with low SLA values—may represent optimal candidates for nutrient-rich wastewater treatment applications [66]. Notably, engineered sequential wetland systems have proven particularly effective for purifying polluted urban waterways even in challenging cold climate conditions, demonstrating robust year-round treatment capabilities [67].

This study investigates the wastewater treatment capacity of constructed wetlands in the context of livestock effluent, particularly given the upstream location of a globally significant swine slaughtering center that generates substantial volumes of nutrient-rich

wastewater containing elevated concentrations of carbon, nitrogen, and phosphorus compounds. Aquaculture effluents, similarly characterized by high nutrient loads, present significant environmental challenges with nitrogen and phosphorus being primary contributors to ecological degradation [68]. Research demonstrates that constructed wetland systems can reliably achieve total nutrient removal efficiencies exceeding 60% when treating bullfrog aquaculture wastewater [69], while Euryale ferox Salisb-based ecological ponds exhibit exceptional performance in both the in-situ and ex-situ treatment of shrimp aquaculture effluent, showing particularly high removal rates for total nitrogen (TN) and total phosphorus (TP) [70]. Advanced multi-stage treatment systems combining lotus ponds with surface flow wetlands have proven particularly effective for swine wastewater remediation, capable of transforming heavily contaminated influent into lightly polluted effluent through efficient nitrogen and phosphorus removal mechanisms [71], though these systems require careful operational management including seasonal lotus root harvesting during winter–spring periods and periodic sediment dredging to maintain treatment efficacy.

Constructed wetlands have emerged as a highly efficient, cost-effective, and environmentally sustainable solution for wastewater treatment, offering distinct advantages over conventional treatment systems in terms of operational simplicity, minimal maintenance requirements, and ecological compatibility [72]. The field has witnessed an evolutionary shift from basic treatment wetlands to sophisticated, multi-functional integrated systems. This transition is exemplified by the Integrated Constructed Wetland (ICW) concept, which adopts a comprehensive design philosophy that systematically incorporates four key dimensions—economic viability, social acceptance, environmental performance, and landscape integration—throughout all project phases from initial planning to long-term operation. Beyond their core treatment functions, these integrated wetland systems provide substantial secondary benefits, particularly in terms of biodiversity enhancement and habitat creation [73,74]. In this context, while performance assessments reveal that the Jinluo lotus pond demonstrates relatively modest water purification capabilities as a standalone treatment system, it nonetheless makes valuable contributions as a constructed wetland through its significant ecological services and exceptional aesthetic qualities that enrich the surrounding landscape.

Derived from Liebig's Law of the Minimum, this paradigm suggests algal growth in aquatic ecosystems becomes N-limited when the aqueous N:P ratio falls below 16 (molar basis), while P-limitation occurs when ratios exceed 16 [75,76]. Alternative formulations using the TN:TP mass ratio propose N-limitation thresholds at TN:TP < 9 and P-limitation thresholds at TN:TP > 23 [42], with some studies establishing a nitrogen limitation threshold at TN:TP < 25 [77]. Our research shows that from 2022 to 2025, the nitrogen phosphorus ratio in this water area will decrease in Jinluo lotus pond and the river outside the pond in Table 6.

Table 6. The N:P of Jinluo lotus pond and the river outside the pond.

	N:P	Restrictive	Sample Time
Jinluo lotus pond	39.67	P restrictive	2022
	12.00		2025
River outside the pond	98.97	P restrictive	2022
	14.71		2025

5. Conclusions

The main findings indicate that Jinluo lotus pond, as a low-density lotus pond artificial wetland system, has not shown significant water quality improvement effects. Based on these findings, we propose the following management recommendations: (1) a strategic expansion of both natural and constructed reed (*Phragmites australis*) communities along

riparian zones, as these demonstrate superior nitrogen removal capabilities, a and (2) discontinuation of current lotus pond maintenance practices and an avoidance of further lotus cultivation area expansion, given their demonstrated tendency to exacerbate nitrogen accumulation in aquatic systems. This integrated approach would optimize nutrient removal efficiency while enhancing the overall ecological functionality of the watershed.

Author Contributions: Conceptualization, B.L., Y.G., J.Z., Y.W. and J.H.; Methodology, B.L., Y.G., J.Z. and Y.W.; Software, Y.G., J.Z. and J.H.; Validation, Y.G.; Formal analysis, Y.G. and Y.W.; Investigation, Y.G.; Resources, B.L. and Y.G.; Data curation, Y.G. and J.H.; Writing—original draft, B.L., Y.G. and J.Z.; Writing—review & editing, Y.G., J.Z., Y.W. and J.H.; Visualization, Y.G.; Supervision, Y.G.; Project administration, B.L. and Y.G.; Funding acquisition, B.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Shandong Provincial Key Laboratory of Water and Soil Conservation and Environmental Protection (No. STKF202307), and Shandong Province Youth Innovation and Technology Support Program for Higher Education Institutions (2020KJE009).

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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

References

1. Wang, D.; Gan, X.; Wang, Z.; Jiang, S.; Zheng, X.; Zhao, M.; Zhang, Y.; Fan, C.; Wu, S.; Du, L. Research status on remediation of eutrophic water by submerged macrophytes: A review. *Process. Saf. Environ. Prot.* **2023**, *169*, 671–684. [CrossRef]
2. Nimma, D.; Devi, O.R.; Laishram, B.; Ramesh, J.V.N.; Boddupalli, S.; Ayyasamy, R.; Tirth, V.; Arabil, A. Implications of climate change on freshwater ecosystems and their biodiversity. *Desalination Water Treat.* **2025**, *321*, 100889. [CrossRef]
3. Li-Kun, Y.; Sen, P.; Xin-Hua, Z.; Xia, L. Development of a two-dimensional eutrophication model in an urban lake (China) and the application of uncertainty analysis. *Ecol. Model.* **2017**, *345*, 63–74. [CrossRef]
4. Asad, A.A.; El-Hawary, A.M.; Abbas, M.H.H.; Mohamed, I.; Abdelhafez, A.A.; Bassouny, M.A. Reclamation of wastewater in wetlands using reed plants and biochar. *Sci. Rep.* **2022**, *12*, 19516. [CrossRef]
5. Greve, P.; Kahil, T.; Mochizuki, J.; Schinko, T.; Satoh, Y.; Burek, P.; Fischer, G.; Tramberend, S.; Burtscher, R.; Langan, S.; et al. Global assessment of water challenges under uncertainty in water scarcity projections. *Nat. Sustain.* **2018**, *1*, 486–494. [CrossRef]
6. Pahl-Wostl, C.; Knieper, C.; Lukat, E.; Meergans, F.; Schoderer, M.; Schütze, N.; Schweigatz, D.; Dombrowsky, I.; Lenschow, A.; Stein, U.; et al. Enhancing the capacity of water governance to deal with complex management challenges: A framework of analysis. *Environ. Sci. Policy* **2020**, *107*, 23–35. [CrossRef]
7. Zhao, X.; Yang, D. Research on Regional Disparities, Dynamic Evolution, and Influencing Factors of Water Environment Governance Efficiency in China. *Water* **2025**, *17*, 515. [CrossRef]
8. Bakker, E.S.; Van Donk, E.; Declerck, S.A.J.; Helmsing, N.R.; Hidding, B.; Nolet, B.A. Effect of macrophyte community composition and nutrient enrichment on plant biomass and algal blooms. *Basic Appl. Ecol.* **2010**, *11*, 432–439. [CrossRef]
9. Wu, H.; Wang, R.; Yan, P.; Wu, S.; Chen, Z.; Zhao, Y.; Cheng, C.; Hu, Z.; Zhuang, L.; Guo, Z.; et al. Constructed wetlands for pollution control. *Nat. Rev. Earth Environ.* **2023**, *4*, 218–234. [CrossRef]
10. Abd Rasid, N.S.; Naim, M.N.; Che Man, H.; Abu Bakar, N.F.; Mokhtar, M.N. Evaluation of surface water treated with lotus plant; *Nelumbo nucifera*. *J. Environ. Chem. Eng.* **2019**, *7*, 103048. [CrossRef]
11. Mustafa, H.M.; Hayder, G. Recent studies on applications of aquatic weed plants in phytoremediation of wastewater: A review article. *Ain Shams Eng. J.* **2021**, *12*, 355–365. [CrossRef]
12. Xiao, H.; Peng, S.; Liu, X.; Jia, J.; Wang, H. Phytoremediation of nutrients and organic carbon from contaminated water by aquatic macrophytes and the physiological response. *Environ. Technol. Innov.* **2021**, *21*, 101295. [CrossRef]
13. Kou, S.; Yang, J.; Li, Y.; Li, S.; Shen, Y.; Gao, J. Design and Application of an Integrated Landscape Water Purification Device: Long-Term Performance in Nitrogen and Phosphorus Removal. *Water* **2025**, *17*, 556. [CrossRef]
14. Rillig, M.C. Global change refugia could shelter species from multiple threats. *Nat. Rev. Biodivers.* **2025**, *1*, 10–11. [CrossRef]
15. Chan, F.K.S.; Griffiths, J.A.; Higgitt, D.; Xu, S.; Zhu, F.; Tang, Y.-T.; Xu, Y.; Thorne, C.R. "Sponge City" in China—A breakthrough of planning and flood risk management in the urban context. *Land Use Policy* **2018**, *76*, 772–778. [CrossRef]
16. Ferreira, C.S.S.; Kašanin-Grubin, M.; Solomun, M.K.; Sushkova, S.; Minkina, T.; Zhao, W.; Kalantari, Z. Wetlands as nature-based solutions for water management in different environments. *Curr. Opin. Environ. Sci. Health* **2023**, *33*, 100476. [CrossRef]

17. Wilkins, N.R.; Fallowfield, H.; Baring, R. Spatial performance assessment of reed bed filtration in a constructed wetland. *Sci. Total Environ.* **2022**, *820*, 153060. [CrossRef]
18. Chen, J.; Guo, F.; Wu, F.; Bryan, B.A. Costs and benefits of constructed wetlands for meeting new water quality standards from China's wastewater treatment plants. *Resour. Conserv. Recycl.* **2023**, *199*, 107248. [CrossRef]
19. Zhao, Y.; Ji, B.; Liu, R.; Ren, B.; Wei, T. Constructed treatment wetland: Glance of development and future perspectives. *Water Cycle* **2020**, *1*, 104–112. [CrossRef]
20. Gebeyehu, A.; Shebeshe, N.; Kloos, H.; Belay, S. Suitability of nutrients removal from brewery wastewater using a hydroponic technology with *Typha latifolia*. *BMC Biotechnol.* **2018**, *18*, 74. [CrossRef]
21. Hadad, H.R.; Mufarrege, M.M.; Pinciroli, M.; Di Luca, G.A.; Maine, M.A. Morphological Response of *Typha domingensis* to an Industrial Effluent Containing Heavy Metals in a Constructed Wetland. *Arch. Environ. Contam. Toxicol.* **2010**, *58*, 666–675. [CrossRef] [PubMed]
22. Grisey, E.; Laffray, X.; Contoz, O.; Cavalli, E.; Mudry, J.; Aleya, L. The Bioaccumulation Performance of Reeds and Cattails in a Constructed Treatment Wetland for Removal of Heavy Metals in Landfill Leachate Treatment (Etueffont, France). *Water Air Soil Pollut.* **2012**, *223*, 1723–1741. [CrossRef]
23. Licata, M.; Gennaro, M.C.; Tuttolomondo, T.; Leto, C.; La Bella, S.; Singer, A.C. Research focusing on plant performance in constructed wetlands and agronomic application of treated wastewater—A set of experimental studies in Sicily (Italy). *PLoS ONE* **2019**, *14*, e0219445. [CrossRef] [PubMed]
24. Qin, H.; Zhang, Z.; Liu, M.; Liu, H.; Wang, Y.; Wen, X.; Zhang, Y.; Yan, S. Site test of phytoremediation of an open pond contaminated with domestic sewage using water hyacinth and water lettuce. *Ecol. Eng.* **2016**, *95*, 753–762. [CrossRef]
25. Rezania, S.; Ponraj, M.; Talaiekhozani, A.; Mohamad, S.E.; Din, M.F.M.; Taib, S.M.; Sabbagh, F.; Sairan, F.M. Perspectives of phytoremediation using water hyacinth for removal of heavy metals, organic and inorganic pollutants in wastewater. *J. Environ. Manag.* **2015**, *163*, 125–133. [CrossRef]
26. Wang, J.; Chen, G.; Liu, F.; Song, X.; Zou, G. Combined ozonation and aquatic macrophyte (*Vallisneria natans*) treatment of piggery effluent: Water matrix and antioxidant responses. *Ecol. Eng.* **2017**, *102*, 39–45. [CrossRef]
27. Wu, H.; Gao, X.; Wu, M.; Zhu, Y.; Xiong, R.; Ye, S. The efficiency and risk to groundwater of constructed wetland system for domestic sewage treatment—A case study in Xiantao, China. *J. Clean. Prod.* **2020**, *277*, 123384. [CrossRef]
28. Shaharuddin, S.; Chan, N.W.; Zakaria, N.A.; Ab Ghani, A.; Chang, C.K.; Roy, R. Constructed Wetlands as a Natural Resource for Water Quality Improvement in Malaysia. *Nat. Resour.* **2014**, *5*, 292–298. [CrossRef]
29. Billore, S.K.; Prashant; Sharma, J.K. Treatment performance of artificial floating reed beds in an experimental mesocosm to improve the water quality of river Kshipra. *Water Sci. Technol.* **2009**, *60*, 2851–2859. [CrossRef]
30. Yang, L.; Zhang, Z.; Zhang, W.; Zhang, T.; Meng, H.; Yan, H.; Shen, Y.; Li, Z.; Ma, X. Wetland Park Planning and Management Based on the Valuation of Ecosystem Services: A Case Study of the Tieling Lotus Lake National Wetland Park (LLNWP), China. *Int. J. Environ. Res. Public Health* **2023**, *20*, 2939. [CrossRef]
31. Pang, J.; Feng, X.; Wang, X. Purification and utilization of garlic processing wastewater in lotus pond wetlands. *Water Sci. Eng.* **2014**, *7*, 395–402. [CrossRef]
32. Xu, S.Z.; Wang, Y.X.; Wang, Y.D.; Zhao, Y.J.; Gao, Y. Seasonal influence of reed (*Phragmites australis*) and lotus (*Nelumbo nucifera*) on urban wetland of Yi river. *Appl. Ecol. Environ. Res.* **2019**, *17*, 7891–7900. [CrossRef]
33. He, L.S.; Meng, F.L.; Meng, R.; Huang, C.H.; Li, Y.W.; Xi, B.D.; Shu, J.M. In Situ Enclosure Experiment on *Nelumbo nucifera* for Eutrophication Control in Baiyangdian Lake. *Wetl. Sci.* **2013**, *11*, 282–285. [CrossRef]
34. Li, L.; Hou, W.-H. Inhibitory effects of liquor cultured with *Nelumbo nucifera* and *Nymphaea tetragona* on the growth of *Microcystis aeruginosa*. *Environ. Sci.* **2007**, *28*, 2180–2186.
35. Li, X.; Xu, X.Q.; Gou, M.M. Study on the influence of lotus planting in Wuliangsu of Inner Mongolia on water environment. *J. Environ. Health* **2018**, *35*, 457–459. [CrossRef]
36. Li, X.; Gao, Y. Influence of the island with grass and the island with trees to water quality in Yihe River, China. *Desalination Water Treat.* **2018**, *121*, 186–190. [CrossRef]
37. Gao, Y.; Ci, H.X.; Qi, S.C.; Su, Y.X. Seasonal changes of phytoplankton diversity and assessment of water quality in four tributaries of Yi River. *Res. Environ. Sci.* **2009**, *22*, 176–180.
38. Gao, Y.; Qi, S.C.; Su, Y.X. Seasonal changes of phytoplankton diversity and water quality in Yi River and Beng River. *Trans. Oceanol. Limnol.* **2010**, *32*, 109–113. [CrossRef]
39. Gao, Y.; Su, Y.X.; Qi, S.C. Phytoplankton and evaluation of water quality in Yi River watershed. *J. Lake Sci.* **2008**, *20*, 544–548.
40. Zhang, W.-H.; Gao, Y.; Wang, Y.; Zhou, J. Water Quality Assessment and Management Strategies for Nishan Reservoir, Sihe River, and Yihe River Based on Scientific Evaluation. *Water* **2024**, *16*, 1958. [CrossRef]
41. Ge, Z.W.; Fang, S.Y.; Li, C.; Li, Q.; Bu, Q.Q.; Xue, Y.H. Analysis of the plant N and P sequestration from common reed and common reed+ cattail communities in wetland soil in Qinhu Lake of northern Jiangsu, China. *J. Lake Sci.* **2017**, *29*, 585–593. [CrossRef]

42. Guildford, S.J.; Hecky, R.E. Total Nitrogen, Total Phosphorus, and Nutrient Limitation in Lakes and Oceans: Is There A Common Relationship? *Limnol. Oceanogr.* **2000**, *45*, 1213–1223. [CrossRef]
43. *HJ 1147-2020*; Water Quality-Determination of pH-Electrode Method. Ministry of Ecology and Environment of the People's Republic of China: Beijing, China, 2020.
44. *HJ 505-2009*; Water Quality-Determination of Biochemical Oxygen Demand After 5 Days (BOD5) for Dilution and Seeding Method. Ministry of Environmental Protection of the People's Republic of China: Beijing, China, 2009.
45. *HJ 828-2017*; Water Quality-Determination of the Chemical Oxygen Demand-Dichromate Method. Ministry of Environmental Protection of the People's Republic of China: Beijing, China, 2017.
46. *HJ 636-2012*; Water Quality-Determination of Total Nitrogen-Alkaline Potassium Persulfate Digestion UV Spectrophotometric Method. Ministry of Environmental Protection of the People's Republic of China: Beijing, China, 2012.
47. *GB 11893-89*; Water Quality-Determination of Total Phosphorus-Ammonium Molybdate Spectrophotometric Method. State Administration of Technical Supervision of the People's Republic of China: Beijing, China, 1989.
48. *HJ 535-2009*; Water Quality-Determination of Ammonia Nitrogen-Nessler's Reagent Spectrophotometry. Ministry of Environmental Protection of the People's Republic of China: Beijing, China, 2009.
49. *HJ 84-2016*; Water Quality-Determination of Inorganic Anions (F−, Cl−, NO2−, Br−, NO3−, PO43−, SO32−, SO42−)-Ion Chromatography. Ministry of Environmental Protection of the People's Republic of China: Beijing, China, 2016.
50. *HJ 506-2009*; Water Quality-Determination of Dissolved Oxygen-Electrochemical Probe Method. Ministry of Environmental Protection of the People's Republic of China: Beijing, China, 2009.
51. *GB 11892-89*; Water Quality-Determination of Permanganate Index. Environmental Protection Administration of the People's Republic of China: Beijing, China, 1989.
52. *GB 3838-2002*; Environmental Quality Standards for Surface Water. State Environmental Protection Administration of the People's Republic of China and General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China: Beijing, China, 2002.
53. *HJ 1296-2023*; Technical Guidelines for Water Ecological Monitoring-Aquatic Organism Monitoring and Evaluation of Lakes and Reservoirs (on Trial). Ministry of Ecology and Environment of the People's Republic of China: Beijing, China, 2023.
54. *HJ 897-2017*; Water Quality-Determination of Chlorophyll a-Spectrophotometric Method. Ministry of Environmental Protection of the People's Republic of China: Beijing, China, 2017.
55. Borics, G.; Abonyi, A.; Salmaso, N.; Ptacnik, R. Freshwater phytoplankton diversity: Models, drivers and implications for ecosystem properties. *Hydrobiologia* **2021**, *848*, 53–75. [CrossRef] [PubMed]
56. Pielou, E.C. The measurement of diversity in different types of biological collections. *J. Theor. Biol.* **1966**, *13*, 131–144. [CrossRef]
57. Shannon, C.E. A Mathematical theory of communication. *Bell Syst. Tech. J.* **1948**, *27*, 379–423. [CrossRef]
58. Colares, G.S.; Dell'Osbel, N.; Wiesel, P.G.; Oliveira, G.A.; Lemos, P.H.Z.; da Silva, F.P.; Lutterbeck, C.A.; Kist, L.T.; Machado, Ê.L. Floating treatment wetlands: A review and bibliometric analysis. *Sci. Total. Environ.* **2020**, *714*, 136776. [CrossRef]
59. Wang, W.-H.; Wang, Y.; Sun, L.-Q.; Zheng, Y.-C.; Zhao, J.-C. Research and application status of ecological floating bed in eutrophic landscape water restoration. *Sci. Total Environ.* **2020**, *704*, 135434. [CrossRef]
60. Zhu, Z.; Wang, Y.; Han, X.-Y.; Wang, W.-H.; Li, H.-M.; Yue, Z.-Q.; Chen, W.; Xue, F.-R. Strengthen the purification of eutrophic water and improve the characteristics of sediment by functional ecological floating bed suspended calcium peroxide and sponge iron jointly. *J. Environ. Manag.* **2023**, *325*, 116610. [CrossRef]
61. Carleton, J.N.; Montas, H.J. An analysis of performance models for free water surface wetlands. *Water Res.* **2010**, *44*, 3595–3606. [CrossRef]
62. Pan, X.; Liu, S.; Li, R.; Sun, H.; Feng, J.; Cheng, X.; Yao, J. Research on the purification enhancement of ecological ponds: Integrating water cycle optimization and plants layout. *J. Environ. Manag.* **2023**, *344*, 118487. [CrossRef]
63. Sabokrouhiyeh, N.; Bottacin-Busolin, A.; Savickis, J.; Nepf, H.; Marion, A. A numerical study of the effect of wetland shape and inlet-outlet configuration on wetland performance. *Ecol. Eng.* **2017**, *105*, 170–179. [CrossRef]
64. Gong, Y.; Zhang, X.; Li, H.; Zhang, X.; He, S.; Miao, Y. A comparison of the growth status, rainfall retention and purification effects of four green roof plant species. *J. Environ. Manag.* **2021**, *278*, 111451. [CrossRef] [PubMed]
65. Ong, S.-A.; Uchiyama, K.; Inadama, D.; Ishida, Y.; Yamagiwa, K. Performance evaluation of laboratory scale up-flow constructed wetlands with different designs and emergent plants. *Bioresour. Technol.* **2010**, *101*, 7239–7244. [CrossRef] [PubMed]
66. Frenzel, P.; Brunings, O.; Esler, K.J.; le Maitre, D.; Rebelo, A.J. How well do endemic wetland plant species perform in water purification? *Wetlands* **2024**, *44*, 124. [CrossRef]
67. Bai, X.; Zhu, X.; Jiang, H.; Wang, Z.; He, C.; Sheng, L.; Zhuang, J. Purification effect of sequential constructed wetland for the polluted water in Urban River. *Water* **2020**, *12*, 1054. [CrossRef]
68. Kurniawan, S.B.; Abdullah, S.R.S.; Imron, M.F.; Ahmad, A.; Said, N.S.M.; Rahim, N.F.M.; Alnawajha, M.M.; Abu Hasan, H.; Othman, A.R.; Purwanti, I.F. Potential of valuable materials recovery from aquaculture wastewater: An introduction to resource reclamation. *Aquac. Res.* **2021**, *52*, 2954–2962. [CrossRef]

69. Chao, C.; Gong, S.; Xie, Y. The Performance of a multi-stage surface flow constructed wetland for the treatment of aquaculture wastewater and changes in epiphytic biofilm formation. *Microorganisms* **2025**, *13*, 494. [CrossRef]
70. Ni, M.; Yuan, J.; Zhang, L.; Hua, J.; Rong, H.; Gu, Z. In- situ and ex- situ purification effect of ecological ponds of *Euryale ferox* Salisb on shrimp aquaculture. *Aquaculture* **2021**, *540*, 736678. [CrossRef]
71. Wang, C.; Lei, J.; Guo, C. Application studies on purification of piggery waste water by multi-level artificial system of ecological lotus pond-surface flow wetland. *Ecol. Environ. Sci.* **2019**, *28*, 2289–2298.
72. Harrington, C.; Scholz, M. Assessment of pre-digested piggery wastewater treatment operations with surface flow integrated constructed wetland systems. *Bioresour. Technol.* **2010**, *101*, 7713–7723. [CrossRef]
73. Harrington, R.; McInnes, R. Integrated Constructed Wetlands (ICW) for livestock wastewater management. *Bioresour. Technol.* **2009**, *100*, 5498–5505. [CrossRef] [PubMed]
74. Scholz, M.; Harrington, R.; Carroll, P.; Mustafa, A. The Integrated Constructed Wetlands (ICW) concept. *Wetlands* **2007**, *27*, 337–354. [CrossRef]
75. Keck, F.; Lepori, F. Can we predict nutrient limitation in streams and rivers? *Freshw. Biol.* **2012**, *57*, 1410–1421. [CrossRef]
76. Liu, J.; Wang, Y.; Li, Y.; Liu, X.; Jiang, Y.; Fu, Y.; Jin, W.; Wu, J. Ecosystem N:P stoichiometric ratios determine the catchment surface water N:P ratio through subsurface hydrological processes. *CATENA* **2020**, *194*, 104740. [CrossRef]
77. Gal, G.; Hipsey, M.; Parparov, A.; Wagner, U.; Makler, V.; Zohary, T. Implementation of ecological modeling as an effective management and investigation tool: Lake Kinneret as a case study. *Ecol. Model.* **2009**, *220*, 1697–1718. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.