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Food Consumption by *In Situ* Pen-Cultured Planktivorous Fishes and Effects on an Algal Bloom in Lake Taihu, China

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ABSTRACT

Silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) were used as a new pen-cultured biomanipulation technique to control algal blooms in Meiliang Bay of Lake Taihu. In order to evaluate the capacity of these two fishes to decrease algal blooms, diel feeding samplings were carried out in May (without algal blooms) and September (with algal blooms) in 2005. Based on estimated food consumption by the Elliott-Persson model, silver carp increased daily food consumption from 2.07 g dry weight per 100 g wet body weight in May before the outbreak of algal blooms to 4.98 g dry weight per 100 g wet body weight in September during algal blooms outbreak. However, no obvious variation of food consumption was observed in bighead carp during the study period. This species 1.88 and 1.54 g dry weight of plankton per 100 g wet body weight in May and September, respectively. Silver carp had a higher feeding capacity for plankton than bighead carp. Biotic factors (i.e., fish size and conspecific competition with natural species in the lake) may affect the feeding behaviors of both carps as well as seasonal variation of plankton communities in the pen.

INTRODUCTION

The planktivorous filter-feeding silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) are among the most common Chinese cyprinids, contributing most of the fish yields of freshwater culture since the 1970s in China and have been introduced worldwide for both aquaculture fish production and algal control (Zhong and Power 1997, Xie 2003). As filter-feeding fishes, they feed not only on phytoplankton (i.e., cyanobacteria, green algae) but also on suspended detritus and zooplankton (Chen 1990). In contrast to particle-feeding fish that visually select individual prey items (primarily larger zooplankton) (Lazzaro 1987), filter-feeders collect food by passing water through their filtering apparatus, feeding on phytoplankton (usually $>10\ \mu\text{m}$), suspended detritus, and also zooplankton if they are unable to evade the fish (Xie 2003).

Many studies have reported the utilization of silver carp and/or bighead carp to manage algal community structure (Smith 1985, Miura 1990, Opuszynski and Shireman 1991, Starling 1993, Starling et al. 1998, Xie 1999 and 2001, Turker et al. 2003). Recently, based on the successful practice for a period of 16 years in Lake Donghu, silver carp and bighead carp are being used to control or tested to counteract cyanobacteria blooms in many Chinese lakes, such as Lake Dianchi, Lake Chaohu, and Lake Taihu, by stocking fry and fingerling in these lakes (Xie and Liu 2001, Xie 2003). However, little information is available on the quantitative food consumption of silver and bighead carp in the practice of large-scaled biomanipulation, though some studies have tested these carps as agents for elimination of algal blooms in a variety of small-scale experiments (Fukushima et al. 1999, Xie 2003). Therefore, we established a large fish pen (1.036 km²) in Meiliang Bay of Lake Taihu stocked with silver and bighead carp for an *in situ*

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experiment to evaluate the abilities of these fishes to decrease the biomass of cyanobacteria.

Generally, the quantity of food consumed by fishes in their natural habitat can be estimated by different models based on gut fullness in the field (Bajkov 1935, Eggers 1977, Thorpe 1977, Elliot and Persson 1978). However, detailed *in situ* evaluations of diel feeding patterns of fish populations are highly laborious due to the large number of samples of fish that have to be scrutinized frequently over 24 hours. The most commonly used models for estimating food consumption in the field are the Eggers (1977) and Elliott and Persson (1978) models. The two models have been reported to be adequate for estimating the daily ration of fish that feed through the day on a wide range of prey types (benthivorous/planktivorous fish) and exhibit occasional feeding peaks (Eggers 1979, Boisclair and Leggett 1988). Due to its simplicity, the Eggers model seems to offer lower variances for the daily ration estimates and the Elliott-Persson model is appropriate not only for daily ration estimates, but also for estimates of diel changes in food consumption. Therefore many studies have applied the two models for estimation of food consumption of fishes in the field (Chen 1990, Boisclair and Marchand 1993, Héroux and Magnan 1996, Grant and Kott 1999, Specziár 2002, Vašek and Kubečka 2004, Guo and Xie 2005).

The purpose of the present study was to describe the diets of silver carp and bighead carp, to estimate food consumption of both species using a large enclosure, and to evaluate their efficiencies of feeding on cyanobacteria.

METHODS AND MATERIALS

Study sites and fish pen-culture

Lake Taihu is located in the south of the Yangtze River delta. The total area of the lake is 2,338 km², with an average depth of 2 m and a total capacity of 47.6 × 10⁸ m³. In recent years, water pollution by cyanobacterial blooms has become a severe problem in this lake. In Meiliang Bay of Lake Taihu, heavy *Microcystis* spp. blooms have occurred annually during the warm season (from May to October) (Shen et al. 2003).

A large fish pen was built by a mesh size of 3 cm of polyethylene net to allow exchange water in Meiliang Bay of Lake Taihu (120°12'46"-120°13'07"E, 31°29'07"-31°29'55"N), and the pen was divided into three smaller pens with areas of 0.339, 0.346 and 0.351 km². Silver carp juveniles (24,775 kg) with average body weight of 102 g (ranging from 78.5 g to 255.3 g) and 8,005 kg bighead carp juveniles with average body weight of 116.2 g (ranging from 49.7 g to 183.4 g) were stocked in the three pens before Jan. 10, 2005.

Fish sampling

Fish were captured by gillnet at 4-h intervals over a 24-h period both before the outbreak of algal blooms (May) and during the bloom period (September) in Meiliang Bay in 2005. At each sampling time, five specimens of silver and bighead carp were killed immediately and then measured for total length (TL) and weighed (wet weight). Guts were dissected, and all contents were weighed (fresh weight). Prey items from fore-gut contents were collected from the proximate end of the intestine to the middle of the first loop (Xie 1999). Individual samples of gut contents were fixed in Lugol's iodine and then preserved in 10% formaldehyde. The gut contents were homogenized in cool distilled water with an electronic stirrer for 3-5 min and then examined under magnifications. 2 ml of gut contents were used for determination of phytoplankton and zooplankton composition. Wet weight of zooplankton was estimated according to the weight-body size regression. To count *Microcystis* cells, the samples were agitated by

gentle ultrasonication to split the colonies into single cells. After mixing, 0.1 ml samples were counted directly under 400× magnification. Biomass (wet weight) of phytoplankton was calculated assuming a wet weight density of 1 g cm⁻³. In order to assess the actual prey biomass in the diet, all gut contents were dried at about 60 °C and then weighed.

Daily consumption

Gut contents weight of each fish was expressed as gut fullness, F_i (g dry weight per 100 g wet body weight), which was estimated as $F_i = 100G_i(W_i)^{-1}$, where G_i is the dry weight (g) of the gut content of fish i and W_i is the net wet body weight (g) of fish i (total fish weight minus gut content weight; g). In order to normalize percentage distributions, mean gut fullness for each 4-h interval was estimated from arcsine-transformed data ($\arcsin \sqrt{0.01F_i}$) and was used in further calculations in its backtransformed form.

The Elliott-Persson model was used to estimate daily food consumption, and we assumed that the initial gut fullness was equal to that at the end of the 24-h period (Eggers 1979, Boisclair and Marchand 1993, Specziar, 2002). Daily food consumption (C , g wet weight per 100 g fish wet weight per day) was calculated by the Elliott-Persson

(1978) model as $C = \sum_{t=1}^p C_t$, where $C_t = (F_t - F_0 e^{-Rt}) R_t (1 - e^{-Rt})^{-1}$. C is the quantity of food

consumed by fish during an interval t between two successive sampling periods t and $t + 1$, and p is the number of intervals per day. C is the mean amount of food (g wet weight per 100 g wet weight of fish) consumed during a sample interval t (4 h), F_0 and F_t are the mean gut fullnesses at the beginning and end of a sample interval t , and R (h⁻¹) is the instantaneous gastric evacuation rate.

Evacuation rate can be estimated under laboratory conditions, as the slope of the relationship between digestive tract contents and time while fish are not fed (Elliott 1979) or, under field situations, as the steepest slope of the daily survey or digestive tract contents (Boisclair and Leggett 1985). Since several studies have shown that the gut emptying of silver and bighead carp in the laboratory can be appropriately described by the exponential model (Chen 1990), we determined R as the slope of the relation between \ln -transformed gut fullness and time. For convenience, R was estimated as the maximum rate at which food was evacuated as (Boisclair and Marchand 1993, Guo and Xie 2005): $R = (\ln F_{t+4} - \ln F_t) / 4$, where $\ln F_t$ and $\ln F_{t+4}$ are the mean of the \ln -transformed (ln, natural logarithm) weight of digestive tract contents at the beginning and at the end of a 4-h interval.

RESULTS

Fish growth

Mean wet weight of silver carp ranged from 202.1 g (in May) to 1,041.2 g (in September), and it tended to increase by 0.005 g day⁻¹ from January to May but was 0.014 g day⁻¹ from May to September. Bighead carp had a similar growth rate with mean body weight ranging from 238.9 g in May to 1,109.9 g in September, and the specific growth rate ranged from 0.005 to 0.013 g day⁻¹. No significant difference of growth was found between silver and bighead carp ($P > 0.05$).

Diet

The diet compositions of silver and bighead carp varied during the May and September samplings (Fig. 1). In the gut contents of silver carp, phytoplankton was mainly dominated by chlorophyta in May but by cyanophyta in September. No obvious changes were found in zooplankton composition in the diet of silver carp. As for bighead

carp, phytoplankton was mainly dominated by chlorophyta and cyanophyta in May but absolutely by cyanophyta in September. Cladocerans dominated in the zooplankton composition in the diet of silver and bighead carp both in May and September. Bighead carp had a higher proportion of zooplankton in the diet than did silver carp both in May and September. The phytoplankton community of the lake water varied greatly between May and September; it was mainly composed of chlorophyta in May but cyanophyta in September. There were no appreciable differences in the zooplankton community composition during the study period.

Gut fullness

Both silver and bighead carp actively fed during daytime from May to September (Fig. 2). In May, mean gut fullness of silver carp increased and reached the maximum at 1000 h then decreased in the afternoon. However, bighead carp gut fullness increased from 0600 to 1800 h, when it reached a maximum; these was only one feeding peak for both carps. In September, silver and bighead carp showed a similar feeding activity, which reached a first feeding peak at 1500 h and a second at 0200 h but the gut fullness was lower at 0200 h than at 1500 h.

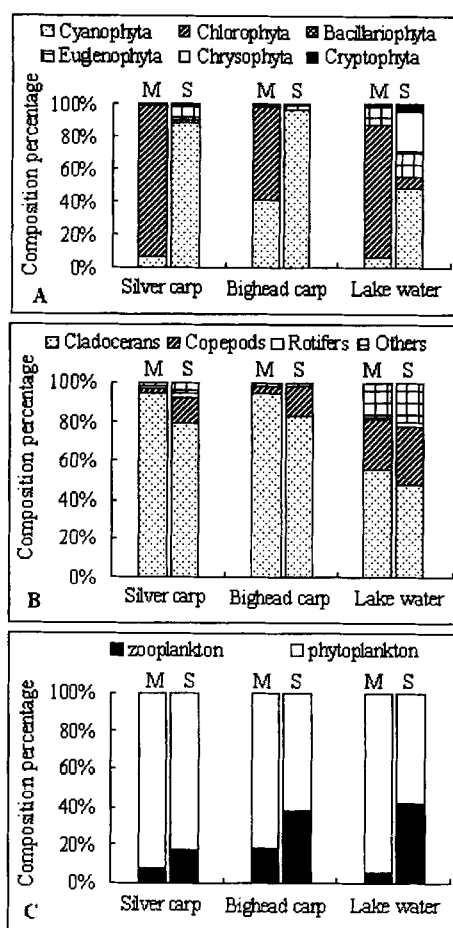


Figure 1. Phytoplankton (A), zooplankton (B) and total plankton (C) composition in the lake water and gut contents of silver and bighead carp. M-May, S-September.

The gut fullness of silver carp ranged from 0.231 (bighead carp) to 1.645 g dry weight per 100 g wet body weight (silver carp) in May, then from 0.504 (bighead carp) to 1.530 g dry weight per 100 g wet body weight (silver carp) in September (Fig 2). It varied significantly between silver and bighead carp (t-test, $P < 0.001$). Mean gut fullness did not vary significantly by season in silver carp (t-test, $P = 0.059$) or bighead carp (t-test, $P = 0.072$).

Evacuation rate and food consumption

For silver carp, a lower evacuation rate was observed in May (0.061 g h^{-1}) than in September (0.183 g h^{-1}) (Table 1). However, bighead carp had a higher evacuation rate in May (0.176 g h^{-1}) than in September (0.103 g h^{-1}).

The daily consumption of plankton by silver carp was significantly higher in September than in May, but no significant difference was observed in bighead carp (Table 1). On a daily basis, silver carp consumed 2.07 g dry weight of plankton per 100 g wet body weight in May and 4.98 g dry weight of plankton per 100 g wet body weight in September. In contrast, bighead carp showed a similar food consumption with silver carp in May (1.88 g dry weight of plankton per 100 g wet body weight), but a significantly lower daily consumption (1.54 g dry weight of plankton per 100 g wet body weight) was found in September.

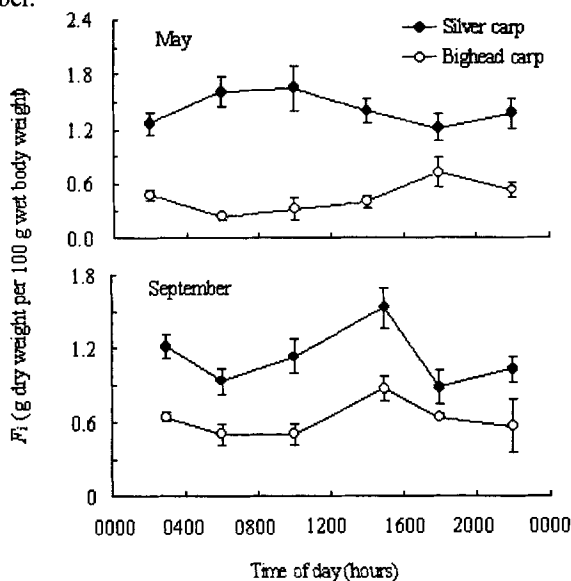


Figure 2. Diel variation in the mean gut fullness (F_t) of silver carp and bighead carp in May and September of 2005. Vertical bars represent \pm SE.

DISCUSSION

Variation of the plankton community due to algal blooms may have significantly affected the behavior of both carps in the pen. In September, *Microcystis* spp. (cyanobacteria) dominated the phytoplankton community, and small zooplankters (e.g., *Bosmina* and *Ceriodaphnia* species) dominated the zooplankton community; in May no algae blooms were observed, phytoplankton was mainly represented by green algae, and zooplankton was mainly dominated by large-size cladocerans (e.g., *Daphnia* and *Moina* species). This was consistent with previous studies (Chen 1990, Miura 1990). Compared with previous results however, the diet of silver carp contained more than 80%

phytoplankton species, including cyanobacteria (less than 10%) in May but 85% phytoplankton (more than 50% cyanobacteria) in September. In the diet of bighead carp, zooplankton comprised 90% of the food item in May but less than 50% in September. Our results suggest that the outbreak of a cyanobacterial bloom can be an important factor affecting feeding behaviors of both carps. Additionally, dense blooms can cause a great decrease in water transparency, and increased turbidity can affect prey selection of both zooplankton and fish (Vogel and Beauchamp 1999, Guo and Xie 2005). Miura (1990) reported that colonial *Microcystis* spp., blooms can disturb the selective feeding of bighead carp on zooplankton and result in a greater consumption of the algae. Smith (1989) reported that silver and bighead carp can more efficiently filter-feed larger algae than small ones. During the outbreak of *Microcystis* spp. blooms, the low zooplankton/phytoplankton ratio in the lake water may be responsible for the declined selectivity of fish on zooplankton (Dong and Li 1994). On the other hand, *Microcystis* spp. always formed large colonies and floated on the surface of the lake, which perhaps was then easily fed upon by silver and bighead carp.

There has been a common understanding that feeding intensity of fishes varies with time so as to form a definite diel feeding rhythm (Wootton 1998). We observed feeding peaks for both carps at 1500 h in September, but different peaks were found in May. Chen (1990) reported similar feeding rhythms of silver carp (6.8-12.8 cm in body length) and 217 bighead carp (4.6-11.7 cm in body length) in July to August in Lake Donghu, with the maximum feeding intensity appearing at 1600-1900 h. However, we found that bighead and silver carp showed a reversed feeding activity in May, and the gut fullness of bighead carp was significantly lower than that of silver carp. The reason may be explained by the length of alimentary canal and the prey composition. Generally the relative gut length tends to decrease from herbivores to omnivores to carnivores (Wootton, 1998). Silver and bighead carp lack a stomach but have well-developed pharyngeal bones that can physically break up algal cell walls, and the extended gut length offers digestive benefits (Xie 1999 and 2001). Our study suggests that the outbreak of algal blooms in Meiliang Bay might have changed the feeding activities. On the other hand, according to Li (1999), the natural fish fauna of Lake Taihu are all zooplanktivorous fish, such as Engraulidae (*Coilia* spp.) and Salangidae (*Neosalanx* spp.). Due to the fact that bighead carp tend to feed on zooplankton, interspecific competition is inevitable.

Chen (1990) reported that the digestion of gut contents of the juveniles of these species varied from the status of satiation. The food evacuation rates (0.12 g h⁻¹ for silver carp and 0.127 g h⁻¹ for bighead carp) were much higher during continuous feeding. The respective rates were 0.04 g h⁻¹ and 0.04 g h⁻¹ for the carps when feeding was not active. In our study, we estimated the evacuation rate according to the gut fullness decline in the

Table 1. Growth of silver and bighead carp in the fish pens of Meiliang Bay of Lake Taihu. No data (-).

	Month	Mean body weight (g)	Mean total length (cm)	Mean total gut length(cm)	Specific growth rate (%)
Silver carp	Jan.	102.0	-	-	-
	May	202.1	25.9	185.8	0.005
	Sept.	1,041.2	45.6	388.4	0.014
Bighead carp	Jan.	116.2	-	-	-
	May	238.9	26.2	126.6	0.005
	Sept.	1,109.9	44.3	216.5	0.013

field. The results indicated that the evacuation rate of silver carp increased from 0.061 g h⁻¹ to 0.183 g h⁻¹ from May to September, but the evacuation rates of bighead carp decreased from 0.176 g h⁻¹ to 0.103 g h⁻¹ during this time. Similar results were reported by Opuszynski and Shireman (1991), and they found that food passage time tended to be shorter for larger fish.

The growth rate of silver carp and bighead carp were similar from May to September, but the daily ration of silver carp was higher than that of bighead carp. Based on food consumption, silver carp and bighead carp quite obviously decreased the algal blooms in the fish pens. According to Yang et al. (2006), the algal blooms in August reached 93 mg L⁻¹ outside the pen, which was 5 to 22 times greater than that in the pens. Based on the changes in fish weight over the study, we estimate that about 13,900 kg of plankton (equivalent to 11,200 kg cyanobacteria) were eliminated by stocked fishes in the pens. Therefore, stocking of filter-feeding fishes could be an effective control for algal blooms.

Table 2. Daily consumption estimates for silver and bighead carp in fish pens of Meiliang Bay of Lake Taihu. Temp. = mean water temperature; F = mean gut fullness \pm SE during the 24-h period; R = gut evacuation rate; C = daily consumption.

	Month	Temp. (°C)	F (g dry weight per 100 g wet fish weight)	R (g h ⁻¹)	C (g dry weight per 100 g wet fish weight)
Silver carp	May	24.0	1.414 \pm 0.161	0.061	2.071
	Sept.	24.3	1.118 \pm 0.124	0.183	4.975
Bighead carp	May	24.0	0.445 \pm 0.088	0.176	1.880
	Sept.	24.3	0.623 \pm 0.094	0.103	1.542

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