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Impacts of two biomanipulation fishes stocked in a large pen on the plankton abundance and water quality during a period of phytoplankton seasonal succession

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ABSTRACT

Silver and bighead carp were stocked in a large pen to control the nuisance cyanobacterial blooms in Meiliang Bay of Lake Taihu. Plankton abundance and water quality were investigated about once a week from 9 May to 7 July in 2005. Biomass of both total crustacean zooplankton and cladocerans was significantly suppressed by the predation of pen-cultured fishes. There was a significant negative correlation between the N:P weight ratio and phytoplankton biomass. The size-selective predation by the two carps had no effect on the biomass of green alga *Ulothrix* sp. It may be attributed to the low fish stocking density (less than 40 $g\,m^{-3}$) before June. When *Microcystis* dominated in the water of fish pen, the pen-cultured carps effectively suppressed the biomass of *Microcystis*, as indicated by the significant decline of chlorophyll *a* in the >38 μm fractions of the fish pen. Based on the results of our experiment and previous other studies, we conclude that silver and bighead carp are two efficient biomanipulation tools to control cyanobacterial (*Microcystis*) blooms in the tropical/subtropical eutrophic waters. Moreover, we should maintain an enough stocking density for an effective control of phytoplankton biomass.

1. Introduction

The trophic state of a lake is controlled not only by external nutrient load, but also by the structure of the food web. The use of food web manipulation as a method for the control of cyanobacterial blooms has been extensively studied for many years (McQueen et al., 1989; Horppila et al., 1998; Kasprzak et al., 2002).

Fish is a major factor determining the algal blooms, structuring the composition of both zooplankton and phytoplankton communities (Lazzaro et al., 2003). Fish predation strongly suppresses the zooplankton even during the winter (Jeppesen et al., 2004). The decline of phytoplankton biomass has been observed as a response of reductions or removal of planktivorous fish and this has been attributed to increased zooplankton grazing (Shapiro et al., 1975). Large-sized zooplankton are known to be highly efficient grazers and may be more important for the improvement of water quality. A 'clear water phase' in early summer may be attributed to the grazing of large crustacean zooplankton (Talling, 2003). Fish kills or low fish recruitment may lead to high grazing pressure on phytoplankton and clear water conditions throughout the summer (Hosper and Meijer, 1993; Jeppesen et al., 2004). However, most experiments are focused on zooplanktivorous fish that are dominant in temperate lakes (Kasprzak et al., 2002). In tropical or subtropical eutrophic lakes, the potential for controlling the

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water quality with zooplankton grazing is often more questionable than in temperate lake, and the possible reasons are attributed to the uningestible size, grazing-resistant coverings and the toxicity associated with certain species of cyanobacteria (Horppila et al., 1998). Meanwhile, the top-down effect of zooplankton on phytoplankton is related to the tropic state of a lake (McQueen et al., 1989). It is unclear whether models developed for temperate systems, such as the trophic cascade hypothesis, are appropriate for the tropics (Lazzaro et al., 2003).

Silver carp (*Hypophthalmichthys molotrix*) and bighead carp (*Aristichthys nobilis*) are two native planktivorous fishes in China. There were many controversial reports on the effects of silver and bighead carp on phytoplankton communities. Some authors have thought that stocking of these carps may increase nannoplankton and reduce herbivorous zooplankton, or even increase total chlorophyll *a* and algal biomass (Lieberman, 1996; Domaizon and Devaux, 1999). But much research has indicated that stocking of silver and bighead carp for biomanipulation is appropriate in tropical or subtropical lakes that are highly productive and naturally lack large-sized cladoceran zooplankton (Starling et al., 1998; Radke and Kahl, 2002). Moreover, much N and P can be removed form the lake through harvesting the fish products (Li and Yang, 1995). In southern China, silver and bighead carp have been stocked in many lakes for the sake of controlling algal blooms (Xie, 2003).

In Meiliang Bay of Lake Taihu, silver and bighead carp were cultured in pens for the control of *Microcystis* blooms in drinking water resource. The main objective of the present study was to evaluate the influence of silver and bighead carp on the plankton communities and water quality during a period of phytoplankton seasonal succession from late spring to early summer with emphasis on the applicability of stocking filter-feeding fishes in large fish pens to control *Microcystis* blooms.

2. Materials and methods

Lake Taihu, the third largest freshwater lake in China, is located in the south of the Yangtze River delta. The total area of the lake is 2338 km^2, with an average depth of 2 m, and a total volume of 47.6×10^8 m^3. It is very important of the urban water supply and irrigation. Because of a large population increase and rapid industrial and agricultural pollution in the lake's drainage basin, Lake Taihu has undergone rapid eutrophication (Pu et al., 1998; Qin et al., 2004).

A large fish pen (total surface area 1.08 km^2 and mesh size 2 cm × 2 cm) was built in Meiliang Bay of Lake Taihu. Silver and bighead carp were stocked in the pen in order to reduce the dense *Microcystis* blooms in the bay in the warm months. The fish pen experiment was a part of the Lake Taihu restoration program. Field sampling was conducted between 9 May and 7 July in 2005 when the fish biomass was estimated to be 35–70 g m^{-3} in the pen. Four sampling stations were set up: Stations 1 and 2 were in the center of the fish pen, and Stations 3 and 4 were located in just outside the fish pen (Fig. 1).

Sampling was carried out approximately once a week. Integrated water column samples were collected with the Patalas-Schindler trap. Surface water temperature was measured with a thermometer. pH and conductivity were measured by a pHB-4pH meter (Leici Instrument Co., Shanghai, China) and a DDB-303A meter (Leici Instrument Co., Shanghai, China), respectively. Water transparency was measured with a 20-cm diameter black and white Secchi disk. Orthophosphate (PO_4–P) was analyzed by the ascorbic acid method. Total phosphorus (TP) and total dissolved phosphorus (TDP) were measured by the same method after persulphate digestion in disposable polycarbonate bottles in an autoclave at 120 °C for 45 min. Total nitrogen (TN) and total dissolved nitrogen (TDN) were determined by the kjeldahl method. Nitrate (NO_3–N) was analyzed using the automated

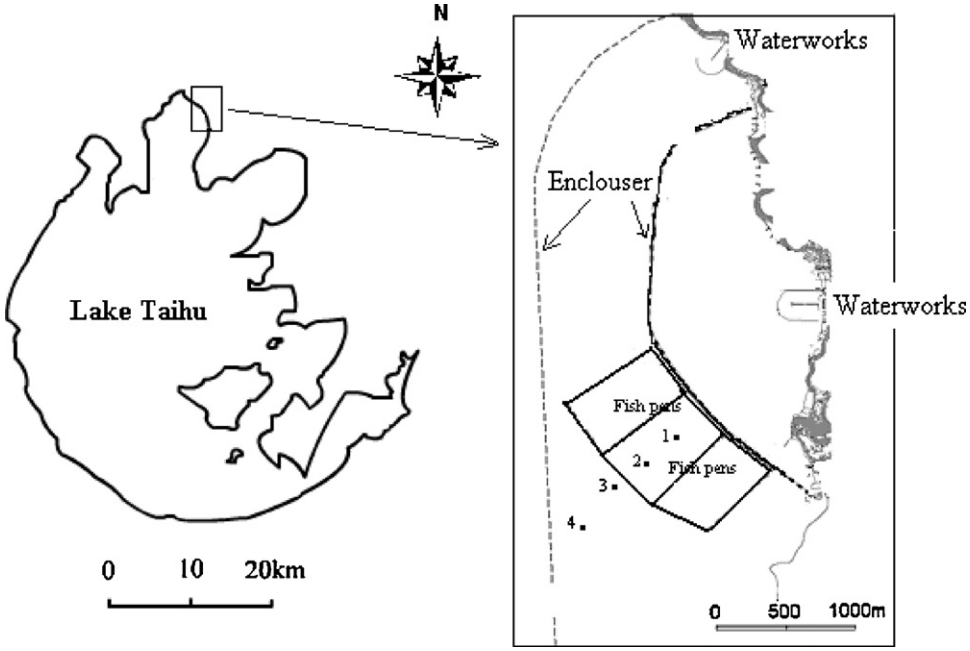

Fig. 1 – Map of Lake Taihu and the location of sampling stations in Meiliang Bay.

korolev/cadmium reduction method. Ammonium (NH_4–N) was determined by the Nessler method and nitrite (NO_2–N) by the a-naphthylamine method (APHA, 1992).

For chlorophyll *a* measurement, additional 350-mL subsamples of water were filtered through a Whatman GF/C glass fiber filter (0.7 μm). The filtered water was retained for analysis of the dissolved nutrients. The filters were then ground using 90% acetone in the dark (4 °C). Additional replicate integrated water samples were filtered through a 38-μm mesh screen to collect <38 μm size fractions on Whatman GF/C filters. The chlorophyll *a* concentrations were determined spectrophotometrically after 24 h extraction in acetone.

Zooplankton were sampled with a 69-μm net and fixed in 5% formalin. Densities were determined by counting all individuals in the sample using a microscope. When densities were too high, subsamples were taken and at least 100 individuals in each subsample were counted. If possible, up to

Table 1 – Physical and chemical characteristics (mean ± S.D.) in the fish pen and the lake during the study period

	In fish pen	In lake
Transparency (cm)	24.78 ± 3.26	25.39 ± 3.79
pH	8.63 ± 0.31	8.64 ± 0.34
Conductivity (mS/cm)	0.63 ± 0.08	0.62 ± 0.08
NH_4–N (mg/L)	0.95 ± 0.9	0.73 ± 0.76
NO_2–N (mg/L)	0.22 ± 0.08	0.2 ± 0.08
NO_3–N (mg/L)	1.15 ± 0.32	1.18 ± 0.31
TN (mg/L)	2.19 ± 0.73	2.19 ± 0.53
TDN (mg/L)	1.77 ± 0.77	1.71 ± 0.61
PO_4–P (mg/L)	0.011 ± 0.005	0.013 ± 0.006
TP (mg/L)	0.186 ± 0.039	0.197 ± 0.050
TDP (mg/L)	0.044 ± 0.014	0.053 ± 0.025
TN:TP	12.39 ± 4.82	11.83 ± 3.97

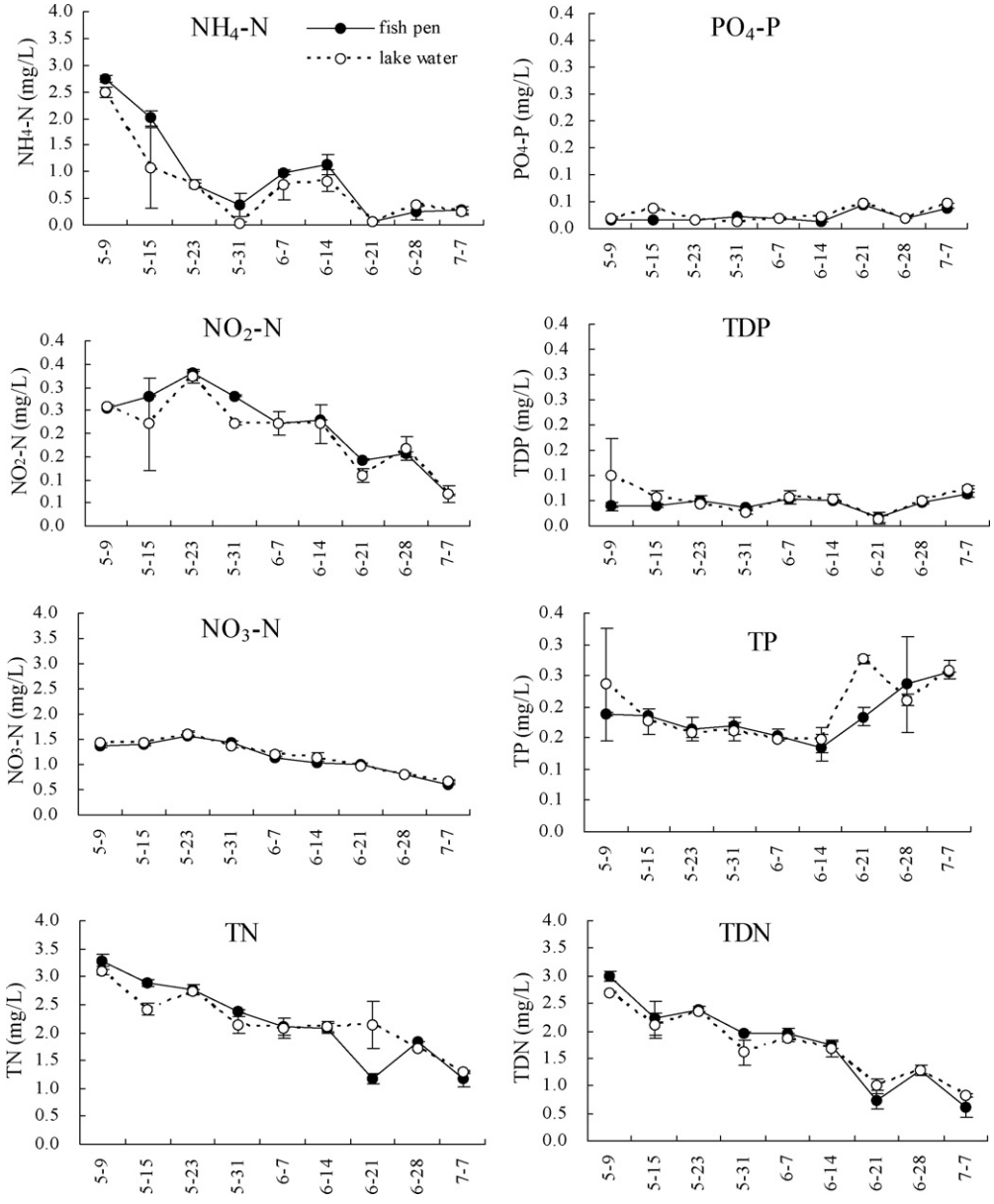

Fig. 2 – Temporal changes of nutrient concentrations in the fish pen and in the lake water.

30 individuals were measured for body length. Length–weight relationships were used to estimate biomass according to Huang et al. (1984). Phytoplankton samples were concentrated to 50 mL by sedimentation (APHA, 1992), and preserved with Lugol's iodine solution immediately after sampling. Phytoplankton cells were counted under a microscope and sized to derive volumes from appropriate geometric shapes. Biomass (wet weight) was calculated assuming a wet weight density of 1 g cm^{-3}.

Analysis of variance was performed to test the effects of fish and time on crustacean zooplankton community. Because of low replication and statistical power, we chose a probability level $P < 0.1$ to reduce the chance of making the type II error of failing to reject a false null hypothesis. Statistical analysis was performed with SPSS 10.0.

3. Results

3.1. Chemical and physical factors

Surface temperature ranged from 20 °C at the start of sampling to 29 °C at the end. The mean values of the environmental variables were generally similar inside the fish pen and outside (Table 1). Generally, the nutrient concentration declined simultaneously over time during the study period, except for the PO_4–P, TDP and TP (Fig. 2). Only the concentrations of NH_4–N and NO_2–N were significantly higher in the fish pen ($P < 0.1$). The ratio of TN:TP in weight has a significant decreasing trend during the period of our study (Fig. 3).

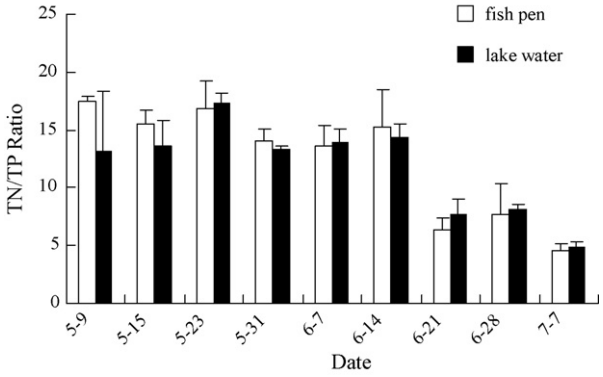

Fig. 3 – Temporal changes of the TN:TP ratios in the fish pen and the lake water.

3.2. Zooplankton

Only crustacean zooplankton were considered in this study. During the study period, the crustacean zooplankton community shifted from large-size to small-size species in the fish pen and lake water (Fig. 4). In the first sampling, *Daphnia* and *Moina* predominated the crustacean zooplankton, comprising 47% and 18% of the total crustacean zooplankton biomass, respectively. However, biomass of these two cladocerans decreased gradually, and *Daphnia* almost was absent after 7 June. Afterwards, *Bosmina* and *Ceriodaphnia* became dominant, comprising

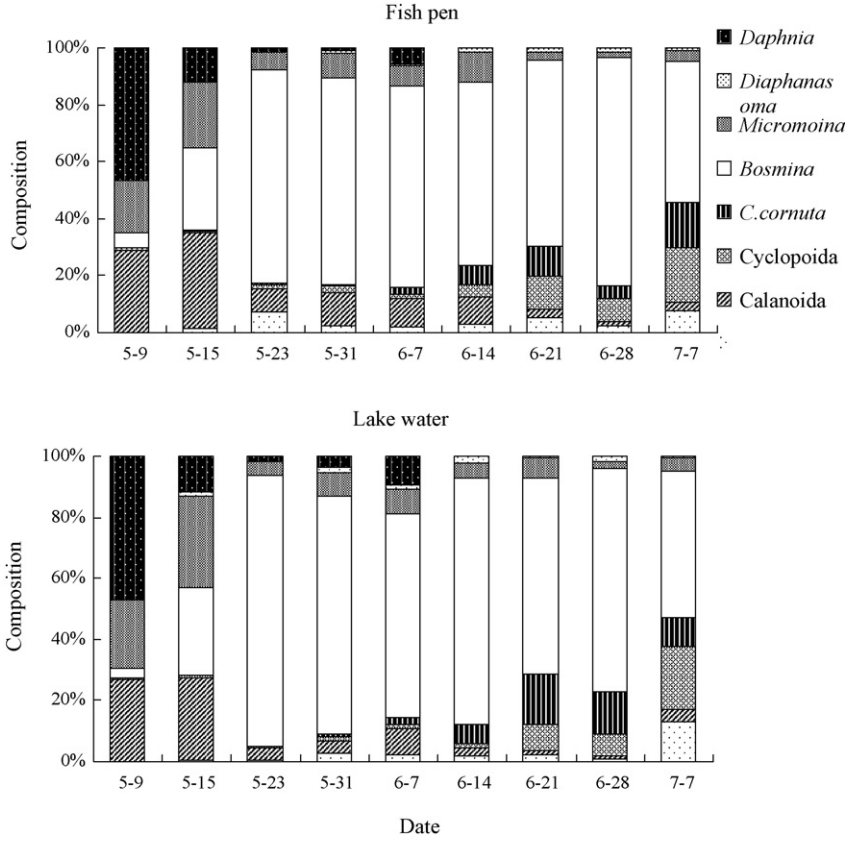

Fig. 4 – Community structure of crustacean zooplankton in the fish pen and the lake water.

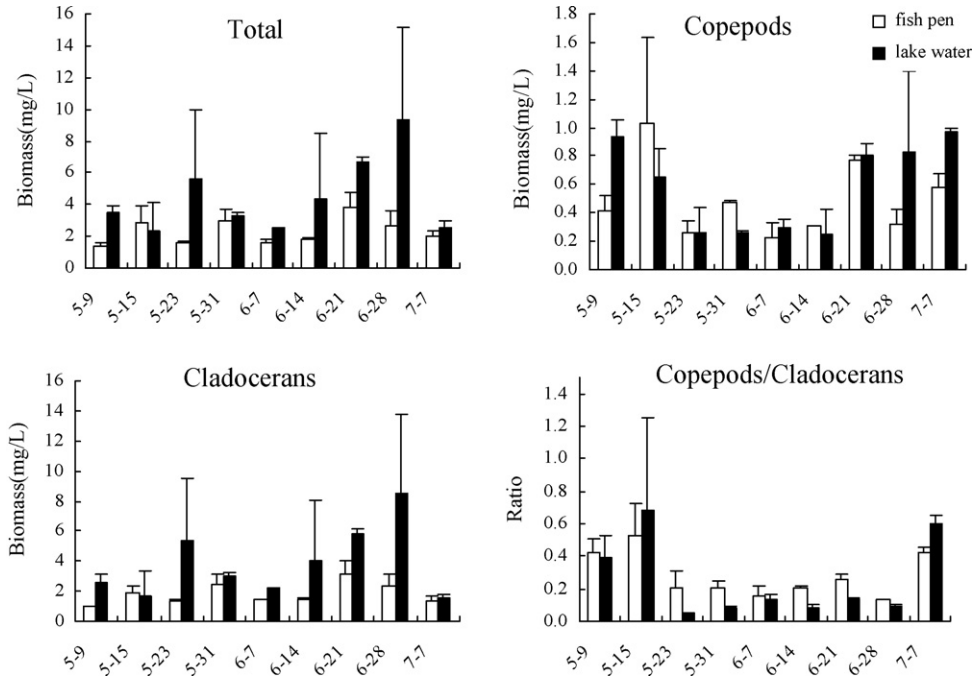

Fig. 5 – Temporal changes of crustacean zooplankton biomass in the fish pen and the lake water.

49% and 16% of the total zooplankton biomass, respectively.

The average biomass of total crustacean zooplankton was strongly suppressed by the pen fish with 2.3 mg L^{-1} in the fish pen and 4.45 mg L^{-1} in the lake water. In general, zooplankton biomass tended to be lower in the fish pen than in the lake water (Fig. 5). The influence of fish predation on cladocerans was more significant than on copepods (Table 2). The biomass ratio of copepods to cladocerans was roughly higher in the fish pen than in the lake water, but the difference was not statistically significant.

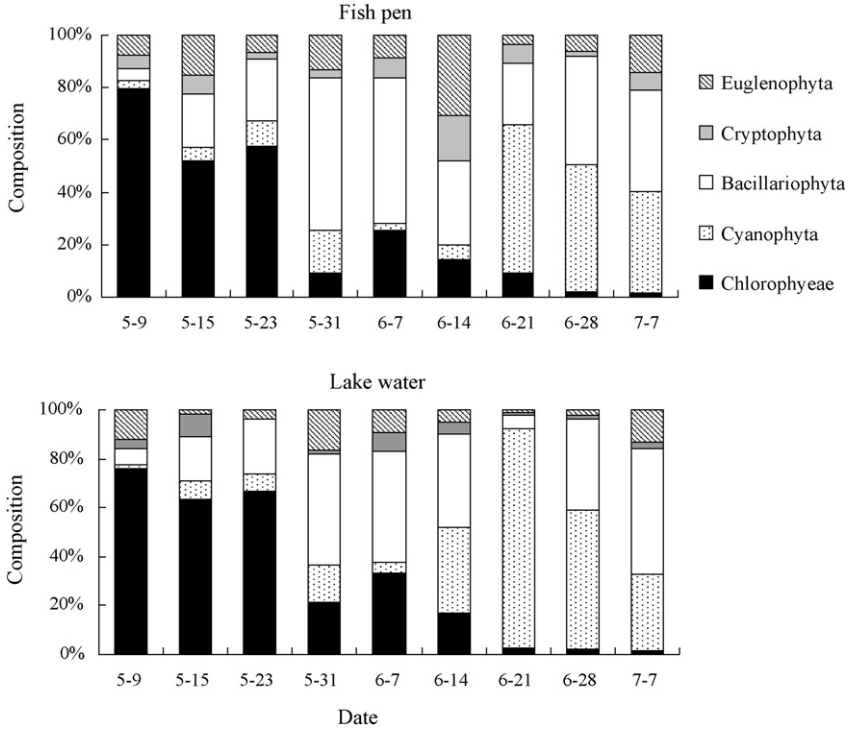

Fig. 6 – Community structure of phytoplankton in the fish pen and the lake water.

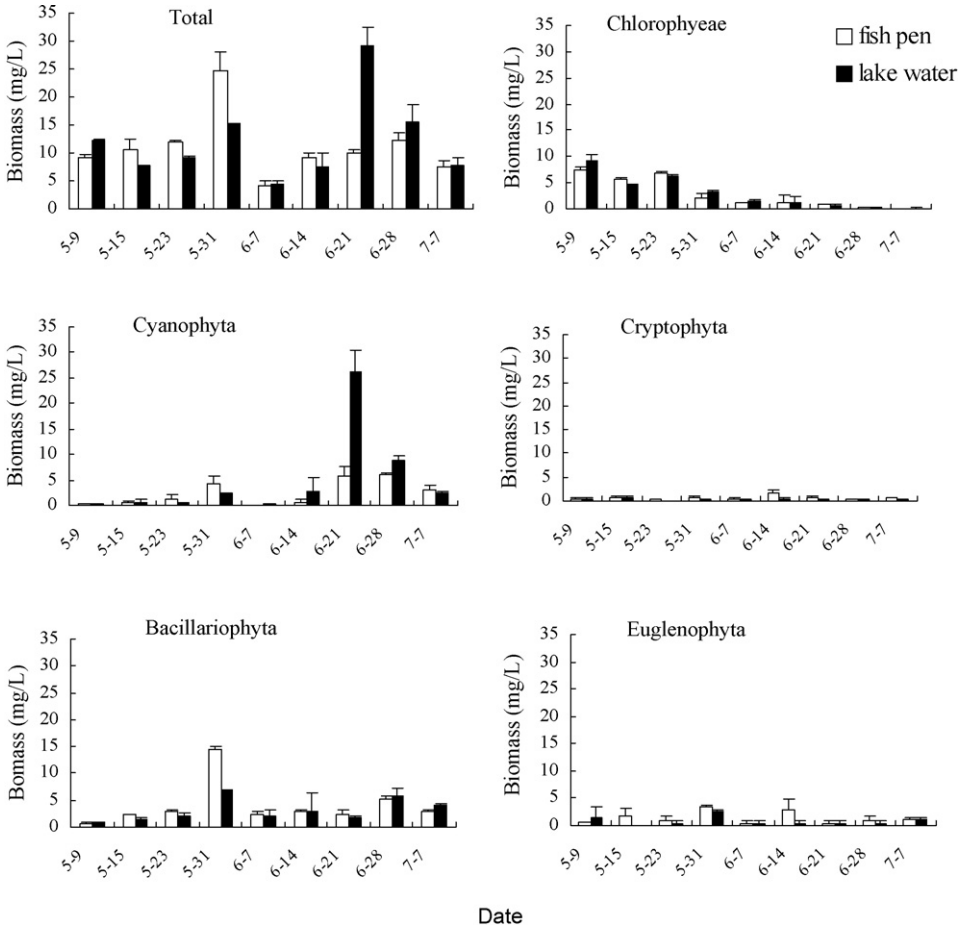

Fig. 7 – Temporal changes of phytoplankton biomass in the fish pen and the lake water.

3.3. *Phytoplankton*

Phytoplankton also showed a temporal change in both the fish pen and the lake water. Initially, *Ulotrix* sp. constituted more than 50% of the total phytoplankton biomass. Its dominance was replaced by *Microcystis* which comprised more than half of the total phytoplankton biomass on 21 June (Fig. 6). Bacillariophyta also made a substantial contribution to total phytoplankton biomass during the study period. When *Microcystis* completely dominated in the phytoplankton community, phytoplankton biomass was obviously lower in the fish pen ($9.75 \pm 1.99\,mg\,L^{-1}$) than in the lake water ($14.97 \pm 10.11\,mg\,L^{-1}$) after 14 June (Fig. 7). Species composition of phytoplankton was not significantly different between the fish pen and the lake water ($P > 0.1$).

Total chlorophyll *a* concentration was higher in the fish pen than in the lake water, except on 21 June (Fig. 8), indicating that the large-size fractions of chlorophyll *a* were significantly reduced in the fish pen after the outbreak of *Microcystis* blooms. After 7 June, the mean chlorophyll *a* in the >38 μm size fractions was remarkably lower in the fish pen ($25.07\,\mu g\,L^{-1}$) than in the lake water ($46.04\,\mu g\,L^{-1}$) (Fig. 9).

Table 2 – One-way ANOVA results for crustacean zooplankton for all sample days in the fish pen and in the lake

Source of variation	R-value	P-value
Total crustacean zooplankton	6.897	0.018*
Cladocerans	6.531	0.021*
Copepods	0.612	0.445
Copepods:cladocerans	0.431	0.521

* Significant difference.

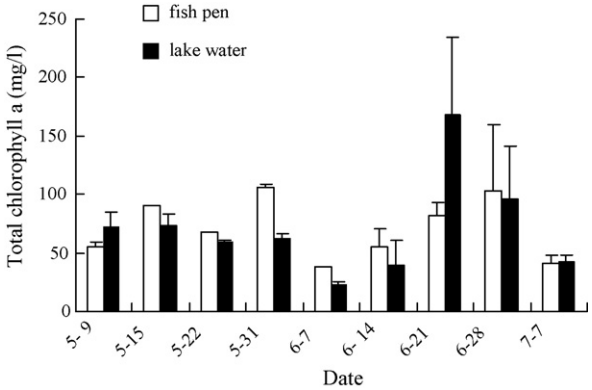

Fig. 8 – Temporal changes of total chlorophyll *a* concentration in the fish pen and the lake water.

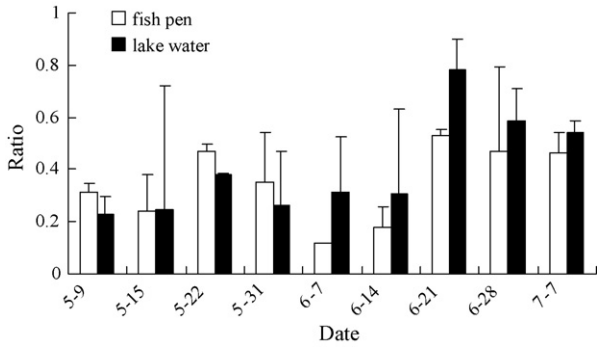

Fig. 9 – Temporal changes in the percentage of chlorophyll *a* in the large-sized (>38 μm) fractions.

4. Discussion

In the present study, the effects of fishes on plankton communities were also influenced by the water exchange between the fish pen and the lake. Because the fish pen was large, we consider that water exchange between the fish pen and the lake was relatively limited in most period of time. But more accurate estimate of water exchange rate is needed in our future study.

Silver and bighead carp feed on both phytoplankton and zooplankton (Smith, 1989; Opuszynski and Shireman, 1995). Predation by the two carps tends to shift the zooplankton communities toward smaller and more evasive species (Lu et al., 2002; Yang et al., 2005). Similarly, in the present study, the biomass of crustacean zooplankton (especially cladocerans) was strongly suppressed in the fish pen, but the copepods were little affected, probably because copepods are more evasive from the capture mechanisms of filter-feeding planktivorous than cladocerons (Dong and Li, 1994; Xie and Yang, 2000).

At the beginning of our study, *Daphnia* dominated in the zooplankton community. It is well known that a clear water phase occurs with a high density of *Daphnia* (Kasprzak et al., 2002; Talling, 2003). However, this was not the case in our study. Our results suggested that top-down effect of large-size cladocerans on phytoplankton dominated by *Microcystis* may be weak in subtropical lakes. In the present study, *Daphnia* abundance declined rapidly over time. One possible explanation was that cyanobacteria may increase the mortality of large *Daphnia* because of feeding interference and cyanotoxin (Carmichael, 1989; Watanabe et al., 1992). However, in our study, it might not be the main reason because the abundance of *Microcystis* was not high before the disappearance of *Daphnia* on 7 June. Sommer et al. (1986) indicated that the food limitation and predation by zooplanktivorous fish were the main reason that causing the decline of the density of herbivorous populations (such as *Daphnia*) during late spring and early summer. In the present study, our results showed that the biomass of *Daphnia* had a significantly positive correlation with the biomass of Chlorophyta (mainly *Ulothrix* sp.), suggesting food limitation might be the most plausible explanation for the rapid decline of *Daphnia* biomass in early summer in Lake Taihu.

There were marked temporal variations of both nutrient concentration and plankton communities during our study period. Smith (1983) found a negative relationship between the proportion of cyanobacteria and TN:TP ratio in 17 lakes worldwide. More studies have also found that cyanobacteria tended to outcompete other phytoplankton when N:P ratio is low (Jacoby et al., 2000; Stahl-delbanco et al., 2003). Xie et al. (2003) found that the low N/P ratio is not a cause but a result of cyanobacterial dominance. Our study found a similar coincidence between cyanobacterial blooms and low N/P ratio. In addition, we found that the TN:TP ratio had a significant positive correlation with the biomass of Chlorophyta (Table 3).

In previous studies, filter-feeding fish were found to reduce net phytoplankton because of size selection (Lieberman, 1996; Radke and Kahl, 2002). *Ulothrix* sp. is a large-size phytoplankton with a mean length of ca. 2 mm. In the present study, the size selection predation by silver and bighead carp seemed to have no effect on *Ulothrix* sp. in our study. The stocking density of silver plus bighead carp (less than 40 g m^{-3}) was likely too low to achieve an adequate control of phytoplankton before June. It may be attributed to that the nutrient excretion by fish had more effect on *Ulthrix* sp. than the size selection predation by the fish in that stocking density. However, when *Microcystis* became dominant after 7 June, silver and bighead carp effectively suppressed the *Microcystis* blooms, as indicated by the significant decline of chlorophyll *a* in the >38 μm fractions in fish pen. During that period, the stocking density maybe become high enough because of the growth of fish, and can suppress the *Microcystis* biomass. Xie (2003) empha-

Table 3 – *R*- and *P*-value of correlation analysis for the phytoplankton and the TN:TP ratio

	Chlorophyeae	Cyanophyta	Bacillariophyta	Cryptophyta	Euglenophyta
In fish pen					
TN/TP					
R-value	0.743	−0.74	−0.029	0.181	0.286
P-value	0.022*	0.023*	0.941	0.641	0.456
In lake					
TN/TP					
R-value	0.743	−0.612	−0.353	0.276	0.108
P-value	0.022*	0.08*	0.351	0.472	0.782

* Significant correlation.

sized that the biomass of silver and bighead carp should be held at or above 50 g m^{-3} for a successful biomanipulation in Lake Donghu. In an enclosure experiment, Zhang et al. (2006) found that a fish stocking density of 55 g m^{-3} was the most efficient in controlling *Microcystis* blooms and increasing water clarity. The decline of algal biomass may be a function of fish biomass. We should ensure that the stocking density of silver and bighead carp is high enough for an effective control of phytoplankton biomass.

In conclusion, based on the results of our experiment and previous other studies, silver and bighead carp are efficient biomanipulation tools to control cyanobacterial (*Microcystis*) blooms when Cyanobacterial blooms dominate the plankton biomass in tropical or subtropical eutrophic waters. Moreover, we should maintain a sufficient stocking density for an effective control of phytoplankton biomass.

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