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Effects of Silver Carp Density on Zooplankton and Water Quality: Implications for Eutrophic Lakes in China

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ABSTRACT

We examined the responses of zooplankton community, water transparency, chlorophyll *a* and nutrients to manipulation of density of silver carp (*Hypophthyalmichthys molitrix*) in an one-way factorial experiment using enclosures placed in Donghu (East Lake, 30° 33' N, 114° 23' E), located in Wuhan, P. R. China. Enclosures (18.75 m^3) were treated with four silver carp densities, 0, 81, 225, 485 g/m^2. Total zooplankton abundance (excluding nauplii and rotifers except for *Asplanchna* sp.) and the mean size of dominant cladoceran species were significantly greater in enclosures with 0 and 81 fish densities than those in enclosures with 225 and 485 fish densities. Water transparency also improved significantly when silver carp densities were 0 or 81 g/m^2. We did not find significant effects of silver carp density on chlorophyll *a*, total phosphorus, or total nitrogen concentrations. We conclude that by reducing planktivorous fish to below the current density (190 g/m^2), the zooplankton community can be shifted from the dominance of small-bodied *Moina* sp. to dominance of large-bodied *Daphnia* sp. Further, the water clarity can be increased.

INTRODUCTION

A recent survey reported that the proportion of lakes that can be classified as eutrophic (total phosphorus ranging from 0.018 to 0.97 mg/L) in China has increased from 5% to 55% in the past decade (Jin 1994). Water transparency of less than 1 m and reduced fish production have been reported in many of these lakes. Moreover, the quality of drinking water derived from many lakes in southern China has deteriorated below standards (Jin 1994). Recent studies suggested that a blue-green algal bloom (*Microcystis* sp.), usually associated with the eutrophication in Chinese lakes, produces toxins that can be fatal to vertebrates (Carmichael 1986, Sonzogni *et al.* 1988). Discharge of excessive nutrients (from raw sewage) is considered as the main cause of lake eutrophication in China (Jin 1994). However, with the absence of sewage treatment facilities and with increasing pressure from economic development, practical and cost-effective strategies for reversing the trend of eutrophication of Chinese lakes are urgently needed.

Manipulation of fish populations has shown cascading effects on lower trophic levels in freshwater ecosystems (McQueen *et al.* 1986), a phenomenon called the top-down effect (Carpenter and Kitchell 1984). Such biomanipulation has been effective in improving water clarity in shallow lakes and ponds (McQueen 1990). For example, an increase of top piscivorous fish can cause a reduction in planktivorous fish, which can lead to an increase of large cladoceran zooplankton, the major herbivores in many lakes. As a result of increased grazing by zooplankton, a decrease of phytoplankton and an increase in water clarity are often reported (Shapiro and Wright 1984, McQueen *et al.* 1986, Carpenter *et al*, 1987, Grimm 1989).

In southern China, two planktivorous species, silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Ctenopharyngodon idella*), have been historically stocked and then harvested in lakes and reservoirs for two purposes: (1) human consumption and (2) controlling algal blooms. These two planktivorous fish have now become the dominant species in many lakes and reservoirs in southern China (Xie 1994). Recent studies indicated that silver carp also consume zooplankton (Dong and Li 1994). Because we were interested in whether regulation of these species could influence water quality (clarity and nutrients) through the plankton community, we conducted enclosure experiments to examine the effect of silver carp density on the zooplankton and phytoplankton community in a shallow eutrophic lake.

METHODS AND MATERIALS

Study Site

Donghu (Dong=East, hu=lake; 30° 33' N, 114° 23' E), located in Wuhan, P. R. China, is a shallow lake (surface area = 32 km^2, maximum depth = 5 m). In the past decade, the lake has become hypereutrophic, and the fish community is dominated (> 90%) by two planktivorous silver carp and bighead carp (Xie 1994).

Experimental Design

We conducted experiments in eight enclosures, placed into Donghu at the Donghu Experimental Station, Institute of Hydrobiology, Wuhan. Polyhexene enclosures (2.5x2.5x3 m) were sealed off from sediments at the bottom and filled with lake water to a depth of 2.5 m. Because most lakes in southern China are relatively shallow, sediment could play an important role in nutrient cycling and plankton dynamics. Thus, sediment (about 2 cm) from Donghu was added into each enclosure five days before fish were added.

Silver carp were collected from a local hatchery and transferred immediately into the enclosures. Based on the average standing biomass of silver carp and bighead carp in Donghu of 190 g/m^2 (Xie 1994), four treatment levels of silver carp biomass (0, 81, 225, 485 g/m^2) were established. Each treatment combination was randomly assigned to enclosures and replicated twice. The four biomass levels resulted in 0, 5, 15, 30 silver carp per enclosure. Twenty-six silver carp were randomly chosen for length and wet weight measurement . Mean individual weight and length (± SD) of stocked silver carp were 102 g (±21 g) and 184 mm TL (±11 mm), respectively.

Sampling and Analyses

Beginning 30 May, 1995 (day 0), enclosures were sampled at 4-5 d interval until 26 June. Surface temperature was measured daily with a thermometer and ranged from 24-28 °C. We sampled zooplankton with a 6.5 L Patalas-Schindler trap (net mesh = 56 μm). One sample was taken in each enclosure, consisting of water collected from surface, 1 m, and 1.8 m deep. Zooplankton was immediately preserved in 5% sucrose-formalin, and a 5 ml subsample was examined for zooplankton abundance. To estimate the grazing pressure, body lengths of at least 20 individuals of the most abundant cladoceran species were measured. Rotifers (except for *Asplanchna* sp.) and copepod nauplii were not included in the calculation of total zooplankton abundances. We measured water transparency using a Secchi disk.

Integrated water column samples were also collected with the Patalas-Schindler trap for analysis of chlorophyll *a* and various nutrients. Chlorophyll *a* was measured by first filtering water sample through a Whatman GF/C glass fiber filter (0.7 μm; Shelodon 1972). The filters were then ground using 90% acetone in the dark (5 °C). The extract was centrifuged, and the supernatant was used for absorbance measurement with a spectrophotometer. Chlorophyll *a* concentrations were then calculated using equations of Lorenzen (1967). Total phosphorus was analyzed by colorimetry after a wet digestion to orthophosphate with boiling H_2SO_4. Total nitrogen was analyzed by a wet digestion (Kjeldahl digestion) to ammonia.

Statistical Analysis

Visual inspection of data suggested that enclosures containing no (0 fish) and low (5 fish) silver carp densities behaved similarly and very differently from enclosures with medium (15 fish) and high (30 fish) densities. Therefore, we pooled data for no and low fish density enclosures as one treatment (low fish density treatment) and data for medium and high fish density enclosures as a second treatment (high fish density treatment) for statistical analysis. We analyzed the data with an one-way repeated-measures (split-plot) analysis of variance (ANOVA). For main effects, repeated-measures ANOVA is equivalent to taking a mean of all sampling dates for each enclosure and then testing for treatment effects (low fish density vs high fish density). In a repeated-measures ANOVA, the significance tests of time and time x treatment indicate difference in two statistical treatments (i.e., low fish density and high fish density) during experimental period. All analysis was done using SPSS Advanced Statistics (SPSS Inc., 1994).

Table 1. One-way repeated-measures ANOVA of zooplankton community, Secchi, chlorophyll *a*, and nutrient responses to silver carp manipulation.

Source of variation	ss	df	ms	F	*P*
		Total zooplankton abundance			
Fish density	129793.04	1	129793.04	11.24	0.015
Time	196898.09	5	39379.62	5.67	0.001
Time x fish	114131.92	5	22826.38	3.28	0.018
		Dominant cladoceran mean size			
Fish density	1.00	1	1.00	7.69	0.032
Time	0.31	5	0.06	0.94	0.469
Time x fish	0.38	5	0.08	1.18	0.343
		Water transparency (or Secchi)			
Fish density	17671.69	1	17671.69	15.68	0.007
Time	66457.85	5	12391.57	27.25	<0.001
Time x fish	7265.19	5	1453.04	2.98	0.027
		Chlorophyll *a* concentration			
Fish density	698.90	1	698.90	5.19	0.063
Time	5244.86	4	1311.05	12.42	<0.001
Time x fish	328.40	4	82.10	0.78	0.550
		Total nitrogen			
Fish density	15.25	1	15.25	1.13	0.329
Time	50.59	4	13.15	6.24	0.001
Time x fish	30.53	4	7.63	3.62	0.019
		Total phosphorus			
Fish density	0.29	1	0.29	1.16	0.324
Time	0.48	4	0.12	2.66	0.057
Time x fish	0.25	4	0.06	1.42	0.259

RESULTS

We did not recover all silver carp at the end of this study because another experiment was still in progress. However, we collected 23 fish from all treatment enclosures for length and wet weight measurements. Final weight was 113 g (±24 g); final length was 195 mm TL (±16 mm).

In the low density treatments, total zooplankton abundance was significantly higher than that in the high density treatments (Table 1, Fig. 1). Similarly, the mean size of dominant cladocerans was greater in enclosures of low densities of silver carp than in high density enclosures. In addition, species composition of cladoceran community changed. All enclosures were dominated by *Moina* sp. at the beginning of the experiment (Table 2). *Daphnia* sp. later dominated the cladoceran community in low fish treatments. At high densities of silver carp, however, *Moina* sp. continued to be the dominant species in the cladoceran community. Thus, the impact of silver carp at high densities was to shift zooplankton to a community dominated by smaller cladocerans.

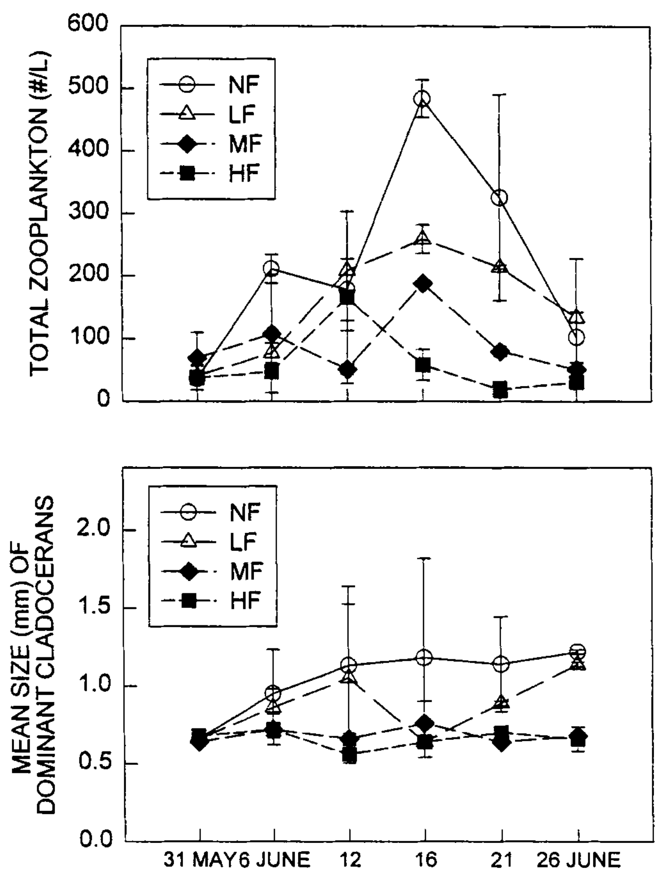

Fig. 1. Zooplankton dynamics over the course of the experiment. (a) Total zooplankton abundance (excluding nauplii, rotifers except for *Asplanchna* sp.) in each treatment; (b) mean body size of dominant cladocerans in each treatment. Symbols are means of two replicate enclosures; vertical lines represent ± 1SE. NF = no fish, LF = 81 g/m^2, MF = 225 g/m^2, HF = 485 g/m^2.

Table 2. Dominant cladoceran species and their mean sizes (mm) in four treatments. NF = no fish; LF = low silver carp density (81 g/m^2); MF = medium silver carp density (225 g/m^2); HF = high silver carp density (485 g/m^2). *Diapha.* = *Diaphanosoma* sp..

TIME	NF		LF		MF		HF	
	Species	Size	Species	Size	Species	Size	Species	Size
31 MAY	*Moina*	0.66	*Moina*	0.66	*Moina*	0.66	*Moina*	0.66
6 JUNE	*Moina*	0.95	*Moina*	0.86	*Moina*	0.72	*Moina*	0.72
12 JUNE	*Daphnia* *Diapha.*	1.65 0.62	*Daphnia* *Diapha.*	1.53 0.58	*Moina*	0.70	*Moina* *Diapha.*	0.62 0.54
16 JUNE	*Daphnia* *Diapha.*	1.82 0.54	*Daphnia*	0.64	*Moina*	0.76	*Moina* *Diapha.*	0.74 0.54
21 JUNE	*Daphnia* *Diapha.*	1.45 0.83	*Daphnia*	0.91	*Moina* *Daphnia*	0.62 0.66	*Moina* *Diapha.*	0.70 0.70
26 JUNE	*Daphnia*	1.22	*Daphnia*	1.14	*Diapha.*	0.68	*Moina* *Diapha.*	0.74 0.58

Water transparency, like responses of zooplankton community to silver carp manipulation, differed between the low and high density treatments. The water was much more transparent in the low density enclosures than in the high density enclosures (Table 1, Fig. 2).

Chlorophyll *a* concentrations were similar in all enclosures at the beginning of the experiment (Fig. 3), although their concentrations were marginally higher in the high density treatments than in the low density treatments during the entire experimental period (Table 1). The manipulation of silver carp density did not influence concentrations of total nitrogen and total phosphorus (Table 1, Fig. 4).

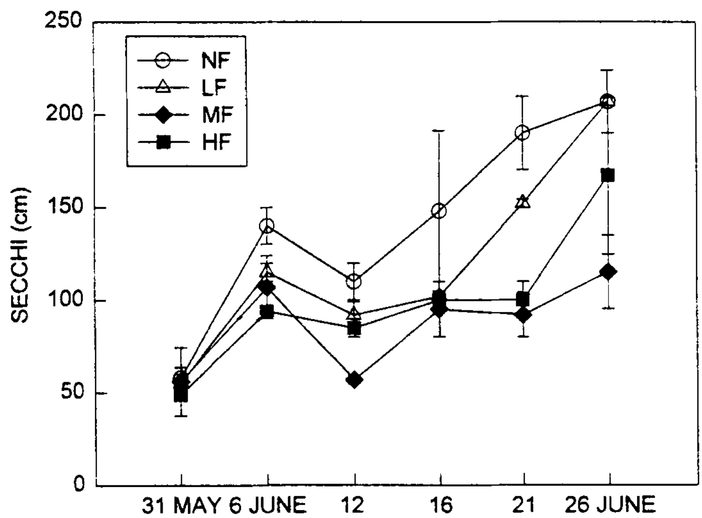

Fig. 2. Changes in water transparency (Secchi) over the course of the experiment in each treatment. Symbols are means of two replicate enclosures: vertical lines represent ± 1SE. NF = no fish, LF = 81 g/m^2, MF = 225 g/m^2, HF = 485 g/m^2.

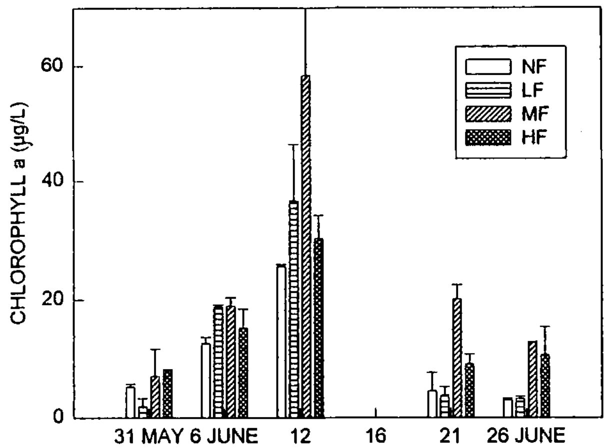

Fig. 3. Chlorophyll *a* concentrations over the course of the experiment in each treatment. Bars are means of two replicate enclosures; vertical lines represent ± 1SE. Measurements were not made on 16 June. NF = no fish, LF = 81 g/m^2, MF = 225 g/m^2, HF = 485 g/m^2.

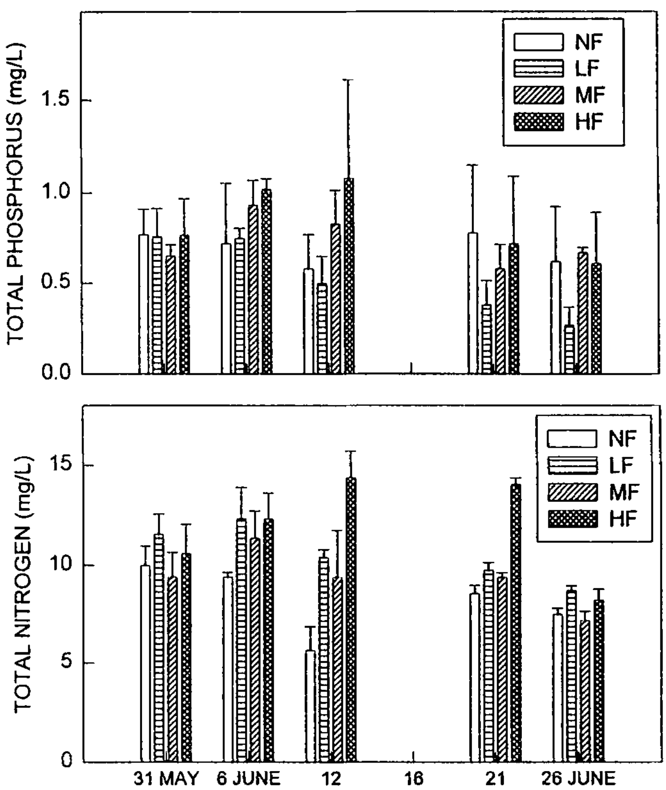

Fig. 4. Concentration of total phosphorus and total nitrogen over the course of the experiment in each treatment. Bars are means of two replicate enclosures; vertical lines represent ± 1SE. Measurements were not made on 16 June. NF = no fish, LF = 81 g/m^2, MF = 225 g/m^2, HF = 485 g/m^2.

DISCUSSION

Silver carp at densities > 200 g/m² not only suppressed total zooplankton abundance, but also shifted the cladoceran community from dominance by large-bodied species (*Daphnia* sp.) to dominance by small-bodied species (*Moina* sp.). Most studies of silver carp feeding have suggested that they filter-feed on phytoplankton. This is the main reason why silver carp have been heavily stocked to reduce algal abundance in eutrophic lakes in southern China. However, recent studies showed that silver carp are able to filter both phytoplankton and cladoceran species (Spataru and Gophen 1985, Dong and Li 1994). Although we did not analyze diets of silver carp, our results indicated that abundant silver carp could suppress populations of large-bodied *Daphnia* sp.. If silver carp fed mainly on phytoplankton, we would expect a lower chlorophyll *a* concentration in enclosures with high fish densities than in enclosures with low fish densities. On the contrary, chlorophyll *a* concentration increased or changed little in treatments with high silver carp densities. This suggested that silver carp were not feeding solely on phytoplankton. Instead they fed like bighead carp (Dong and Li 1994), selectively removing large-bodied daphnids. A recent survey also suggested that the zooplankton community in Donghu has shifted from dominance by large-bodied cladoceran species to dominance by small-bodied cladocerans in the past decade (Xie 1994), which coincides with the increase in planktivorous fish particularly silver carp and bighead carp.

The classic study of Brook and Dodson (1965) and many later studies (reviewed by Lazzaro 198‾) demonstrated that selective predation by planktivorous fish tends to reduce densities of large cladoceran species (such as *Daphnia* sp.) in lakes, resulting in a reduction in grazing pressure on the phytoplankton community. McQueen et al. (1986) further suggested that this top-down effect tends to be stronger at the top of the food chain (e.g., fish-zooplankton) than at the bottom (e.g., phytoplankton - nutrients). Our study showed that, by reducing silver carp density, we could shift zooplankton community from dominance by a small-bodied cladoceran to dominance by a large-bodied cladoceran. However, the effects of silver carp manipulation on chlorophyll *a* and nutrients were much less pronounced. Furthermore, our study suggests that large zooplankton such as *Daphnia* sp. are more efficient in removing phytoplankton, thus increasing water clarity.

Silver carp have historically been an important management tool, stocked to reduce algal abundances in lakes of southern China. Many lakes currently have densities of planktivorous fish (dominated by silver carp and bighead carp) equal to or greater than 190 g/m² (Xie 1994). Based on our results, we recommend that (1) a management strategy to reduce the density of planktivorous species should be implemented, via reducing stocking or increasing harvest, and (2) the practice of using silver carp to control algal abundances should be evaluated. Reducing planktivorous fish density in eutrophic lakes in China could enhance densities of large cladocerans (*Daphnia*) and thus improve water clarity.

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