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Research Article

Effects of Pond Water Depth and Method of Aeration on Phytoplankton Communities in *Macrobrachium rosenbergii* Farming Ponds

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Recently, profitable *Macrobrachium rosenbergii* farming has developed rapidly in Asia. The occurrence of cyanobacterial blooms is one of the major environmental problems usually encountered in freshwater prawn farms. This study investigated the effects of pond water depth and aeration mode on phytoplankton communities in selected *M. rosenbergii* farming ponds in China. We adjusted pond water depth and aeration mode (pond water depth: 1.2 m or 1.8 m; method of aeration: surface or both surface and bottom) to compare and analyze phytoplankton community structure and characteristics between ecological (pond water depth: 1.8 m, both surface and bottom aeration) and traditional (pond water depth: 1.2 m, surface aeration) farming ponds. Water quality parameters were compared in six aquaculture systems, which were measured in situ or lab. The results showed that ecological culture suppressed Cyanophyta abundance and significantly increased the numbers of phytoplankton species leading to a 30.43–136.84% increase in the number of species for ecological ponds compared with that in traditional ponds. In all seasons, ecological culture tended to have decreased total nitrogen and ammonia nitrogen, and significantly lower total phosphorus and reactive phosphate compared with traditional ponds. In conclusion, ponds should maintain deeper water depth (1.8 m) and higher N/P ratio (>3) to promote phytoplankton diversity and suppress blooms; applying optimized culture may resolve planktonic algae problems in aquaculture ponds in Asia.

1. Introduction

The giant freshwater prawn (GFP), *Macrobrachium rosenbergii*, is the world's largest freshwater prawn and is one of the most important commercial aquaculture crustacean species globally, such as in China, India, Thailand, Vietnam, and Bangladesh [1]. This species is easily and profitably raised; consequently, the industrial culture of *M. rosenbergii* has developed rapidly worldwide [2, 3]. It was reported that the net production reached 137,300 tons in China in 2017, which was approximately 50% of the global production of *M. rosenbergii* that year [4]. However, the GFP farming industry was affected by several critical issues, such as slow growth rate, size variation at harvest, disease, and deterioration of the pond environment [5, 6].

Environmental sustainability is one of the long-term concerns of prawn farming. Major prawn and shrimp-producing countries in Asia have recently experienced a substantial decline in production as a result of diseases caused by environmental degradation [7]. A major environmental problem usually encountered in freshwater prawn farms is the possible occurrence of harmful algal blooms (HABs). HABs occur when there are extreme phytoplankton community accumulations in water bodies, and they are often accompanied by the production of numerous algal toxins [8, 9]. Toxins produced by HABs have widespread harmful consequences for organisms and are detrimental to human health [10–12]. Animal deaths and human illnesses caused by these toxins have been reported throughout the world [13, 14]. These toxins are detrimental to cultured prawns, other bottom-dwelling organisms in farm ponds, and food webs, which leads to agricultural and economic problems [8].

Traditional *M. rosenbergii* cultivation involves the establishment of "green water" by adding organic or inorganic fertilizers, or fish waste, to promote phytoplankton growth [15, 16], which usually results in the occurrence of cyanobacterial blooms in *M. rosenbergii* aquaculture ponds. The outbreak of cyanobacteria produces a variety of toxins and decreases dissolved oxygen in the water, which could reduce productivity as a result of frequent disease outbreaks of *M. rosenbergii* [3, 15, 17, 18]. Also, cyanobacterial blooms could cause taste and odor adverse effects in *M. rosenbergii* [19–21], which further reduces the price of *M. rosenbergii* and the income of aquaculture.

Physical removal, chemical spraying, and biological methods are generally used to control pond cyanobacteria outbreaks [22, 23], but these methods are not ideal in terms of efficiency, financial costs, environmental pollution, and toxicity to aquatic products [23]. An environmentally friendly and effective method to improve these aquaculture environments is urgently required.

Studies have been carried out in situ water environment regulation of ponds [24] and cyanobacteria control in ponds through aquaculture management [25]. A previous study suggested that higher phytoplankton diversity lowers the probability of cyanobacterial blooms [26]. However, little research has been conducted on the relationships among phytoplankton communities, pond water quality, and *M. rosenbergii* culture mode.

In the production practice of *M. rosenbergii*, our preliminary investigation found ponds with balanced phytoplankton communities in some places, while cyanobacterial blooms were in other places. These differences in phytoplankton communities were caused by different cultivation modes of *M. rosenbergii*. Therefore, in this study, we compared phytoplankton growth and water quality parameters among six *M. rosenbergii* aquaculture farming ponds, adjusted the structure of ponds, and optimized aquaculture methods to explore the main cause of cyanobacterial blooms in *M. rosenbergii* farming ponds.

This is the first study to investigate the effect of pond structure and cultivation mode on phytoplankton communities in selected *M. rosenbergii* farming ponds in China. Our study will provide detailed information that can be used to develop an environmentally sustainable system for *M. rosenbergii* culture, which will further optimize the development of the GFP industry.

2. Materials and Methods

2.1. Ethics Statement. All methodologies used in the experiments of this study were approved by the Committee of Ethics and Animal Welfare of Huzhou University and complied with local wildlife protection laws.

2.2. Study Site and Experiment Design. The experiments were conducted in 2019 in six continuous breeding culture ponds in Gaoyou City, Jiangsu Province, China (Table 1). Six ponds were affected by cyanobacterial outbreaks in the previous 3 years. The ecological mode was determined based on the characteristics of culture ponds that were not prone to cyanobacteria outbreaks during *M. rosenbergii* production. Three of the ponds were transformed to conform to these characteristics and designated as ponds with ecological culture mode; the other three ponds, which maintained the original structure and breeding mode, were designated as ponds with traditional culture mode (Table 1).

The water depth in traditional Gaoyou *M. rosenbergii* culture ponds is 1.2 m, and a surface aerator (used paddle aerator) is used for oxygenation; however, the water depth was increased to 1.8 m and bottom aeration (carried out microporous aeration through the bottom hose) was also used in the ecological culture mode. Each pond covered an area of ~140 acres dominated by *M. rosenbergii* culture. The outdoor culture of *M. rosenbergii* in that area usually occurs from May to October, and individuals meeting market requirements are harvested in batches from July to October.

The post-larvae*M. rosenbergii* used in each pond were from Jiangsu Shufeng Prawn Breeding Co. Ltd (Gaoyou, China), and the density was ~13,000/acre. The diet used in each pond was designed for *M. rosenbergii* by Jiangsu Fuyuda Feed Co. Ltd (Gaoyou, China), and the proximate composition of the diet was crude protein, ≥38.0 g/kg; crude lipid, ≥5.0 g/kg; ash, ≤16.0 g/kg; crude fiber, ≤7.0 g/kg; moisture, ≤12.0 g/kg; and lysine, ≥2.2 g/kg. The feed conversion ratio was 1.2–1.3 and the culture water was extracted from the same river for each pond. The final harvest quantity, sales amount, and cost of *Macrobrachium rosenbergii* culture were obtained through the investigation of farmers, and then the annual output and breeding income of ponds were assessed.

2.3. Sampling and Measurements. Water samples were collected every 10 days for water quality analysis during the harvest period when local farmers sold shrimp from July to October. Samples of subsurface water (depth~0.5 m) were collected from each pond using a 5 L Perspex water collector. The size of each pond was approximately 140 acres, and three evenly distributed points were sampled in each pond. Three samples from the same pond were mixed to create a combined sample for each pond. The sampling points were independent of each other.

2.3.1. Water Quality. The physical characteristics, such as water temperature, conductivity, dissolved oxygen (DO), and pH were measured during sampling using a portable multimeter device (YSI Professional Plus, YSI Inc., USA). Transparency was measured during sampling using a Secchi disk. Turbidity was measured with a turbidity meter (Hash 2100Q, Hash Inc., USA).

Chemical oxygen demand (COD), total nitrogen (TN), ammonia nitrogen (TAN), nitrate nitrogen (NO_3^--N), nitrite nitrogen (NO_2^--N), total phosphorus (TP), soluble reactive phosphate (PO_4^{3-}-P), and chlorophyll a (Chla) were analyzed in the Water Quality Analysis Laboratory of Jiangsu Shufeng Prawn Breeding Co. Ltd. Water samples were stored in iceboxes and analyzed within 24 h.

TAN, TN, TP, and PO_4^{3-}-P were determined using the method of Qian and Fu [27]. NO_3^-N and NO_2^--N were determined by the method of Laskov et al. [28] and Tu et al. [29]. Chla was extracted and measured following the method of Pápista et al. [30]. A Hach DR 5000 analyzer was used to measure COD.

2.3.2. Phytoplankton. The 1 L water samples were preserved by adding 2 mL of Lugol's reagent and shaking the well. After returning to the laboratory, the samples were allowed to settle in the dark for 24 h; then the supernatant was removed to retain the settled phytoplankton samples, which were concentrated to 100 mL for identification and enumeration [31]. The phytoplankton was counted by microscopy (Nikon, Japan) and identified to the species level as possible, and the estimation of algal biomass was based on density.

Simpson's diversity index [32], Shannon's diversity index [33], and Pielou's evenness index [34] were used to evaluate the phytoplankton biodiversity.

$$\begin{aligned}
&\text{Simpson's diversity index}\,(D)\text{ is } D = 1 - \sum_{i=1}^{S} P_i^2, P_i^2 = \frac{n_i(n_i-1)}{N(N-1)},\\
&\text{Shannon's diversity index}\,(H_e')\text{ is } H_e' = -\sum_{i=1}^{S} P_i \ln P_i, P_i = \frac{n_i}{N},\\
&\text{Pielou evenness index}\,(J_e)\text{ is } J_e = \frac{H_e'}{H'_{\max}}, H'_{\max} = lnS,
\end{aligned} \tag{1}$$

where S was the number of species, n_i was the total number of organisms of a particular species "i", and N was the total number of organisms of all species.

2.4. Data Analysis. One-way repeated analysis of variance (ANOVA) was conducted to analyze the effects of culture mode on the phytoplankton community and water quality index (main effect: culture mode; within-subjects term: times). Differences were regarded as significant at $P < 0.05$. All data were $\log(x+1)$ transformed to meet assumptions of normality prior to analysis. Statistical analyses were conducted using Statistica 10.0 (StatSoft Inc., Tulsa, USA). The relationship between phytoplankton abundance, phytoplankton diversity index, and pond water quality parameters was analyzed by the random forest model (randomForest package) [35] and generalized additive model (GAM) ("mgcv" package) [36, 37] in the R 3.6.2. IncMSE reflected the relative importance of variables; after removing the current variable of % IncMSE, the accuracy of random forest prediction was reduced. IncNodePurity represented the cumulative contribution of each variable to the observed values at each node of the classification tree.

3. Results

3.1. Phytoplankton Abundance of Different Groups in the Ponds. In total, 155 species of phytoplankton that belonged to 67 genera and 7 phyla were identified (Supplementary Table S1). Based on phytoplankton abundance, Cyanophyta was the dominant algal phylum in all sampling seasons (Figure 1(a)). *Merismopedia* was the most dominant algal genus in ecological ponds, whereas Microcysis with traditional ponds (Supplementary Table S1). In both ecological and traditional ponds, Scenedesmus was the dominant algal genus in the Chlorophyta phylum (Supplementary Table S1). For Bacillariophyta, Cyclotella was the most dominant genus in ecological ponds, whereas *Navicula* was the most dominant genus in traditional ponds (Supplementary Table S1).

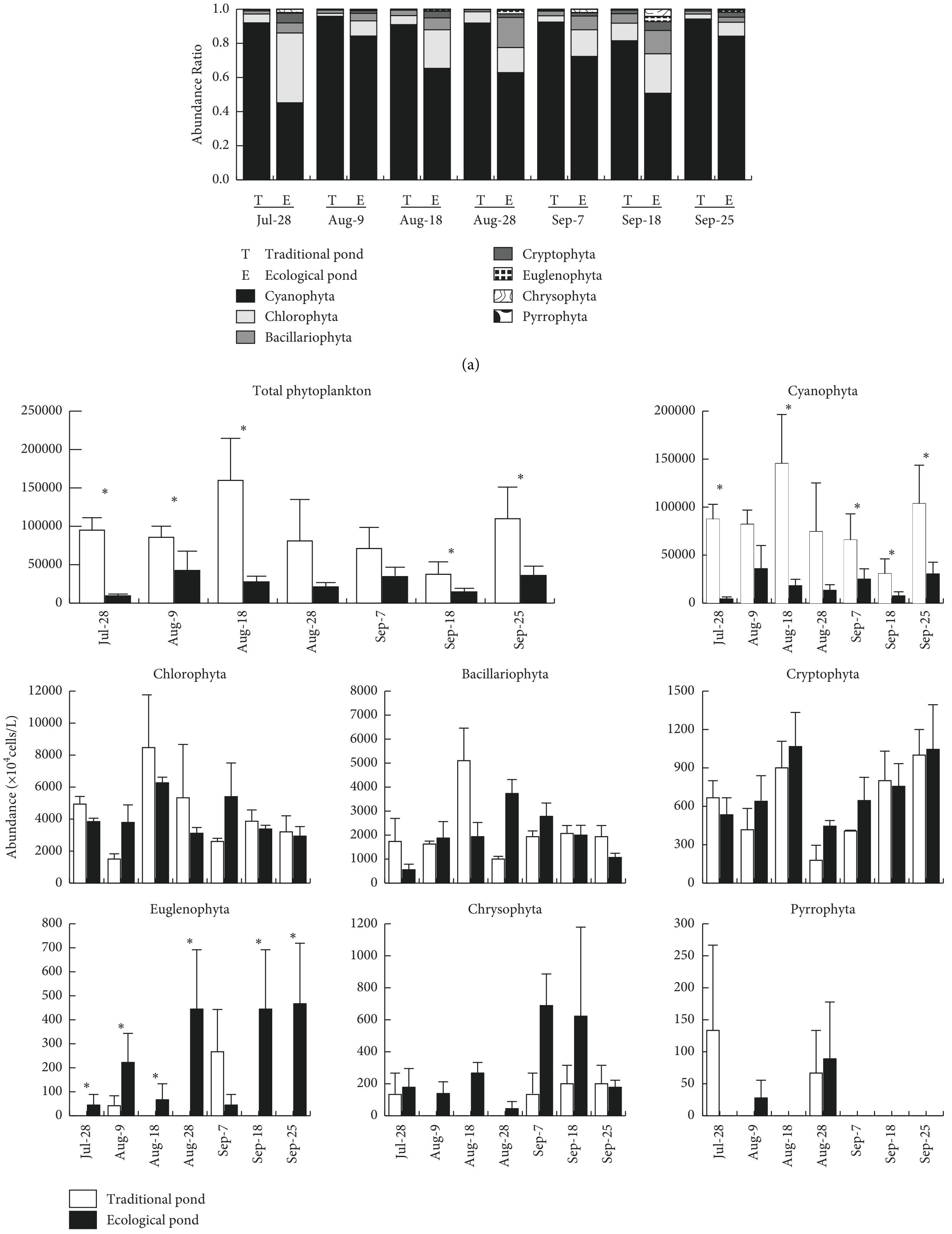
Different culture modes obviously affected the proportions of different phytoplankton groups (Figure 1(a)). The ecological culture was found to suppress Cyanophyta abundance. The present results showed that Cyanophyta abundance was 81.49–95.82% in traditional ponds and 45.15–84.28% in ecological ponds. The abundance ratios of the other phytoplankton groups including Chlorophyta ($P = 0.007$), Bacillariophyta ($P = 0.014$), Cryptophyta ($P = 0.003$), and Chrysophyta ($P = 0.003$) was significantly higher in ecological ponds (Figure 1(a); Table 2). For example, the ratios of Chlorophyta abundance in traditional ponds were 1.75–10.32% vs 8.15–40.90% in ecological ponds.

From July to September, total phytoplankton abundance in ecological ponds ($9400.00–42486.11 \times 10^4$ cells/L) was consistently lower than in traditional ponds ($37466.67–159766.67 \times 10^4$ cells/L) (Figure 1(b); $P < 0.001$). The ecological mode of prawn culture significantly decreased the total phytoplankton abundance by 50.41–90.10%.

The culture mode in ecological ponds had a significant suppressive effect on Cyanophyta abundance (Figure 1(b); $P < 0.001$). Cyanophyta abundance in ecological ponds varied from 4244.44 to 35791.67×10^4 cells/L vs from 30533.33 to 145300.00×10^4 cells/L in traditional ponds.

Table 1: Characteristics of traditional and ecological ponds. Study site at the continuous breeding area in Gaoyou city, Jiangsu province, China. “Traditional pond”: sampling points inside the pond applied the less water depth and surface aeration measures; “Ecological pond”: sampling points inside the pond applied the more water depth and bottom aeration methods, respectively.

Ponds	Original state	Area (acre)	Transformed	Water depth (m)	Aerobic methods	Yield (kg/acre)	Profit (¥/acre)
Traditional	Affected by cyanobacterial outbreaks in the previous 3 years	~140	No transformed	1.2	Surface aeration	60	700
Ecological	Affected by cyanobacterial outbreaks in the previous 3 years	~140	Transformed	1.8	Surface aeration +bottom aeration	45	550



(a)

(b)

Figure 1: Abundance ratio of total phytoplankton, and abundance of individual phyla (Cyanophyta, Chlorophyta, Bacillariophyta, Cryptophyta, Euglenophyta, Chrysophyta, and Pyrrophyta) from July to September 2019. Mean values + SE. An asterisk (*) represents a significant difference ($P < 0.05$) between ecological and traditional ponds at each sampling time, compared by Tukey HSD test following repeated measures of ANOVA.

Table 2: Results of one-way repeated analyses of variance testing the effects of culture mode on phytoplankton abundance and diversity index, and on water quality parameters. Significant P values (<0.05) are in bold.

	Culture mode		Time		Time × culture mode	
	F	*P*	*F*	*P*	*F*	*P*
Abundance						
Total phytoplankton abundance	**20.239**	**0.000**	**2.395**	**0.043**	1.313	0.276
Cyanophyta abundance	**22.432**	**0.000**	**2.342**	**0.048**	1.322	0.272
Chlorophyta abundance	0.030	0.863	2.300	0.051	0.772	0.615
Bacillariophyta abundance	0.757	0.391	**4.260**	**0.002**	**4.258**	**0.002**
Cryptophyta abundance	0.798	0.378	**2.328**	**0.049**	0.194	0.985
Euglenophyta abundance	**8.388**	**0.007**	1.249	0.306	2.112	0.071
Chrysophyta abundance	3.693	0.064	1.319	0.273	0.816	0.581
Pyrrophyta abundance	0.225	0.639	1.118	0.376	0.672	0.694
Diversity						
Simpson's diversity index	**52.867**	**0.000**	**3.499**	**0.010**	0.486	0.813
Shannon's diversity index	**57.408**	**0.000**	2.197	0.073	0.397	0.874
Pielou evenness index	**44.028**	**0.000**	**3.401**	**0.012**	0.391	0.878
Water quality parameters						
pH	2.983	0.095	**2.647**	**0.037**	1.133	0.369
Transparency	**53.409**	**0.000**	1.070	0.404	**5.727**	**0.001**
COD	**16.329**	**0.000**	**3.644**	**0.008**	2.059	0.091
DO	**27.548**	**0.000**	**13.105**	**0.000**	**3.256**	**0.015**
TN	**4.918**	**0.035**	1.147	0.362	1.091	0.392
NH_3-N	**6.446**	**0.017**	**5.527**	**0.001**	**4.104**	**0.004**
NO_3-N	0.024	0.879	**3.860**	**0.006**	0.791	0.585
NO_2-N	2.950	0.097	1.354	0.267	1.252	0.311
TP	**13.070**	**0.001**	**2.575**	**0.041**	1.498	0.215
Phosphate	**21.287**	**0.000**	**2.778**	**0.030**	**3.480**	**0.011**
N: P	**17.749**	**0.000**	**20.666**	**0.000**	**2.994**	**0.022**
Chl a	**13.485**	**0.001**	1.791	0.137	1.591	0.187

Chlorophyta abundance remained high throughout the sampling seasons, showing no significant difference between traditional and ecological ponds (Figure 1(b); Table 2; $P = 0.863$). There was no consistent variation in the abundance of the other phyla between traditional and ecological ponds (Figure 1(b); Table 2).

3.2. Pond Phytoplankton Species Diversity. Three phyla, Cyanophyta, Chlorophyta, and Bacillariophyta dominated 75.56–91.67% of the total number of phytoplankton species (Figure 2(b)). There were 10 Cyanophyta genera, 31 Chlorophyta genera, 18 Bacillariophyta genera, 4 Euglenophyta genera, 2 Cryptophyta genera, and one genus each of Chrysophyta and Pyrrophyta (Supplementary Table S1).

The ecological culture mode significantly affected the phytoplankton species diversity, and the species number in ecological ponds increased by 30.43–136.84% compared with that in traditional ponds (Figure 2(a); $P < 0.001$).

The ecological culture mode also assisted in increasing the species number of different algal phyla (Figure 2(b)). Except for Pyrrophyta, the species number of algal phyla significantly increased in the ecological ponds compared with that in the traditional ponds (Figure 2(b); $P < 0.05$). For example, the average species number of Cyanophyta varied from 5.33 to 10.67 in ecological ponds and from 3.33 to 6.00 in traditional ponds, whereas that of Chlorophyta varied from 7.67 to 12.33 in ecological ponds vs from 4.67 to 6.33 in traditional ponds.

The phytoplankton diversity index showed significantly higher values in ecological ponds than in traditional ponds (Figure 2(c); Table 2; $P < 0.001$). Ecological culture consistently improved the algal Simpson's diversity index, Shannon's diversity index, and Pielou evenness index.

3.3. Pond Water Quality. The pH values did not significantly differ between traditional and ecological ponds (Figure 3; Table 2; $P = 0.095$). There were significantly higher transparency and DO values in ecological ponds than in traditional ponds (Figure 3; Table 2; $P < 0.001$). Conversely, the ecological ponds had consistently lower COD values (40.00–88.33 mg/L vs 54.00–243.00 mg/L) and Chla values (0.16–0.26 mg/L vs 0.26–1.53 mg/L) than the traditional ponds (Figure 3; Table 2; $P < 0.05$).

In all sampling seasons, the ecological culture mode tended to cause a decrease in the TN and TAN values. No obvious differences were detected in nitrate nitrogen and nitrite nitrogen between the ecological and traditional ponds (Figure 3; Table 2).

In the ecological ponds TP and reactive phosphate had significantly lower values (TP: 0.41–2.29 mg/L; reactive

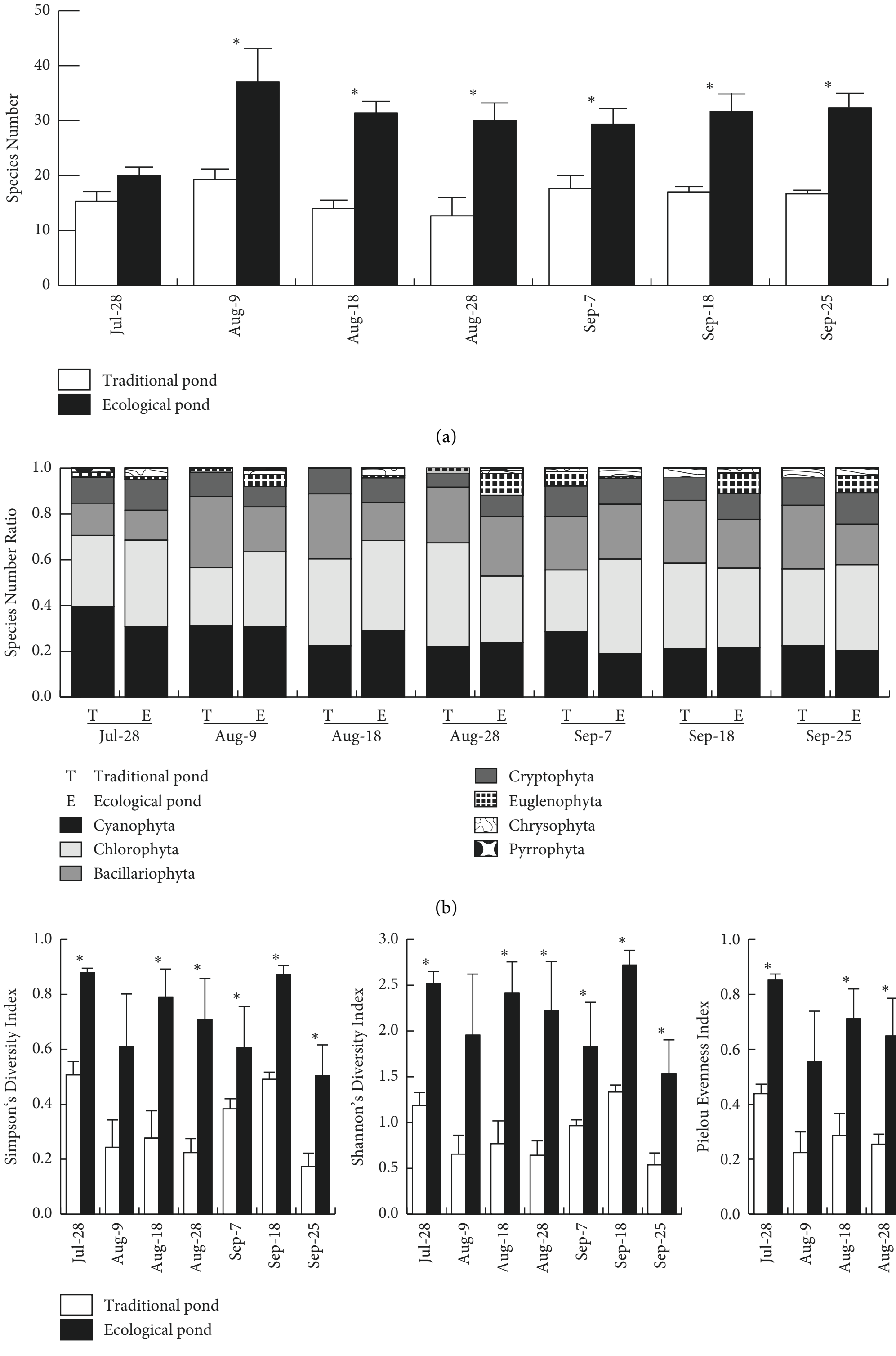


Figure 2: Species number, species number ratio, and diversity index from July to September 2019. Mean values + SE. An asterisk (*) represents a significant difference ($P < 0.05$) between ecological and traditional ponds at each sampling time, compared by Tukey HSD test following repeated measures of ANOVA.

phosphate: 0.07–0.29 mg/L) than in the traditional ponds (TP: 0.65–6.51 mg/L; reactive phosphate: 0.17–1.21 mg/L), which induced an obviously higher N: P ratio in the ecological ponds (2.19–8.76, mean value was 3.62) than in traditional ponds (1.38–4.95, mean value was 2.43) (Figure 3; Table 2; $P < 0.05$).

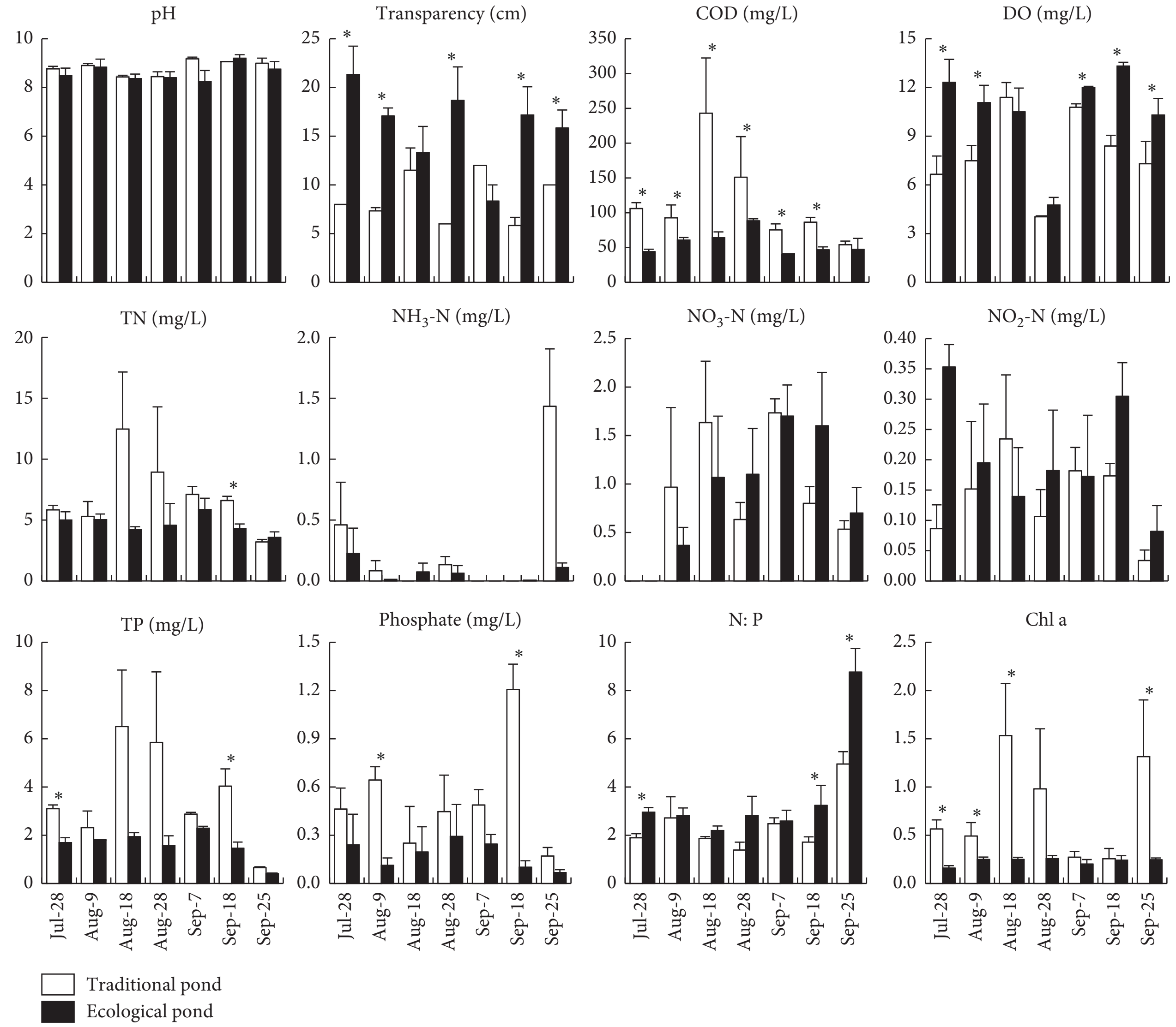


Figure 3: Twelve water quality parameters (pH, transparency, COD, DO, TN, NH_3-N, NO_3-N, NO_2-N, TP, reactive phosphate, N:P, and Chla) from July to September 2019. Mean values + SE. An asterisk (*) represents a significant difference ($P < 0.05$) between ecological and traditional ponds at each sampling time, compared by Tukey HSD test following repeated measures of ANOVA.

3.4. Correlation between the Abundance and Diversity of Phytoplankton and Water Quality Parameters.

The results of the random forest model showed that the total algal abundance was closely related to the TP, TN, and COD (Figure 4). The GAM results suggested TN and COD were positively correlated with total algal abundance, whereas TP concentrations were negatively correlated with phytoplankton abundance (Figure 5). The relationship between cyanobacterial abundance and water quality parameters was consistent with that of total phytoplankton abundance (Figures 4 and 5).

The relationship between Shannon's diversity index, Simpson's diversity index, Pielou's evenness index, and the water quality parameters were consistent. For example, Shannon's diversity index was closely related to transparency, TP, DO, and COD (Figure 4). The GAM results showed that transparency and DO were positively correlated with the diversity index (Figure 5). When the concentration of TP was low (<3 mg/L), it was positively correlated with the diversity index; however, when TP exceeded a certain threshold (nearly 3 mg/L), the diversity index was negatively correlated with an increase in the concentration of TP (Figure 5).

The number of phytoplankton species was closely related to TP and water transparency in the results (Figure 4). When the TP level was low, the number of phytoplankton species remained at a high level; however, as the TP level improved the number of species decreased (Figure 5). When transparency was low (<18 cm), it was positively correlated with the number

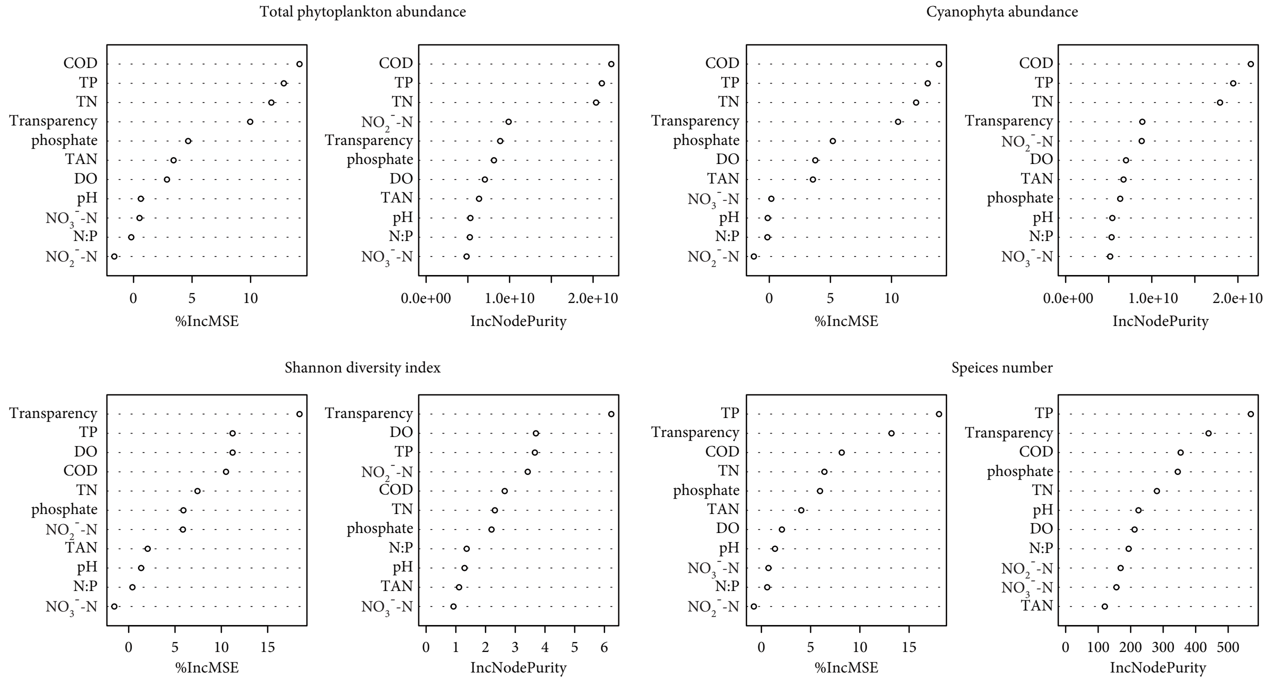


FIGURE 4: The relative importance of water quality parameters to explain phytoplankton abundance and diversity index variables based on random forest models. The default random number was 1000 times.

of phytoplankton species; when transparency exceeded a certain threshold (nearly 18 cm), it was negatively correlated with the number of phytoplankton species (Figure 5).

4. Discussion

4.1. Effects of Culture Mode on Phytoplankton Community in M. rosenbergii Culture Ponds. We found that phytoplankton abundance was lower significantly in ponds under ecological culture. Additionally, the decrease in phytoplankton abundance mainly manifested as a low in the density of cyanobacteria, which was the dominant phylum, but the abundance of other phyla did not change significantly (Figure 1).

Cyanobacteria tend to be more environmentally adaptable and competitive than other algae [38]. When the pond environment is more conducive to algal blooms, cyanobacteria tend to dominate, while other algae are inhibited by cyanobacterial competition, and their density is maintained at a low level [39]. However, when the pond environment restricts algal reproduction, the advantages of cyanobacteria are not obvious and their density decreases. Other algae can also be inhibited by environmental pressure when reproduction is restricted, and their density may also remain at a low level [40].

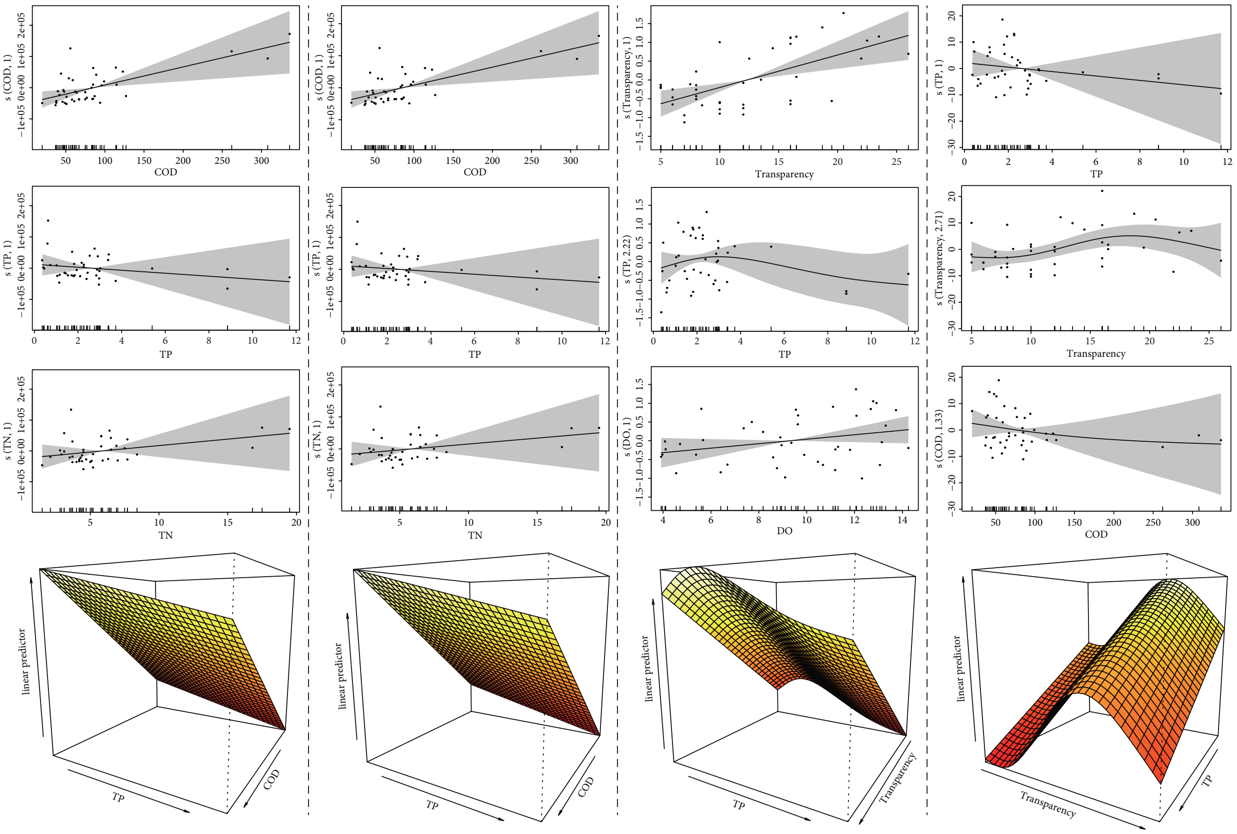
In this study, the ecological culture mode was represented by greater pond water depth and lower amounts of feed (Table 1). Water depth has been repeatedly shown to be an important factor in controlling cyanobacteria [41]. When the water depth is less than 1 m, cyanobacterial blooms are more likely to occur [42]. Therefore, increasing the water depth might be an effective way to suppress cyanobacterial outbreaks in ponds. Moreover, some studies have shown that, when the nutrient level of the water body falls, the chance of large-scale cyanobacterial growth will decrease [43, 44]. Reducing the amount of feed will directly limit the amount of residual bait, which may reduce water eutrophication [45], thereby reducing the proliferation of cyanobacteria.

Our results revealed that phytoplankton diversity increased significantly in ecological culture. Increasing the water depth can expand the space available for algal growth and provide more ecological niches, which is beneficial for improving phytoplankton diversity [46, 47].

In this study, the ecological culture mode was also partially represented by more bottom aeration (Table 1). Continuous bottom aeration is often more efficient than surface aeration in improving the DO level, which is conducive to the growth of algae such as Bacillariophyta and Chlorophyta, and thus improves algal diversity [48, 49].

The diversity of Cyanophyta, Bacillariophyta, and Chlorophyta all increased significantly in ecological culture, which indicated that appropriately increasing the depth of the pond and reducing excessive bait feeding can improve algal diversity and reduce the accumulation of a single dominant alga.

4.2. Effects of Culture Mode on Water Quality in M. rosenbergii Culture Ponds. Our research showed that the water in ecological ponds had obviously higher transparency and lower COD; this could be caused by the increase of water depth in ecological aquaculture. Deeper water produces a more conducive environment to the natural precipitation of suspended solids, providing conditions for increased transparency [50, 51]. Deeper water increases pond water capacity, and COD might simultaneously decrease with this dilution [52]. However, the deeper water led to a relative decrease in



(a) Total phytoplankton abundance (b) Cyanophyta abundance (c) Shannon diversity index (d) Speices number

Figure 5: Generalized additive model (GAM) plot of the probability of (a) total phytoplankton abundance, (b) Cyanophyta abundance, (c) Shannon diversity index, and (d) Species numbers for the important water quality parameters. The choice of water quality parameters is based on random forest model results. The model incorporated the solid black lines show the nonlinearity of multivariable-adjusted relation between the important water quality parameters and community indicators (with 95% confidence intervals shown in shaded part, expressed as centralization predicted mean value by the smooth functions using penalized regression splines), and visualization of GAM objects used perspective and contour plot views of GAM model predictions. The little vertical bars (i.e., rugs) on the horizontal axis of the GAM plots display the distribution of individual observations.

oxygen content at the bottom of the pond. This can inhibit nitrification to a certain extent; therefore, the change rule of nitrite and nitrate nitrogen was not obvious overall.

Bottom aeration and the change in water depth had a clear influence on nitrification and denitrification. The bottom aeration measures used in ecological culture can increase DO near the bottom of the pond, inhibit denitrification under anaerobic conditions, reduce the ammonia nitrogen content, and increase the nitrite and nitrate nitrogen content.

The accelerated precipitation of suspended matter owing to the deeper water might also be an important reason why the decrease in phosphorus was higher than that of nitrogen [53]; this indirectly led to a significant increase in the water N/P ratio. The water N/P ratio is an important index of the water environment and has a great influence on aquatic communities [54]. There are two ways for the N/P ratio in water to change. One is a change in exogenous N/P input, and the other is a dynamic change in the N/P cycle [55, 56]. The current results tended to support the hypothesis that the effect of the change in suspended matter settlement caused a significant increase in the N/P ratio in ecological culture. There may, therefore, be more phosphorus deposition at the pond bottom in the ecological cultivation, and attention should be paid to this when cultivation is continuous over numerous years.

4.3. Correlation between Phytoplankton Community and Water Environment Quality. In this study, total phytoplankton and Cyanophyta abundance were closely related to TN, TP, and COD (Table 2, Figure 4), reflecting the close relationship between water N and P content and algal growth. The present results are consistent with those of several other studies [56–58].

The abundance of total phytoplankton and Cyanophyta was found to be positively correlated with TN (Figure 5), which supported the view that controlling nitrogen content had an inhibitory effect on algal blooms in aquaculture ponds [57, 59, 60]. The abundance of total phytoplankton and cyanobacteria decreased as TP content rose (Figure 5). When the TP content is low, cyanobacteria might become the dominant phylum [61, 62] under the condition of P stress, which is unfavorable to other phytoplankton. Along with the TP content increase, the P stress of algae decreased, and some algae could compete with cyanobacteria, thus reducing the abundance of total algae and cyanobacteria

[39, 63]. When the TP content increased to a certain extent the water became eutrophic and massive algal (especially cyanobacteria) proliferation and cyanobacterial blooms could occur [64]. The average value of TP was 2.60 mg/L in this study, which belonged to the lower range of P content in the correlation analysis results. Therefore, there was no situation in which the growth of cyanobacterial blooms increased with TP.

The correlation between the abundance of total phytoplankton and cyanobacteria with COD might be the result of increased COD, owing to the increase in the number of phytoplankton and cyanobacteria and the secretion of a large amount of organic matter [65]. The increase of COD further enhanced the inhibition of other algae, causing an increase in the abundance of cyanobacteria [66].

There was a close positive correlation between transparency and phytoplankton diversity (Figures 4 and 5), reflecting greater phytoplankton diversity with higher transparency. When the transparency was high, perhaps because of better light transmittance through the water, the light requirements of different algae could be met, which increased the competition among different algae and thus improved phytoplankton diversity [67].

The present results also showed that there was a strong correlation between TP and phytoplankton diversity (Figures 4 and 5). With increased TP levels, the growth potential of most phytoplankton was enhanced, intensifying competition, and leading to a further increase in phytoplankton diversity and the formation of a peak at a lower TP level (Figure 5). When the TP level rose further it was no longer a limiting factor for phytoplankton growth, and the growth potential of cyanobacteria was maximized [68, 69]. It would induce the dominance of cyanobacteria and a decline in algal species diversity (Figure 4). This phenomenon further suggested the importance of phosphorus for cyanobacteria control in aquaculture ponds.

There was, however, a significant positive correlation between DO and phytoplankton diversity. Bottom oxygenation in the ecological culture ponds made water oxygenation more effective. Moreover, increasing the oxygen content of the water surface might benefit competition between cyanobacteria and other algae, thus improving phytoplankton diversity. This result suggests that COD can be reduced by increasing oxygen, which may have some positive effects on phytoplankton diversity.

Previous studies showed that the N/P ratio is an important index affecting cyanobacterial growth. Generally, a high N/P ratio is more beneficial in controlling cyanobacteria than a low N/P ratio [70, 71]. The interpretation rate of the N/P ratio was lower in the random forest model analysis of the experimental data (Figure 4). Nevertheless, the abundance of cyanobacteria in the ecological ponds with a higher N/P ratio was still found to be much lower than in the traditional ponds with a lower N/P ratio (Figure 3).

This study suggested that lower TP content and higher oxygen content contribute to increased phytoplankton diversity and inhibit cyanobacterial blooms in ponds. The effects of phosphorus and oxygen were considered important ecological factors affecting phytoplankton communities in aquaculture ponds.

4.4. Implications for Environmental Friendly Aquaculture and Aquatic Product Safety Management of M. rosenbergii. Cyanobacterial blooms in pond culture have become important factors restricting the safety of *M. rosenbergii* products. Algal toxins accumulate easily in cyanobacterial environments, affecting the taste and quality of edible prawns, and exposing consumers to potential risks. A number of researchers, therefore, are trying to solve this problem in *M. rosenbergii* ponds [3, 15, 72]. This study used pond reconstruction and optimal management to address the issue of cyanobacterial blooms and appeared to achieve good results. There are three main advantages of this pond reconstruction and optimal management such as (1) it is easy to operate and can be realized through simple pond reconstruction and management optimization, (2) it involves no increase in pond inputs and there is limited impact on prawn growth, and (3) related reconstruction costs are low and additional land is not needed. Consequently, this method can be easily promoted.

Although the annual yield and income of the ecological ponds in this study were not higher than those of the traditional ponds (Table 1), there is potential for environmental governance and product safety, which have extremely positive impacts and provide greater overall benefits in the long run. Our results revealed the need for comprehensive consideration of pond structure and cultivation methods in prawn culture. Furthermore, although the algal toxin content of *M. rosenbergii* is not covered in this paper, from the perspective of food safety and consumer health, future research needs to examine the different farming models. The content of algal toxins in the muscles of *M. rosenbergii* needs to be measured to comprehensively evaluate different farming modes.

5. Conclusions

This study examined the effects of culture mode on algae in GFP culture ponds by a continuous sampling method. The results showed that the ecological mode inhibited Cyanophyta abundance, decreased total algal abundance, and increased the abundance of the other algal phyla including Chlorophyta, Bacillariophyta, Cryptophyta, and Chrysophyta. All ecological culture ponds contained many more algal species (including Cyanophyta) and higher levels of algal diversity than traditional culture ponds. Ecological culture ponds also showed higher transparency and N/P ratios, but lower COD and TP contents, which may be the source of algal community dynamics. The present study suggests that, for healthy GFP culture, culture ponds should be maintained at a deeper water depth (1.8 m) and higher N/P ratio (>3) to promote algal diversity and suppress cyanobacterial blooms. Further studies need to be done to confirm the effect of ecological and traditional ponds on cultured species' sensory quality and evaluate the level and the type of toxins produced.

Data Availability

All data, models, or code generated or used during the study are available from the corresponding author or the first author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

Supplementary Table S1: the phytoplankton abundance of 67 individual genera belongs to 7 phyla (Cyanophyta, Chlorophyta, Bacillariophyta, Cryptophyta, Euglenophyta, Chrysophyta, and Pyrrophyta) between ecological and traditional ponds at each sampling time from July to September 2019. Mean values ± SE, $\times 10^4$ cells/L. (*Supplementary Materials*)

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