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Effects of nitrogen and phosphorus from fish cage-culture on the communities of a shallow lake in middle Yangtze River basin of China

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Abstract

In recent decades, net-cage aquaculture has become one of the main patterns of the intensive fish-culture in the lakes, reservoirs and even rivers in China. This aquaculture pattern results in enriching exogenous nutrients in water and, consequently, accelerates the process of lake eutrophication. To ensure that normal environmental conditions and fisheries in a lake remain sustainable, qualitative estimations of nutrients in relation to ecosystem changes are essential. A study, mainly on nitrogen (N) and phosphorus (P) influences due to cage fish-culture was carried out in a shallow 35.5 ha bay in Niushanhu Lake, a shallow lake located in middle Yangtze Basin, during the period from March to December 2000. Net-cages in total covered an area of 1000 m^2 and the annual fish yield was 16.0 metric tons (MT). Fish feeding residue entering the water during the period was equivalent to 1532.9 kg of total N and 339.2 kg of total P. Sampling and analyses of the total N and total P concentrations, diversity and biomass of plankton and Chl *a* were made monthly, while data on zoobenthos were collected twice, respectively, at the beginning and the end of the study. Results showed that the Chl *a* content in water was correlated negatively to distance from the cage. The Chl *a* content that is converted into wet biomass of phytoplankton may be expressed by the regression: $B = 2.673 - 0.0016D$ (B, biomass in mg/l; D, distance in km; $r = 0.9362$; $n = 7$). The biomass of rotifers inside or near the cages was higher than that in areas more distant, while that of the cladocerans was the opposite. No significant difference of copepod density or biomass was detected between cages and open water. Changes of zoobenthic community were remarkable. At the beginning of fish farming, there were nine zoobenthic taxa inside and 13 outside the cages. Only two saprophilous taxa, chiefly oligochaetes, were present in the cages at the end of the culture. Density and biomass of benthic animals decreased as well. Several bio-indices, such as Shannon-Wiener index, Simpson index, and Margelef index, also exhibited a declining tendency. Through this study, the authors are of the opinion that mass-input of exogenous

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nutrients may cause negative effects on water quality in areas from the cage to a distance of 50 m outwards.

Keywords: Fish-cage culture; Nitrogen; Phosphorus; Shallow lake; Communities

1. Introduction

Freshwater aquaculture is of great importance in commercial fisheries in China, for it supplies more than one third of the total freshwater fishery production of the world. In addition to pond culture, China also carries out commercial fisheries in some lakes, reservoirs, and rivers. In East and Central China, there are more than 4000 lakes, covering an area of about 20,000 km^2 along the lower and middle reaches of the Yangtze River. Most of the lakes are shallow macrophytic lakes that are the major freshwater fisheries bases of China, and their fisheries production comprises more than 60% of the total inland fish yield. Cage aquaculture is one of the main freshwater intensive culture patterns in the country, due to its benefits in terms of increased fishery production and profit. During the fish cage culture, a large amount of waste matter was brought into the water directly. The ecological balance of the aquatic ecosystem was disrupted and resulted in eutrophication in areas where the cages were located, and even entire lakes. As cage aquaculture becomes more prevalent, the problem of water pollution caused by the input of artificial feeds will certainly become more serious. It would be prudent that greater attention be paid to the issue now, to ensure normal environmental conditions persist, resulting in sustainable fisheries in shallow lakes. The present study focuses mainly on the effects of exogenous nitrogen (N) and phosphorus (P) influences resulting from cage fish-culture activity in shallow lakes.

2. Material and methods

2.1. Location of experimental area and cage setting

The study was carried out between March and December 2000 in Niushanghu Lake (114°32′E, 30°19′N), a shallow macrophytic lake located in the middle reaches of the Yangtze River, China. The total lake area is about 4000 ha. One hundred 20-m^3 cages ($3.3 \times 3.3 \times 2.0$ m), divided into 10 groups and covering 1000 m^2 water surface, were used in the study. The net-cages were set-up in a 35.3 ha bay of the lake with a mean water depth of 2.5 m. A 1600 m earthen dam separates the lake from the bay. In the middle of the dam, a passageway 3.0 m in width keeps bay water connected with the main body of water. Location of the cage area is shown in Fig. 1.

2.2. Cage fish stocking

Mandarin fish (*Siniperca chuatsi*), Chinese freshwater bream (*Megalobrama amblycephala*) and Channel catfish (*Ictalurus punctatus*) were reared in 46, 23 and 11

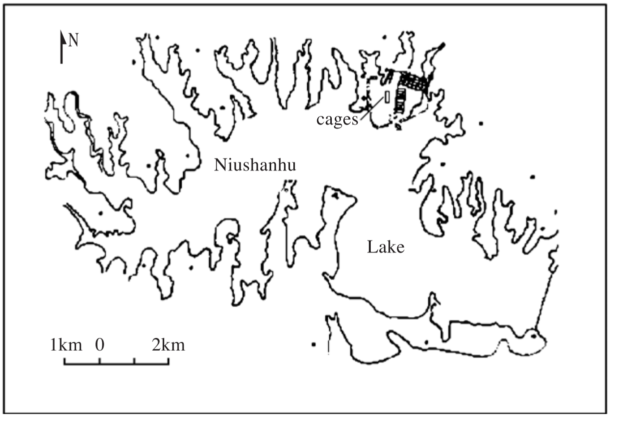


Fig. 1. Map of Niushanhu Lake and cage area.

cages, respectively. The other 20 cages were empty. Stocking parameters are shown in Table 1.

2.3. Experimental diets and feeding practices

Mandarin fish were fed with small live forage fish during the entire experimental period. Freshwater bream and channel catfish were fed a formulated diet containing 29% protein at 2–4% of their body weight per day in three or four daily allocations. Additional grass was added for bream, and the fresh forage fish from the mandarin fish culture cages were reused by the channel catfish. The amount of feed provided was adjusted according to temporal changes in biomass and growth of the fish in the cages.

2.4. Sampling and analytical methods

From March to December 2000, monthly samples were taken from inside the cages, at side stations outside the cages, and stations 20, 50, 80, 100, and 130 m eastward from the cages. Three samples were taken from each station. The parameters included water temperature (T °C), water depth (H), Secchi disk depth (SD), dissolved oxygen (DO), total phosphorus (TP), total nitrogen (TN), Chlorophyll *a* (Chl *a*), zooplankton, and zoobenthos. Data on T, H, SD, DO, concentrations of TN and TP, diversity and biomass of plankton and Chl *a* were collected monthly, while data on zoobenthos were obtained twice, at the beginning and the end of the study, respectively. The input of TN and TP to

Table 1
Fish stocking in the cage culture experiment

Species	Size (g/ind.)	Density (ind./cage)	Total weight (kg)	Culture area (m^2)
Mandarin fish	150–350	120	1272	230
Freshwater bream	25–175	490	3848	460
Channel catfish	350–500	500	1456	110

Table 2
Nitrogen and phosphorus budget of fish cage-culture

Nutrient budget	Nitrogen (kg)	Phosphorus (kg)
Nutrient in feed (*a*)	1798.9	380.9
Nutrient removed by fish (*b*)	266.0	41.7
Estimated nutrient loss (*a*−*b*)	1532.9	339.2
Nutrient loss as kg/ton fish yield	159.7	35.3

lake water was determined by analyses of the diets (%N and %P) and by feeding records presented by fish farms. Total nitrogen and TP were determined by the standard colorimetric methods (Huang, 1999).

2.5. Statistical methods

The N and P loadings from the cage-culture were calculated from the Mass Balance Equation:

$$\text{Nutrient loadings} = \text{Dietary nutrient} - \text{fish body deposition nutrient}$$

All data were analyzed by Statistic Software packet (StatSoft Institute, Version 5.0).

3. Results

3.1. Total nutrient input from cage culture

During the breeding period of eight months, total diets consisted of 35.4 MT formulated feed, 4.4 MT small forage fishes, and 13.2 MT fresh grass. The total fish yield was 16.0 MT (Table 1), consisting of 1.7 MT mandarin fish, 2.8 MT channel catfish,

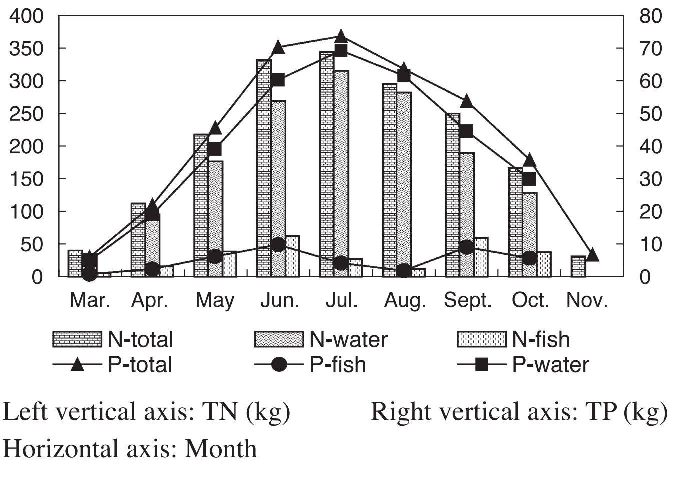
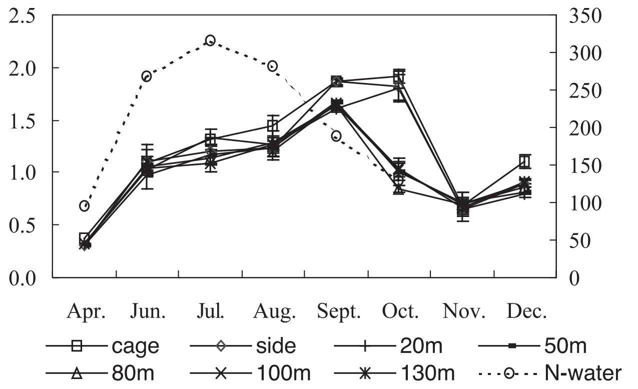


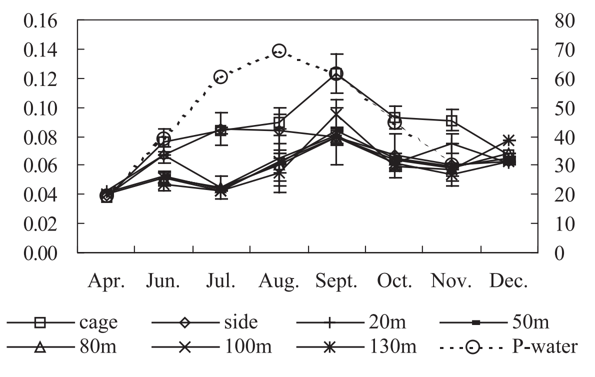
Fig. 2. Input of total nitrogen (TN) and total phosphorus (TP) into the waters and fish, March–December 2000.



Left vertical axis: Water TN (mg/l) Right vertical axis: N input (kg)
Horizontal axis: Month

Fig. 3. TN concentration at different sites, April–December 2000.

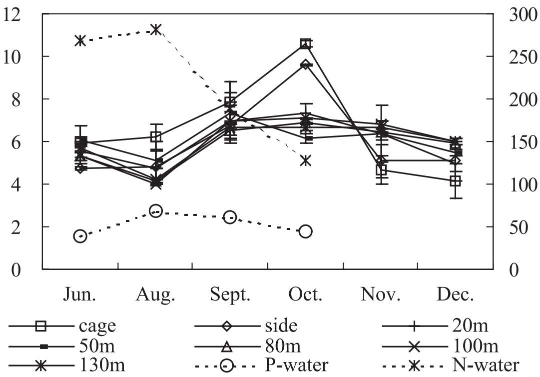
and 11.5 MT Chinese freshwater bream. Table 2 shows N and P budgets during the study. As seen in Table 2, water nutrient loadings of TN and TP were 1532.9 and 339.2 kg, respectively, during the entire period of the test. Utilization rates of the diets by the cultured fish, however, were 14.8%N and 11.0%P of the diets. Most of the dietary N and P were lost in the surrounding water. With this type of cage-culture system, producing 1 kg fresh fish results in 0.160 kg TN and 0.035 kg TP being introduced into the lake environment.



Left vertical axis: Water TP (mg/l) Right vertical axis: P input (kg)

Horizontal axis: Month

Fig. 4. TP concentration at different sites, April–December 2000.



Left vertical axis: Chl a (μg/l) Right vertical axis: N and P input (kg)

Horizontal axis: Month

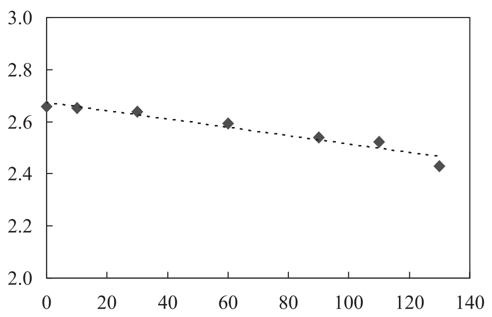
Fig. 5. Chlorophyll *a* (Chl *a*) concentration at different sites, June–December 2000.

3.2. Monthly water loadings of N and P

Monthly N and P in the diet, culture fish deposit, and water loadings during the study are shown in Fig. 2. The loading of TN and TP increased from the beginning of feeding, reached a peak in July, and then declined to the end of the experiment. As a rule, more than 85% of the N and P from the feed was discharged into the cage culture area. The efficiency of fish use of the dietary N and P decreased in July and August, probably due to the extremely high water temperature (28–31 °C).

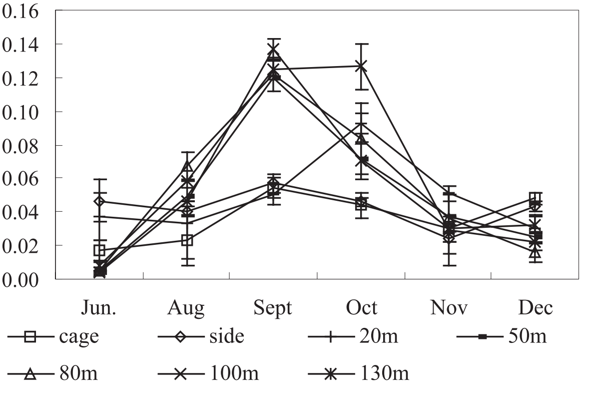
3.3. Effects of input N and P on water TN, TP concentrations

During the monitoring period, TN concentration found in the water at all of the sampling sites increased from the beginning of the trial to October, and declined



Vertical axis: Phytoplankton biomass (B) (mg/l) Horizontal axis: Distance (m)

Fig. 6. Correlation between phytoplankton biomass and distances from cage.

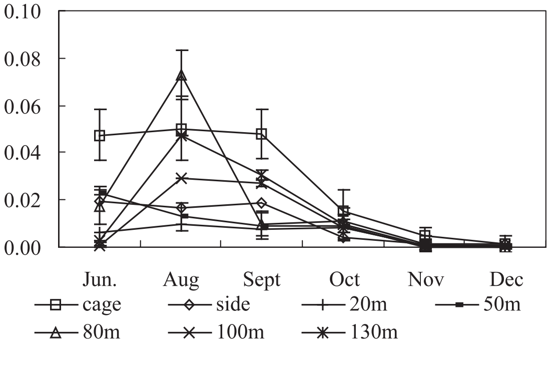


Vertical axis: Rotifer biomass (mg/l) Horizontal axis: Month

Fig. 7. Rotifer biomass at different sites, June–December 2000.

sharply in November. The TN concentration inside the cage was significantly (t-test, $P<0.05$) higher than that of other sampling sites. In October, the TN inside the cage, at cage side, and 20 m away from the cage reached the highest levels, about three times as high as at the other sites. In contrast, the TN in more distant sites (50–130 m) were very similar (Fig. 3). For this type of cage culture system, the area in which N input had the greatest impact was chiefly within a range of around 50 m from the cage.

The change in water TP concentration is summarized in Fig. 4. During the entire study period, the concentration of TP inside the cage was significantly (t-test, $P<0.05$) higher than at the other sampling sites. Total phosphorus at 50 m or more



Vertical axis: Cladoceran biomass (mg/l) Horizontal axis: Month

Fig. 8. Cladoceran biomass at different sites, June–Dec. 2000.

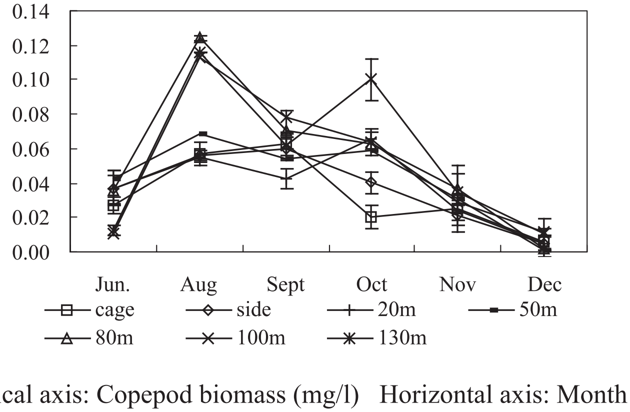


Fig. 9. Copepod biomass at different sites, June–December 2000.

was not significant (*t*-test, $P>0.05$), and there was little variation. Based on these data, the input of P on TP water concentration was limited to within 50 m of the cages.

Table 3
Species composition of zoobenthos during cage culture

Species	Beginning (April)		End (October)	
	Cage-in	Cage-out	Cage-in	Cage-out
Oligochaetes				
Stephensoniana trivandrana		+		
Tubifex sp.	+	+		
Teneridrilus mastix				+
Aulodrilus limnobius				+
A. pluriseta	+	+		
Branchiura sowerbyi	+	+	+	+
Molluscs				
Bellamya	+	+		+
Limnoperna lacustris	+	+		
Sphaerium lacustre			+	
Aquatic insects				
Clinotanypus sp.		+		
Pelopia sp.				+
Chironomus sp.	+	+		
Pagastiella sp.		+		
Microchironomus sp.		+		
Cladopelma sp.		+		
Polypedilum sp.	+	+		
Glyptotendipes sp.				+
Einfeldia sp.	+	+		+
Rheotanytarsus sp.	+			

Table 4
Number and percentage of taxa of zoobenthos inside and outside the cage

	Beginning of culture				End of culture			
	Cage-in		Cage-out		Cage-in		Cage-out	
	Species	%	Species	%	Species	%	Species	%
Oligochaetes	3	33.3	4	30.8	1	50	3	42.8
Aquatic insects	2	22.2	2	15.4	1	50	1	14.4
Molluscs	4	44.5	7	53.8	0	0	3	42.8
Total	9	100.0	13	100.0	2	100.0	7	100.0

3.4. Effects of input N and P on concentration of Chl a in water

During the experimental period, the Chl *a* concentration ranged from 4 to 10 μg/l at all sample sites (Fig. 5). The Chl *a* inside the cage and at cage side differed from other sites (*t*-test, $P<0.05$), peaking in October and declining in November and December. No general trends were found among sites that were between 20 and 130 m from the cage. Chl *a* content can be converted into wet biomass of phytoplankton using a coefficient of 0.405 (Institute of Hydrobiology, 1988). The regression model: $B=2.673-0.0016D$ (*B*, biomass in mg/l; *D*, distance in km; $r=0.9362$; $n=7$) (Fig. 6) was found to provide a good fit of the data (*t*-test, $P<0.05$).

Fig. 6 shows a negative linear relationship between phytoplankton biomass and distance from the cage.

3.5. Effects of fish cage-culture on the lake zooplankton

Biomass of zooplankton was calculated monthly during the study period (Figs. 7–9). Results showed that the biomass of rotifers was lower at the cage site and higher at greater distances from the cage during the period except for June. In June, the biomass of rotifers at the cage side site was higher and differed from other sites (*t*-test, $P<0.05$). Cladocerans were found to exhibit an opposite trend. No obvious trends were observed for copepod biomass, neither among sampling sites nor among the samples monthly.

Table 5
Density (*D*) and percentage of zoobenthos inside and outside the cage

	Beginning of culture				End of culture			
	Cage-in		Cage-out		Cage-in		Cage-out	
	D[a]	%	*D*	%	*D*	%	*D*	%
Oligochaetes	48	40.0	59	23.1	11	68.8	59	35.8
Aquatic insects	32	26.7	157	61.6	5	31.2	85	51.5
Molluscs	40	33.3	39	15.3	0	0	21	12.7
Total	120	100.0	255	100.0	16	100.0	165	100.0

[a] *D*: ind./m^2.

Table 6
Biodiversity indices of zoobenthos between cage-in and cage-out during the study

Index	Beginning of culture		End of culture	
	Cage-in	Cage-out	Cage-in	Cage-out
Margalef	2.12	2.48	0.00	1.02
Sampson’s	4.09	5.93	0.75	2.58
Shannon-Wiener	2.15	2.73	0.00	1.51

3.6. Effects of input N and P on lake zoobenthos

At the beginning of the experimental period, there were nine species of zoobenthos found underneath the cages and 13 species outside the cages. The species composition is shown in Table 3. By the end of the study, only two species (*Branchiura sowerbyi* and *Sphaerium lacustre*) were found underneath the cage, and seven species were found outside of the cage (Table 3).

Comparisons of zoobenthos directly beneath and outside the cages are shown in Tables 4 and 5. Both the number of species and their density markedly decreased beneath the cages at the end of fish culture. In contrast, similar changes in the benthic animal community in areas outside the cage were not apparent (Table 6).

4. Discussion

The main impact of cage aquaculture is the increase in the load of N, P, and organic matter that enrich water and underlying sediment (Alabaster, 1982). The effect depends primarily on the annual fish production, area and depth of the lake, and water residence time (Phillips, 1985; Phillips et al., 1985; Liu et al., 1997; Wallin and Haakanson, 1991; Huang, 1997). In the present study, water residence time was about three years and the depth of sampling sites was similar.

Phosphorus is recognized as the principle factor produced by the fish farm that has an effect on the lake environment (Jones and Lee, 1982; Ketola, 1982; Kelly, 1992). Beveridge (1984) simulated a predictive model of fish production capacity of a lake, while keeping water quality within acceptable limits, mainly on the relation between P loading of lakes and resulting chlorophyll levels. Similar research was conducted by Phillips et al. (1983, 1985), Phillips (1985), and by Li et al. (1994), and Lin and Zhang (1995) in reservoirs in China. Since the 1980s, there has been a large increase in the number of pen cultures sited in lakes, which mainly utilize aquatic macrophytes supplemented with artificial feed. For sustainable development of fisheries in lakes, it is essential to control the impact of cage culture to retain acceptable water quality conditions in the lake. Therefore, a moderate carrying capacity for cage culture should be considered (Chen, 1989; Liu et al., 1997; Shi et al., 1999; Zhang et al., 1997; Li and Chen, 1998; Huang et al., 1998; Wu et al., 1995). Cornel and Whoriskey (1993) reported that cage culture of rainbow trout (*Oncorhynchus mykiss*) in Quebec had short-term, localized impacts on the lake environment. Similar results were reported by Stirling and Dey (1990).

In the present study, the gross yield of fish in 2000 was not high (16.0 MT in total), but the nutrient loads from the diets used were prominent. The nutrient loads were 0.160 kg N/kg fish and 0.035 kg P/kg fish produced, and somewhat higher than results (0.082–0.124 kg N/kg fish and 0.023–0.029 kg P/kg fish) reported by others (Penczak et al., 1982; Foy and Rosell, 1991; Lin and Zhang, 1995). In contrast, Phillips (1985) reported that 0.056 kg P was produced per kg fish.

Comparison of the water quality, plankton, and zoobenthos between the cage site and areas more distant from the cages in the present study showed that cage culture has a significant effect on TN and TP concentration and density of zoobenthos. Differences in the community structure of the plankton (Figs. 6–9) were due to nutrient levels in the water, rather than the use of fish, since all stocked fish in this study were non-plankton feeders. Thus, the increased biomass of the phytoplankton at the cage site due the addition of nutrients during the study period resulted in an increased biomass of Cladocerans. Therefore, at present production levels, the impact of cage culture may extend to 20 m or more from the cages in the lake.

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