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Food assimilation and filtering rate of bighead carp kept in cages

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Abstract

Bighead carp, *Aristichthys nobilis* Rich., dry weight food assimilation rates ranged from 37 to 49% (average 43%). The filtration rate ranged from 185 to 256 ml h^{-1} g^{-1} and was higher in larger fish. Bighead carp filtered *Chlorella vulgaris* (6 ± 0.4 μ diam) inefficiently (0.1%), but the efficiency increased to 13% for the larger *Scenedesmus* sp. (12 ± 1.7 μ diam). Fish kept in cages were forced to filter-feed, whereas fish kept free in the same pond were opportunistic plankton and bottom feeders. Free fish grew faster.

Introduction

Increasing eutrophication in inland water bodies has focused attention to developing counteracting measures, such as ichthyofauna manipulation, which is an environmentally sound, cost effective, biological method for managing aquatic ecosystems (Verigin, 1979; Opuszynski, 1980; Shapiro & Wright, 1984; Smith, 1985; Leventer, 1987). The use of phytoplankton-eating fish to control algal blooms is one of many possible biological methods that should be tested. Although this method has failed to decrease algal standing crop (Boyd, 1979; Opuszynski, 1979; Burke *et al.*, 1986), it has given advantageous changes in water quality, such as higher oxygen concentration, significantly lower ammonia and nitrite levels (Piotrowska-Opuszynska, 1984; Burke *et al.*, 1986; Leventer, 1987).

The bighead carp, *Aristichthys nobilis* Rich., is one of the fish species being considered to control phytoplankton. Although the feeding habits of bighead carp have been studied (Lazareva *et al.*, 1977; Cremer & Smitherman, 1980; Opuszynski, 1981; Spartaru *et al.*, 1983), there is no information about the quantity of food eaten. The effectiveness of bighead carp in controlling planktonic algae might be diminished because it feeds also on zooplankton which, in turn, can be an effective algal control agent (Hrbacek *et al.*, 1961; Lampert, 1985). Keeping bighead carp in cages may prevent them from preying upon zooplankton and force them into phytoplankton grazing. The purpose of the present study was to determine food assimilation, filtration rate and some elements of the feeding behavior of bighead carp kept in cages. Such information is indispensable in evaluating the ability of this fish to alleviate nuisance growths of phytoplankton, and is also necessary for the design of further experiments.

Materials and methods

The experiments were carried out in 0.05 ha ponds with an average depth of 1.6 m. The ponds were fertilized with superphosphate and ammonium nitrate. When the experiments were conducted the water temperature was 28.5 and 24 °C, respectively. Hatchery fish were used. They were grown in ponds at the University of Florida, Gainesville, Florida. Three groups of fish were used. The first group were fingerlings with an initial mean weight of 34.1 ± 8.9 g and mean total length (TL) of 146.1 ± 13.3 mm (data variability is shown either by the standard error proceeded by a ± sign, or by the range given in parenthesis). Up to 30 fish were placed in a cage situated in pond No. 2 and 53 fish were stocked free into this pond on August 31, 1988. These fish were used for the experiments of September 17 and 21, 1988 (Table 1). The second group consisted of 30 fingerlings with an initial mean weight of 101 ± 24 g and mean total length of 205 ± 18.4 mm. The third group consisted of 15 two-year-old fish with a mean weight of 2242 ± 574 g and mean total length of 597 ± 62 mm. These fish were caged in pond No. 1 on September 29, 1988, and used for the experiments on October 20 and 21, 1988 (Table 1).

Circular floating cages with a bottom diameter of 120 cm and a height of 125 cm were placed in the ponds. The cages were made from plastic net material with square openings of 2 cm per side. The water capacity of each cage was 1.2 m^3. We assumed that the caged fish were not subjected to undue stress because the stocking rate was low and the large mesh size allowed free water circulation through the cages and assured proper oxygen and feeding conditions.

Five fish were used for each experiment. They were randomly selected from the cages and from pond No. 2. After collection, the fish were killed immediately, measured, weighed, and their intestines removed. Three subsamples of food were immediately taken from both the foregut and hindgut to estimate the dry weight of food and the percentage of organic matter. The entire intestinal contents were removed, weighed and preserved in 10% formalin solution. For further analysis the contents from each intestine were carefully mixed and stirred in a known volume of formaldehyde solution. Two subsamples were taken for quantitative and qualitative analysis. The first subsample (1 ml) was examined in a counting chamber under 40 and 100 × magnification to identify and count the larger food items. The second subsample (0.05 ml) was placed on a microscope slide with cover slip and examined under 400 × magnification using the method of Edmondson (1971). At least three replicate samples were examined. All food organisms were measured and the biomass of animal food was calculated by the method of standard weights (Morduchaj-Boltovskoj, 1954; Starmach, 1955).

Table 1. Total lengths, weights, and food of bighead carp.

	September 17 cage in pond No. 3	September 21 pond No. 3	October 20 cage in pond No. 1	October 21 cage in pond No. 1
Total length (mm)	143 (127–151)	173 (166–180)	203 (168–231)	619 (562–690)
Weight (g)	27 (21–34)	60 (55–65)	96 (52–139)	2,150 (1,500–2,800)
Food wet weight (g)	0.6 (0.5–0.7)	2.8 (1.9–3.2)	0.8 (0.7–0.8)	22.5(14.8–29.3)
Relative food weight (%)	2.0 (1.7–2.4)	4.4 (3.4–5.2)	1.1 (0.8–1.4)	0.9 (0.8–1.1)
% of animal food	0.7 (0.1–1.1)	4.9 (3.2–7.7)	1.4 (1.0–1.8)	1.1 (0.6–1.4)
Phytoplankton (No. × 10^3 g fish body weight^{-1})				
Chlorella vulgaris	288 (177–467)	5869 (4444–7280)		
Scenedesmus sp.	58 (38–105)	20 (14–42)		
Rotifer (No. g fish body weight^{-1})	< 10	< 10	388 (163–652)	369 (231–605)

Pond water samples consisted of 13 one-liter samples taken randomly from each pond and mixed. The samples were collected from mid-depth water using a Patalas plankton sampler. Ten liters were filtered through a plankton net, with openings of 60 μ. This sample was used for zooplankton examination. Two liters were used to determine the amount of chlorophyll *a*, phaeopigment and particulate organic matter. A 200 ml sample of pond water was centrifuged for 5 min at 5000 *g* and concentrated to 5 ml for phytoplankton estimation. The algae were resuspended and preserved in 10 ml of 4% formaldehyde solution. The methods used for plankton quantification were similar to those described for food quantification. Water quality analysis followed Standard Methods (APHA, 1985).

Food assimilation was calculated by modifying the formula of Conover (1966):

$$A = \frac{F - E}{(1 - E)(F)} 100 \qquad (1)$$

where F = ash-free dry weight/dry weight ratio of the ingested food

E = the same ratio in a representative sample of feces.

The estimates for F and E in our studies were from samples of food taken from the foregut and hindgut of each fish. This method depends on the assumption that only the organic component of the food ingested by a fish is significantly affected by the digestive process.

Filtering rate was calculated according to the formula:

$$FR = \frac{(\mathrm{Ng}\ \mathrm{P}^{-1})\ \mathrm{W}^{-1}}{Np} \qquad (2)$$

where: FR = filtering rate in ml h^{-1} g^{-1}
Ng = number (or weight) of the food item in a gut
Np = number (or weight) of the same food item in 1 ml of pond water
P = food passage rate in h
W = weight of the fish in g

The food passage rate (P) was estimated in a separate study (Opuszynski & Shireman, in press). Fish were kept in cages located in ponds. Fish were removed from the cages, some of them were killed immediately, and the others were transferred to a clean water tank. These fish were killed at intervals and the advance of food in the intestines was determined. Linear regression equations (% gut evacuated = $a + bx$, where x = time in min) were used to calculate evacuation times.

Filtering rate was calculated using rotifers, a food item that was large enough to be effectively sieved by the fish and that possessed little evasive capability. Bighead carp gill raker spaces average 87 μ (Spataru *et al.*, 1983), whereas rotifers averaged 140 ± 17 μ in our study. We assumed, therefore, that all rotifers were strained from the water, whereas other organisms were stained less effectively because they were smaller or could evade the fish. The term 'filtering efficiency' therefore, is used to describe the relative efficacy of fish in filtering these organisms. Filtering efficiency was calculated according to the same formula (2) as was filtering rate. When difference between filtering rate and filtering efficiency values increased, a smaller proportion of a given food item is removed by the fish.

Results

The percentage of organic matter assimilated by the bighead carp is shown in Table 2. Data from all foregut and hindgut samples were pooled,

Table 2. Food assimilation by bighead carp (means and 95% confidence intervals).

Sampling date and place	Fraction of organic matter		Percent assimilation
	Foregut	Hindgut	
September 17 cage in pond No. 3	0.82 (0.81–0.82)*	0.70 (0.69–0.71)	49 (46–52)
September 21 pond No. 3	0.51 ± 0.03	0.38 ± 0.03	41 ± 4.0
October 20 cage in pond No. 1	0.45 ± 0.07	0.38 ± 0.04	37 ± 2.8
October 21 cage in pond No. 1	0.49 ± 0.03	0.31 ± 0.06	47 ± 3.1

* Two fish examined in 2 replications.

because an F-test indicated that the differences between individual fish were not significant ($P > 0.05$). The average assimilation of organic matter was 43% (37–49%).

The characteristics of each pond are shown in Table 3. While phytoplankton abundance, as estimated by chlorophyll *a* content, was identical in both ponds, the higher phaeopigment value in pond 1 indicated more detritus in the samples. The phytoplankton communities in the two ponds were quite different. *Chlorella vulgaris* was the dominant species in pond 2, whereas *Chroococcus* sp. was the dominant in pond 1. In pond 2 *Chlorella vulgaris* cells measured $6\,\mu \pm 0.4\,\mu$. *Scenedesmus*, which was not as numerous, consisted mainly of small individuals of *S. quadricauda*, *S. bijuga*, *S. abundans* and *S. arcuatus*. The mean size of these colonies (excluding spines) was $12\,\mu \pm 1.7\,\mu$.

Distinctive differences were found in the *Chlorella*/*Scenedesmus* ratio between pond water and the food of the fish kept in cages (Tables 1 and 3). The ratio in pond water was 505 ± 158 to 1 and only 5 ± 1 to 1 in the food of the caged fish. It is interesting to note, however, that the ratio of *Chlorella*/*Scenedesmus* was 293 ± 91 to 1 in the food of the free swimming fish from the pond (Table 1). This value did not differ significantly from that of the pond water.

The bluegreen alga, *Chroococcus* sp. ($2.2\,\mu \pm 0.07\,\mu$ diam), predominated in pond 1 (Table 3). Rotifers were also abundant in pond 1, which made it possible to calculate bighead carp filtering rates. Rotifer populations consisted of *Keratella cochlearis*, *Trichocerca* sp. and *Cephalodella* sp. (mean size $140 \pm 17\,\mu$). Filtering rate was calculated according to formula (2). To calculate the filtering rate, the food passage rate was also needed. It was assumed as 10.3 h for 96 g fish and 7.1 h for 2150 g fish (Opuszynski & Shireman, in press). The filtering rate was calculated as 185 ± 41 and 256 ± 58 $\mathrm{ml\,h^{-1}\,g^{-1}}$ for the smaller and larger fish, respectively. Similar calculations could not be made for fish in pond 2, because the small number of rotifers in the pond and in the fish (Table 1 and 3) did not permit accurate calculations. For further discussion, the filtering rate of the fish in pond 2 will be assumed equal to that of the smaller fish in pond 1.

Table 3. Characteristics of seston in ponds 1 and 3, September 19 and October 19, 1988.

Constituents	September 19 pond No. 3	October 19 pond No. 1
Chlorophyll *a* (μg $\mathrm{l^{-1}}$)	48 (46–51)	48 (43–51)
Phaeopigment (μg $\mathrm{l^{-1}}$)	0.7 (0.4–1.0)	5.5 (3.0–7.1)
Total particulate matter (mg $\mathrm{l^{-1}}$)	46 (44–49)	28 (27–30)
Organic particulate matter (mg $\mathrm{l^{-1}}$)	39 (36–43)	16 (15–17)
Phytoplankton (No. × 10^3 $\mathrm{ml^{-1}}$)		
Chlorella vulgaris	106 (80–135)	
Scenedesmus sp.	0.21 (0.15–0.31)	
Chroococcus sp.[1]		211 (170–235)
Others	0.31 (0.11–0.55)	3.4 (2.2–4.7)
Zooplankton (No. $\mathrm{l^{-1}}$)		
Rotatoria	5 (1–7)	203 (160–231)
Crustacea	10 (4–15)	31 (21–39)

[1] Number of cells.

The filtering efficiency of particulate matter was very low for the small caged fish (Table 4; October 20). It did not exceed 8 $\mathrm{ml\,h^{-1}\,g^{-1}}$ or 4% of the filtering rate. The filtration efficiency for particulate matter was higher in larger fish when expressed in $\mathrm{ml\,h^{-1}\,g^{-1}}$, however, it was as low as in the small fish in terms of the percentage of filtration rate (Table 4; October 21). The filtering efficiency increased with an increase in the size of the food item. For example, it was 0.2 $\mathrm{ml\,h^{-1}\,g^{-1}}$ for *Chlorella vulgaris* and 23.4 $\mathrm{ml\,h^{-1}\,g^{-1}}$ for *Scenedesmus* sp.

The filtering efficiency of the free swimming pond fish was different from that of the fish caged in the same pond. The filtering efficiency for particulate matter, especially inorganic, was high and amounted to 88 $\mathrm{ml\,g^{-1}\,h^{-1}}$ or 47%. Most striking, however, was the high filtration efficiency for *Chlorella vulgaris*. It was 30 times that observed in the caged fish (Table 4). The relative food weight of the pond fish was also higher and the percentage of animal food greater (Table 1). The growth of the fish was reflected in the differences in their food habits. The pond fish gained an average of 29 g between 31 August and 21 September (this increase was significant at

Table 4. Filtering efficiency of free swimming and caged bighead carp.

Food item	Filtering efficiency ml h^{-1} g^{-1}	Percentage of filtering rate
September 17 (caged fish)		
Total particulate matter	5.5	3
Organic particulate matter	5.3	3
Inorganic particulate matter	6.6	4
Chlorella vulgaris	0.2	0.1
Scenedesmus sp.	23.4	13
September 21 (free swimming fish)		
Total particulate matter	23.8	13
Organic particulate matter	12.3	7
Inorganic particulate matter	87.6	47
Chlorella vulgaris	6.6	4
Scenedesmus sp.	11.6	6
October 20 (caged fish)		
Total particulate matter	6.3	3
Organic particulate matter	5.7	3
Inorganic particulate matter	7.1	4
Rotifers	185	100
October 21 (caged fish)		
Total particulate matter	12.4	5
Organic particulate matter	11.7	5
Inorganic particulate matter	13.3	5
Rotifers	256	100

$P = 0.05$, Student t-test), whereas the caged fish lost an average of 3.7 g in the same period. The weight decrease, although not statistically significant, was also observed in the caged fish in pond 1.

Discussion

Conover's (1966) method of estimating assimilation efficiency has caused considerable discussion. For example, Pavljutin (1970) proved, through studies in different aquatic animals, that Conover's estimation method contained significant error. On the other hand, Fisher (1972) feeding grass carp, *Ctenopharyngodon idella*, with plant food, obtained similar results using Conover's method and two methods based on direct calculation of energy budget: $A = P + R/C$ (where P = body growth, R = respiration and C = consumption) and $A = C - FU/C$ (where FU = all excrement). Estimates of assimilation efficiency from these three methods were 20.7 ± 2.1, 17.2 ± 1.2 and 24.8 ± 2.0, respectively).

Most studies on fish assimilation efficiency have been made under laboratory rather than in natural conditions (Morgan, 1980). In the laboratory it is impossible to duplicate natural situations, where fish are capable of selecting food at random. Therefore, we used the method employed in the present study, where fish had the opportunity of randomly feeding on organisms in the pond or on materials that passed through the cages. The percentage of organic matter averaged 85% in pond 2 and 57% in pond 1. The amount of organic matter in the fish food was lower and was 82% for the caged fish in pond 2 and ranged from 45 to 49% for the cage fish in pond 1 (Table 2 and 3). It is difficult to say whether the lower percentage of organic matter in the fish food was caused by food selectivity or was due to digestion. We believe that digestion was not a factor because the food sample was taken at the beginning of the long intestine where digestion is minimal.

The assimilation efficiency found in the present study ranged from 37 to 49% (Table 2), and was considerably higher than that cited for grass carp fed with *Lactuca sativa* by Fisher (1972). It is possible, however, that the results obtained for grass carp were underestimated because the fish were fed a single food item. Gerking (1984) fed another herbivorous fish, *Sarpa salpa*, with a green alga, and found a dry weight assimilation of 59%. Kirilenko *et al.* (1975) reported an average dry weight assimilation of 40% by *Tilapia mossambica* feeding upon *Chlorella* and bluegreen algae, whereas Bowen (1981) reported 63% assimilation of organic matter by the same species feeding on periphytal detritus. Some data indicate that a relationship exists between daily food ration and assimilation efficiency. For example, 10 g *Tilapia nilotica* and *Haplochromis nigripinnis* feeding on phytoplankton had daily rations of

40% and 19%, respectively. The lower rations for *H. nigripinnis* were compensated for by higher assimilation efficiencies equal to 60% for this species in comparison with 43% for *T. nilotica* (Moriarty *et al.*, 1973; according to Morgan, 1980). A similar relationship was shown for silver carp, *Hypophthalmichthys molitrix*, feeding on bluegreen algae. These fish assimilated 40% of the protein in their diet when daily rations were 1.6%, and only 6.6% when daily rations were increased to 9.8% (Kirilenko & Chigrinskaya, 1983). This relationship was also seen in our study, because the fish with the highest relative intestinal food weight exhibited relatively low assimilation efficiencies (Table 1 and 2), even though they had free access to all available food resources.

The bighead carp is considered a filter-feeder (Lazareva *et al.*, 1977; Cremer & Smitherman, 1980; Opuszynski, 1981; Burke *et al.*, 1986) and filter-feeding capacities are associated with gillraker mesh size. Voropaev (1986) reports that the average spacing between gillrakers in the bighead is 20 to 60 μ, whereas Spartaru *et al.* (1983) reported sizes ranging from 84 to 87 μ. The dominant phytoplankton species in our ponds were much smaller than the gillraker mesh size reported for bigheads.

Nevertheless, these small phytoplankton contributed the bulk of the fish diet (Table 1). We did not determine the mechanism used by bigheads for small food particle capture. Some authors suggest that cichlids may collect small particles by entrapping them in mucus to form food-mucus aggregates (Greenwood, 1953; according to Drenner *et al.*, 1987). This mechanism is also possible for bighead carp. Whatever the mechanism might be, filter-feeding on small algae is inefficient. Fish kept in cages had small relative food weights and did not grow when they fed only on small algae.

Filter-feeding efficiencies increased as algal size increased. This was shown distinctly when *Chlorella* and *Scenedesmus* were compared (Table 4), even though both algae were smaller than the spaces between the gillrakers. The *Chlorella* to *Scenedesmus* ratio in the intestines of the caged fish was less than that in the pond. As discussed previously, free swimming pond fish had the same *Chlorella* to *Scenedesmus* ratio in their food as that observed in the pond. This situation indicates that caged and free swimming fish had different feeding habits.

The food of the free swimming pond fish contained more inorganic matter than the food of the caged fish (Tables 2 and 4). This material consisted primarily of sand particles, which were easily recognizable microscopically. The second striking difference was that animal food, primarily benthic chironomid larvae, made a larger contribution (Table 1). The presence of sand and benthic organisms suggests that the pond fish were feeding on the bottom. This behavior might account for the *Chlorella* to *Scenedesmus* ratio being the same in both the food of the pond fish and in the pond plankton, because the fish might have fed on sedimented detrital aggregates of these algae. This also indicates that bighead carp are opportunistic feeders, feeding both on plankton and benthic organisms, which might account for the different opinions as to the importance of phytoplankton, zooplankton, bottom fauna and detritus in their diet (Cremer & Smitherman, 1980; Opuszynski, 1981; Spartaru *et al.*, 1983; Burke *et al.*, 1986).

The use of rotifers to determine filtration rate was justified, because rotifer body lengths were larger than the openings in the filtering apparatus and they could not evade the fish (Drenner *et al.*, 1982). Data are not available for bighead carp filtration rates. However, such data are available for the silver carp, a closely related species. Antalfi & Tolg (1971) reported a filtration rate for this species of 128 ml h^{-1} g^{-1} and Spittler (1981) reported a rate of 241 $\pm$ 139 ml h^{-1} for fish weighing 1.3 $\pm$ 0.2 g. These data agree with our results. Drenner *et al.* (1982) calculated a filtering rate model for gizzard shad, *Dorosoma cepedianum*, and showed that filtering rates per gram of fish decreased as a power function by body length. In this study the filtering rate of the larger fish with a mean length of 619 mm was higher than the smaller fish with a mean length of 203 mm (Table 1 and 4), because the relative food weight did not decrease proportionally with an increase in body size. Also the food evacuation time for larger fish was shorter (Opuszynski & Shireman, in press).

Because plankton feeding fish have the potential to control phytoplankton (Boyd, 1979; Szczerbowski *et al.*, 1983; Leventer, 1987), some preliminary calculations have been made from our data (Table 4). If bighead carp are stocked in cages at a rate of 500 kg in a 1 ha pond with a depth of 1 m (10000 m^3), and with a phytoplankton composition similar to our pond No. 3 (Table 3), the total water volume of the pond would be filtered by the fish in 4.5 days (10000 $m^3/5 \times 10^5$ g × 185 mL × 24 h). However, only 3% of the organic particulate matter, 0.1% of the *Chlorella* standing crop and 13% of the *Scenedesmus* standing crop would be filtered by the fish. If the assimilation efficiency is 43%, more than one half of the food consumed would be returned to a pond as fish feces. Further studies are needed to determine whether bighead carp kept in cages or free in ponds, with or without other fish, can alter the structure of the phytoplankton community consisting of larger algal species. In southern lakes of the U.S. the phytoplankton community is often dominated by large algae. These algae are not eaten by smaller zooplankton or native fish species. It has been shown in the present study that bighead carp are able to filter larger algae more efficiently than smaller ones. If this occurs, the composition of algae should be shifted to smaller forms, which can be consumed by zooplankton and other fish species.

Conclusions

1. Food assimilation was calculated as the difference between ash-free dry weight/dry weight ratio of food samples taken from the foregut and hindgut of fish. The average assimilation of organic matter was 43%.
2. Filtering rates were calculated using rotifers as an indicator because they were large enough to be retained by the fish filtering apparatus and possessed little evasive capability. Filtering rates ranged from 185 to 256 ml h^{-1} g^{-1} of fish body weight, being greater for larger fish.
3. A water volume of 10000 m^3 would be filtered by 500 kg of fish in 4.5 days. However, only 0.1% of the *Chlorella vulgaris* and 13% of the *Scenedesmus* sp. standing crop would be filtered by the fish. Considering assimilation efficiency as 43%, more than one half of the eaten food would be returned to a water body as fish feces.
4. Bighead carp would be ineffective in controlling small-size-algae plankton communities. Further studies are needed to evaluate the influence of bighead carp on plankton communities consisting of larger algae species. If this fish could alter phytoplankton communities toward the domination of smaller algae species, it would alleviate eutrophication processes and encourage fishery management.
5. Comparison of the feeding behavior of caged and free-swimming fish showed that bighead carp are opportunistic feeders, feeding on plankton, sedimented detrital aggregates and benthic organisms. This might account for the different opinions as to the importance of different food items in the diet of this species.

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