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In situ study on effect of food competition on diet shifts and growth of silver and bighead carps in large biomanipulation fish pens in Meiliang Bay, Lake Taihu

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Summary

Silver and bighead carps were cultured in large fish pens to reduce the risks of cyanobacterial bloom outbreaks in Meiliang Bay, Lake Tauhu in 2004 and 2005. Diet compositions and growth rates of the carps were studied from April to November each year. Both carp species fed mainly on zooplankton (> 50% in diet) in 2004 when competition was low, but selected more phytoplankton in 2005 when competition was high. Silver carp had a broader diet breadth than did bighead carp. Higher densities and fewer food resources increased diet breadths but decreased the diet overlap in both types of carps. It can be predicted that silver and bighead carps would be released from diet competition and shift to feed mainly on zooplankton at low densities, decreasing the efficiency of controlling cyanobacterial blooms. Conclusively, when silver and bighead carps are used to control cyanobacterial blooms, a sufficiently high stocking density is very important for a successful practice.

Introduction

Silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) are two large-bodied planktivorous cyprinids that are intensively cultured in Asia. They comprise much of the carp aquaculture production in China (Liang et al., 1981). Food habits of silver and bighead carps and their effects on the plankton communities have been widely reported (Spataru, 1977; Cremer and Smitherman, 1980; Starling and Rocha, 1990). In general, bighead carp is considered an opportunist, feeding more on zooplankton, whereas silver carp feeds mainly on phytoplankton (Cremer and Smitherman, 1980; Chen, 1990). Because of their filter-feeding habits, silver and bighead carp can be used as a means to control algal blooms (Xie and Liu, 2001).

In China, stocking silver and bighead carp for the control of cyanobacterial blooms is being used or tested in many warm-water eutrophic lakes such as Taihu, Chaohu, and Dianchi. However, silver and bighead carps have no specific, stable ecological niche (Spataru and Gophen, 1985). It is assumed that competition can induce a rapid diet change that affects the interactions between community components rapidly when shifts in organic and nutrient loads occur. Stocking density, however, is one management tool that can directly influence diet and habitat choice of the fish species (Wilson and Turelli, 1986; Rowland et al., 2006). Feeding habits of filter-feeding fish also strongly depend on the food availability in their environment (Berthou and Amich, 2000). Diet competition in the water environment of silver and bighead carps is important to determine an optimal stocking density in order to effectively control cyanobacterial blooms under various conditions. However, little is known about diet shifts in these species, especially under different food abundances in the lake systems and under different stocking densities.

Therefore, an *in situ* experiment was conducted using large fish pens in a bay of the hypereuthrophic subtropical Lake Taihu in China, to compare diet composition, diet breadth and diet overlap of silver and bighead carps at two stocking densities. The main purpose of the study was to evaluate the effects of competition on the diet shifts and growth of both carp species, so as to provide a basis for successful management by using these carps for controlling cyanobacterial blooms under changing environmental conditions.

Materials and methods

Meiliang Bay is located in the northern part of Lake Taihu, which has a surface area of 100 km^2 and depths ranging between 1.8–2.3 m. Because of eutrophication, heavy *Microcystis* blooms have regularly occurred in this region during the past few decades. From 2004 onward, silver and bighead carps were pen-cultured in three large fish pens in an attempt to control cyanobacterial blooms in the Meiliang Bay, which was part of a national restoration program for Lake Taihu (Fig. 1). The area of each pen was 0.36 km^2 and average water depth was about 2 m. Mesh size of the net was 2× 2 cm. In 2004, stocking densities for both carps were very low, which resulted in a total yield of only 0.37 g m^{-3} per month. In 2005, we built a fence along the western and eastern sides of the pens to prevent the drift of *Microcystis* blooms from moving directly into the pens. Moreover, we increased the stocking density of the fingerlings and improved the pen management. Total yield of both carps reached about 5.4 g m^{-3} per month. Stocking densities employed in 2004 and 2005 are shown in Table 1. Silver carp and bighead carp comprised, respectively, about 70% and 30% of the total yield in the fish pens.

Six sampling sites were set up in the fish pens to allow detection of the changes in food resources over time (see Fig. 1 for locations). Sampling was conducted monthly from April to November in 2004 and 2005. Integrated water samples (at 0, 0.5, 1.0, and 1.5 m depth) were taken each month at each sampling site with a 5-L Patalas-Schindler trap. Crustacean zooplankton and phytoplankton were also sampled at the same time. Surface water temperature was measured with a thermometer. Conductivity and pH were measured by a DDB-303A meter and a PHB-4PH meter, respectively. Water transparency was measured using a 20-cm diameter black

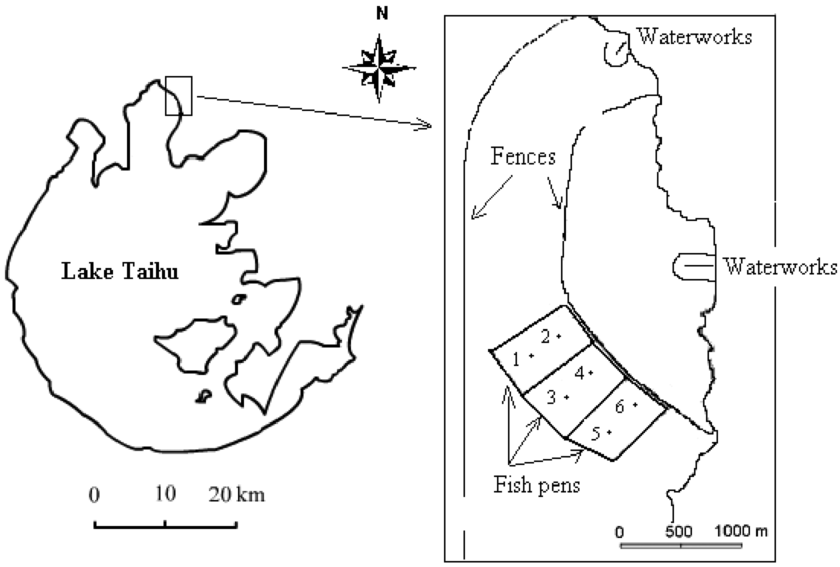

Fig. 1. Sketch of Lake Taihu and location of fish pens (3600 m^2 each) in Meiliang Bay where silver carp and bighead carp were stocked at densities depicted in Table 1. Numbers 1–6 = sampling stations for environmental variables

Table 1
Biomanipulation trials in pens in Meiliang Bay, Lake Taihu

		Individual standard length (cm)		Individual body weight (g)		Stocking density (g m^{-3})	
		Silver carp	Bighead	Silver carp	Bighead	Silver carp	Bighead
2004	Initial	20.1 ± 2.7	21.5 ± 4.2	171 ± 71.1	301 ± 197.9	0.27	0.2
	Final	46.7 ± 1.6	51.6 ± 2.4	1612 ± 155.4	2913 ± 885.5	2.54	1.91
2005	Initial	23.1 ± 1.6	20.9 ± 1.5	265.6 ± 45.0	259.5 ± 62.3	7.91	3.44
	Final	37.4 ± 1.8	38.3 ± 2.3	1217.5 ± 164.1	1438.0 ± 327.7	36.27	19.08

Body weight and body length (mean ± SD, n = 30) as well as stocking density of silver and bighead carp in two consecutive study years.

and white Secchi disk. All water samples were analyzed in the laboratory within 3 h after collection. The densities of crustacean zooplankton and phytoplankton were determined under the microscope. Orthophosphate (PO_4-P) was analyzed by the ascorbic acid method. Total phosphorus (TP) was determined by the same method after persulphate digestion in disposable polycarbonate bottles in an autoclave at 120°C for 45 min. Total nitrogen (TN) was determined by the Kjeldahl method. Nitrate (NO_3-N) was analyzed using the automated Korolev ⁄ cadmium reduction method. Ammonium-nitrogen (NH_4-N) was determined by the Nessler method and nitrite-nitrogen (NO_2-N) by the α-naphthylamine method (APHA, 1992).

On each sampling date, about 30 silver carp and 30 bighead carp were randomly captured from the pens by multi-mesh gillnets to examine individual growth (standard length and body weight). For diet analyses, five individuals of each carp species were dissected and the anterior part of the gut (pharynx – first bend) were removed and preserved in 10% formaldehyde solution. In the laboratory, the gut contents were separated in cool distilled water by light agitation with a magnetic stirrer, and then examined under microscope. Food items were identified to the lowest possible taxon. Diet composition was analyzed from gut samples based on the biomass of food items. Crustacean zooplankton species were examined under ×40 magnification. Biomass (wet weight) of crustacean zooplankton was estimated using the length–weight regressions according to Zhang and Huang (1991). Phytoplankton cells were counted and measured under ×400 magnification and rotifers were examined under ×100 magnification. To count *Microcystis* cells, the samples were agitated by gentle ultrasonication to split the colonies into single cells. Phytoplankton biovolume was estimated according to the appropriate geometric shapes, and the volume of rotifers was estimated according to the formulae given by Ruttner-Kolisko (1977). Biomass (wet weight) was calculated assuming a wet weight density of 1 g cm^{-3} (Zhang and Huang, 1991; Shao et al., 2001).

Food items consumed by silver and bighead carp were grouped by category for diet comparisons: cladocerans, copepods, rotifers, Cyanophyta, Cholrophyta, Bacillariopyta and others. The percent weight (% w) of each category was used to calculate the diet breadth and diet overlap. The diet niche breadth was calculated using the Shannon–Weaver index, defined as follows: $H = -\Sigma\ (P_{ij}\ \log_2 P_{ij})$, where P_{ij} is the percent weight of prey *j* in the diet of predator *i* (Brodeur and Pearcy, 1990). The diet niche overlap was estimated by Schoener's (1970) similarity index: $S = 1-0.5\ [\Sigma\ |\ P_{xi}-P_{yi}\ |\ ]$, where S is the degree of overlap, P_{xi} and P_{yi} are the proportions of food category *i* in the diet of fish species *x* and *y*, respectively. Index values range from 0 to 1, and approach 0 for species that share no prey types and approach 1 for species pairs that have completely identical prey utilization. In the absence of quantitative data concerning the resource availability, this index is the most useful diet overlap index (Wallace, 1981). Condition factors were evaluated according to the formula: condition factor (CF) = $100 * W / L^3$, where W is the fish total weight (g) and L is the standard length (cm).

Results

Environmental variables

Average surface temperature of the lake water was 23.2°C during the study period, with the lowest 12.7°C in November 2005 and the highest 33.6°C in August 2004. Mean values of the environmental variables were lower in 2005 than in 2004 (Fig. 2). According to the OECD (1982), Meiliang Bay of Lake Taihu is in a hypereutrophic status. In the water columns of the pens, biomass of crustacean zooplankton was higher in 2004 than in 2005, except in July, August and September. However, phytoplankton biomass showed a reverse tendency (Fig. 3).

Food composition in the gut contents

Cladocerans were the main zooplankton diet of both carps (Fig. 4), however their proportions in the gut contents decreased significantly in 2005. Chlorophyta were the dominant food resource for both carps only in the spring. In the diet of silver carp, Cyanophyta (mainly *Microcystis*) comprised the highest percentages only in July and August 2004, and after June in 2005. In the diets of bighead carp, cladocerans were predominant most of the time, especially in 2004, and Cyanophyta were important only after July in 2005. Bighead carp always fed on more zooplankton than did silver carp. Both carps significantly predated more zooplankton in 2004 (59% and 83% for silver and bighead carps, respectively) than in 2005 (21% and 60% for silver and bighead carps, respectively) (*T*-test, $P < 0.1$) (Fig. 5).

Diet breadth and diet niche overlap

In general, silver carp had a wider niche breadth than bighead carp, and both carps had wider niche breadths in 2005 than in 2004 (Table 2). Diet breadth indexes of silver and bighead carps ranged from 0.84 (May 2005) to 2.1 (June 2005) and from 1 (May 2004) to 2.04 (September 2004), respectively. Diet breadth of bighead carp was significantly correlated with abundance of crustacean zooplankton ($P < 0.01$), but such a correlation was not significant for silver carp (Fig. 6). Diet overlap estimated by Schoener's similarity index was relatively high between silver and bighead carps. In most months, the Schoener's similarity index exceeded 0.6 (Fig. 7). The index was highest in April 2004 (0.96) and lowest in May 2005 (0.25).

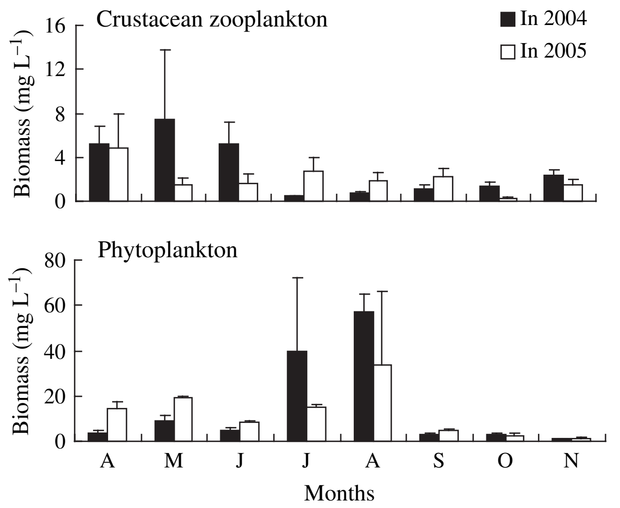

Fig. 3. Monthly changes of total biomass (wet weight basis) of crustacean zooplankton and phytoplankton in water columns of fish pens, April and November in 2004 and 2005. Data show monthly mean values of six sample sites in the three fish pens. Error bars represent 1 SD

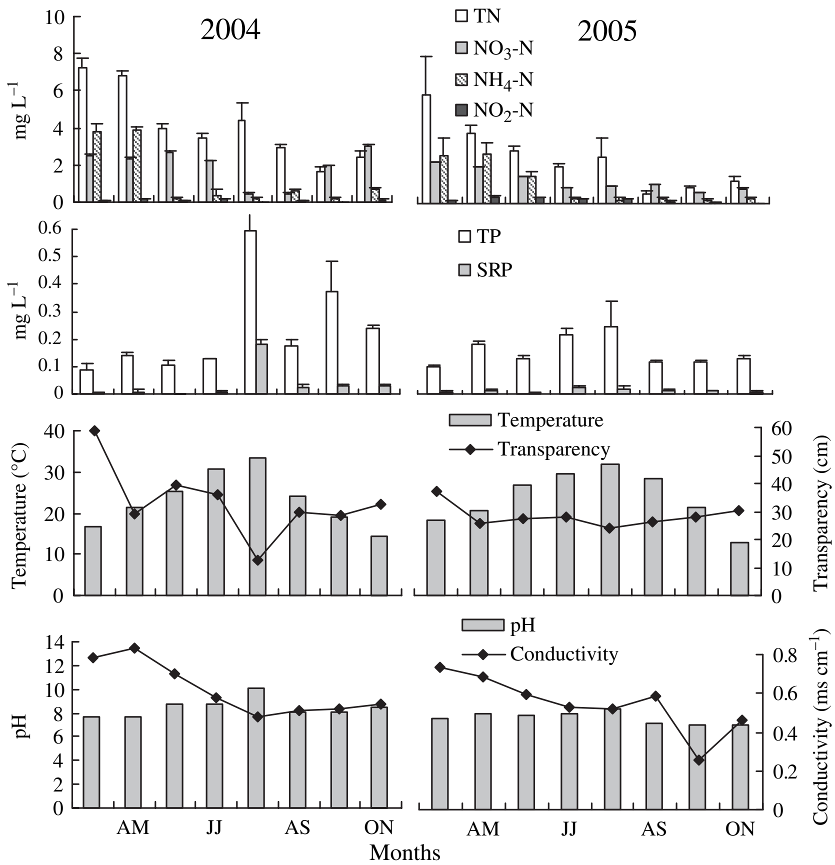

Fig. 2. Variation in environmental variables in fish pen waters, April–November in 2004 and 2005. Data are mean values of six sample sites from each month. Error bars represent 1 SD. Water quality parameter acronyms explained in Materials and methods

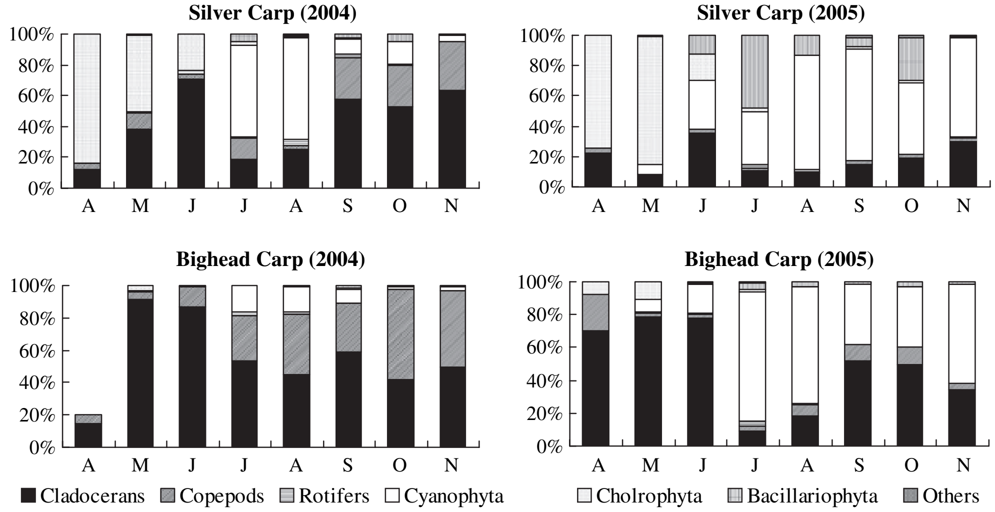

Fig. 4. Feeding behavior of carps stocked in eutrophic lake pens. Monthly relative diet composition of gut content of silver and bighead carps based on relative biomass estimates, April–November in 2004 and 2005. Sample size was five fish from each type each month

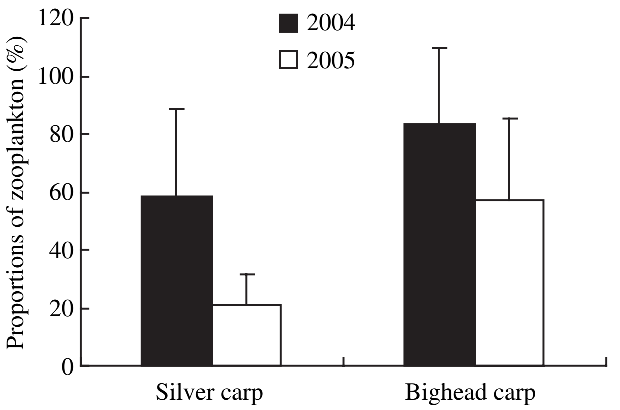

Fig. 5. Overall zooplankton proportions in diets of silver and bighead carps in 2004 and 2005. Columns represent means of data from all sampling sizes and all sampling months each year (40 fish per year for each species). Error bars represent 1 SD

Table 2
Biomanipulation trials in pens in Meiliang Bay, Lake Taihu

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Average
Silver carp									
2004	0.81	1.52	1.18	1.69	1.41	1.60	1.67	1.19	1.38
2005	0.99	0.83	2.04	1.74	1.18	1.35	1.84	1.20	1.40
Bighead carp									
2004	0.95	0.50	0.62	1.57	1.62	1.42	1.16	1.21	1.13
2005	1.13	1.10	0.97	1.21	1.27	1.45	1.57	1.27	1.25

Diet breadth of silver and bighead carps stocked at different densities and calculated by the Shannon–Weaver index during the productive periods from April to November 2004 and 2005.

Diet overlap obviously declined in 2005, with an average value of 0.7 in 2004 and 0.58 in 2005.

Growth rate and condition factor

Growth rates of silver and bighead carps were significantly lower in 2005 than in 2004 (Fig. 8). The average growth rates of silver and bighead carps were 5.2 and 10 g day^{-1} in 2004 and 3.2 and 4.1 g day^{-1} in 2005, respectively. Condition factors of both carps were slightly lower in 2005 than in 2004 (Table 3).

Discussion

Because of the higher density and the decreased water exchange in the pens caused by the perimeter fences, food competition between fishes significantly increased in 2005; the declines in growth and condition factor of silver and bighead carps well reflected poorer availability of food resource in that year. Our results showed that silver carp fed mainly on phytoplankton and that bighead carp predated more on zooplankton, consistent with observations made in previous studies (Spataru, 1977; Cremer and Smitherman, 1980). Many previous studies suggested that size and density of the food resource can exert a great influence on the feeding habits of most filter-feeding fish (Coulter, 1977; Berthou and Amich, 2000; Haertel and Eckmann, 2002). In the present study, the proportion of zooplankton in the gut contents of both carps was significantly lower in 2005 than in 2004; such a diet shift might be caused by alterations in the food abundance and thus availability in the lake water. In 2004, the diet composition of both carps probably reflected more closely their true preferences because of favorable conditions, whereas in 2005 both carps showed a marked decrease in zooplankton consumption that was probably due to the scarcity of the zooplankton resource in the given environment, as predators tend to ignore less valuable food items when better food resource are abundant (Krebs, 1979).

In the present study, diet breadths of both silver and bighead carps increased in higher densities. Similarly, individual and population niche breadths of perch were high when the adult perch population density was high (Svanbäck and Persson, 2004), and when competition can induce a rapid evolution of a wider population niche breadth (Bolnick, 2001). The expansion of the population niche width is thought to be due to increased intraspecific competition (Robinson and Schluter, 2000). In our study, the increased diet breadth reflected an increased food competition for both carps in 2005; silver carp always had a wider niche breadth than did bighead carp, suggesting that silver carp may have a greater potential of

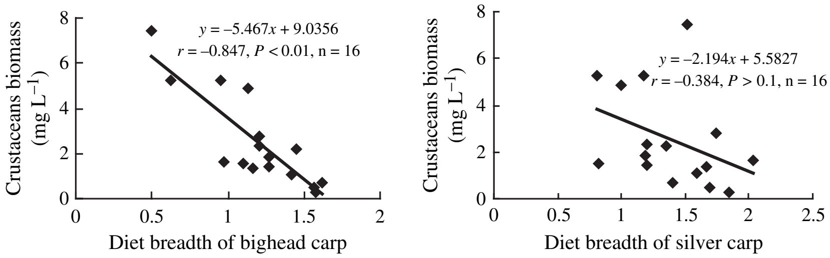

Fig. 6. Relationship between crustacean biomass in fish pens and the diet breadth of silver and bighead carps, calculated by Shannon–Weaver index. Crustacean biomass = mean value of six sample sites in the three pens each month. Diet breadth = mean value of five samples from each month. n = 16

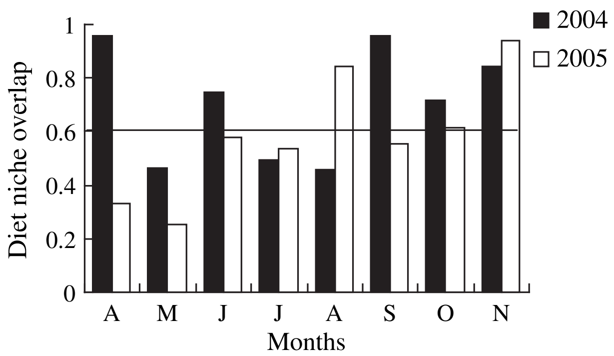

Fig. 7. Diet niche overlap between silver and bighead carps calculated with Schoener's similarity index, April–November in 2004 and 2005. Monthly value calculated by mean diet composition of five silver carp and five bighead carp

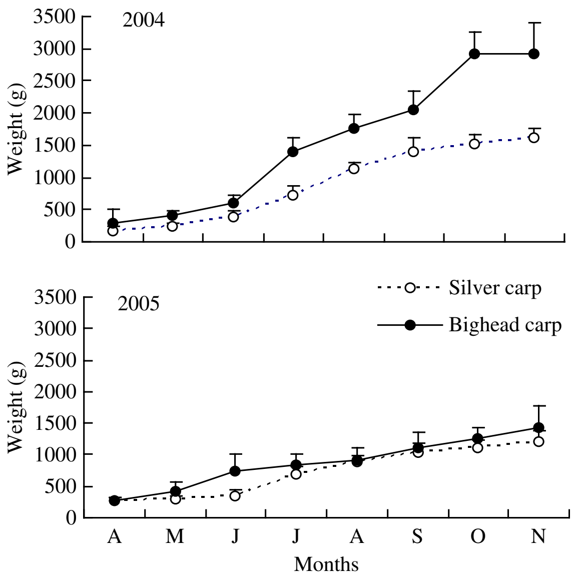

Fig. 8. Monthly mean changes in body weights of silver and bighead carps stocked in fish pens, April and November in 2004 and 2005. n = 30. Error bars represent 1 SD

achieving higher local densities and hence occupying a larger area in natural environments (Gaston and Spicer, 2001).

Generally, values of diet overlap exceeding 0.6 represent 'biologically significant' overlap in resource use (Wallace, 1981). In the present study, diet overlap between silver and bighead carps was very high at most times, suggesting strong interspecific competition between the two carps. A previous study reported that the gill-raker structure plays an important role in diet segregation between silver and bighead carps (Spataru et al., 1983). Our results revealed that competition was also an important factor for the diet segregation of silver

Table 3
Biomanipulation trials in pens in Meiliang Bay, Lake Taihu

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Average
Silver carp									
2004	1.99	2.33	2.47	2.27	2.51	2.26	2.09	2.27	2.27
2005	2.14	2.22	2.38	2.25	2.31	2.06	2.19	2.32	2.23
Bighead carp									
2004	2.68	2.72	2.65	2.48	2.35	2.34	2.50	2.56	2.54
2005	2.81	2.63	2.90	2.32	2.29	2.23	2.40	2.53	2.51

Condition factors of silver and bighead carps from April to November 2004 and 2005. Data show mean values of 30 samples from each month.

and bighead carps: under a lower competition in 2004, both silver and bighead carps preferentially selected the good quality zooplankton, leading to a higher diet overlap. On the other hand, there was a positive correlation between diet overlap and zooplankton / phytoplankton ratio of the lake water ($r = 0.533$, $P < 0.05$), suggesting that food quality can influence niche segregation as well as food abundance in the environment.

In China, because of their filter-feeding capacity silver and bighead carps have been intensively stocked to control algal blooms (Xie, 2003). However, our results indicate that the diets of silver and bighead carps can shift with both stocking density and food availability, which may obscure the anticipated effects of biomanipulation. In a lower stocking density, zooplankton proportion could exceed 50% in the gut contents of silver and bighead carps. In this case, the cultured fish might indirectly promote the development of phytoplankton biomass because of the depleted zooplankton populations which otherwise would also be effective grazers on phytoplankton. Silver and bighead carps have recently been widely stocked, usually at low densities, in eutrophic waters in lakes and reservoirs of China with the aim of controling cyanobacterial blooms. From our results, it can be concluded that silver and bighead carps may be released from heavy diet competition and shift to feed mainly on zooplankton when stocked at low densities, but this may decrease the efficiency of controlling cyanobacterial blooms. Xie and Liu (2001) indicated that the biomass of silver and bighead carps should be held at or above 50 g m^{-3} for a successful biomanipulation of *Microcystis* blooms in Lake Donghu, a hypereutrophic lake in China. Conclusively, if we use filter-feeding fish such as silver and bighead carps in combination for control of cyanobacterial blooms, a sufficiently high stocking density would be very important for a successful practice.

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