PHYTOPLANKTON, ESPECIALLY DIATOMS, IN THE GUT CONTENTS AND FECES OF TWO PLANTIVOROUS CYPRINIDS—SILVER CARP AND BIGHEAD CARP

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Abstract

In order to clarify whether the planktivorous silver carp and bighead carp can collect phytoplankton as small as Cyclotella (<20 μm) in Donghu Lake, studies on phytoplankton in their gut contents and feces were made in 1990. The fish were cultured in both net cage in Donghu Lake and aquaria with the lake water. Past the intestine, the average valve diameter of Cyclotella changed little. The average ratio of empty frustule of Cyclotella to total Cyclotella in the foregut contents of the fishes were 1.8–1.9 times higher than that in the lake water, but changed little from foregut to feces. The aquarium experiment showed that both carps could collect particles as small as 8–10 μm, which was obviously narrower than the distance between their gill rakers. Probably, secretion of mucus plays an important role in collecting such small particles.

Key words: planktivorous fishes, gut contents and feces, diatoms, valve diameter, empty frustule

INTRODUCTION

Donghu Lake, 30 °33′N, 114 °23′E, is located in Wuhan City close to the middle reaches of the Changjiang River. The total surface area is about 32 km² and the maximum depth 4.5 m. According to the production data of the Donghu Lake Fish Farm, the annual fish yield between 1985–1990 varied between 690 and 850 kg/ha, of which over 90% was from two stocked planktivorous species, silver carp (Hypophthalmichthys molitrix) and bighead carp (Aristichthys nobilis). The lake is stocked mainly with fingerlings of the two species every year. No feed is given to the fish once the fingerlings have been released into the lake.

Since 1985, the dominant phytoplankton were Cyclotella (a centric diatom) and Cryptomonas (a dinoflagellate). The diameter of Cyclotella is usually smaller than 20 μm (the majority 6–15 μm), while the length of Cryptomonas is usually smaller than 30 μm (the majority 10–20 μm). However, the distances between gill rakers of silver carp are larger than 15 μm and those of bighead larger than 30 μm (Liu, 1981; Hampl et al., 1983; Spataru et al., 1983). If the carps can only use the food particles larger than the distances between their gill rakers, Cyclotella almost cannot be used by both carps, and Cryptomonas would only be partly used by silver carp.

This work was aimed to study phytoplankton, especially diatoms, in the gut
contents and feces of bighead and silver carp to clarify whether or not the carps can collect phytoplankton as small as *Cyclotella*.

**MATERIALS AND METHODS**

1. **Collection of gut contents and feces from fishes cultured in a net cage in Donghu Lake**

   A net cage experiment was conducted during March–May in 1990. The net cage with a surface area of 2.5 m × 4 m was set up near Station 1 in Donghu Lake. The bottom of the net cage reached down to the sediment of the lake. 150 fingerlings of silver carp and of bighead carp were introduced to the net cage on March 2, 1990.

   Generally, 5–7 of each carp were taken each time from the net cage and dissected to collect their contents. Contents collected from the anterior end of the intestine to its first loop (in some cases, slightly beyond the curvature) were considered as foregut contents. Contents collected in the intestine within 5 cm from the anus were considered as hindgut contents.

   For collecting feces, 7–10 each of both carps were taken from the net cage and introduced separately into two aquaria containing lake water. The feces were collected immediately after egestion by means of a pipette, and washed twice carefully in distilled water.

   The collected gut contents or feces were homogenized separately in cool distilled water with a stirrer for a few minutes.

2. **Collection of feces from fishes cultured in aquaria in the laboratory**

   An aquarium experiment was conducted during June 8–17. Two fish for each carp were introduced separately into two 120 l aquaria containing unstrained lake water; one fish for each carp was introduced separately into two other aquaria containing lake water strained by passing through a 60 μm plankton net, kept from stagnation with two small air pumps to reduce settling of food particles. The strained and unstrained lake water were renewed twice a day. The fish were acclimated to these aquaria for three days prior to the collecting of their feces. The feces were collected immediately after egestion by means of a pipette, and washed twice carefully in distilled water. The feces for both carps were then homogenized separately in cool distilled water with a stirrer for a few minutes.

3. **Examination of phytoplankton in the gut contents, feces and the surrounding lake water**

   The sampled lake water, homogenized gut contents or feces were immediately preserved in 5% formaldehyde solution. The specimens were counted and measured with a Hydro-bios inverted microscope at 500–1000 x magnification.

**RESULTS**

1. **Net cage experiment**

   The water temperature in the lake varied between 11.8 and 14.5 °C during mid-March
to mid-April, and then it ranged from 20.0—26.3 °C till the end of May.

During March—May, the total phytoplankton biomass in the lake water varied between 2.4—18.6 (average 10.7) mg fresh weight/l, of which *Cyclotella* constituted 31.3—78.5 (average 50.3)%, and *Cryptomonas* 5.2—38.2 (average 16.7)%. During the same period, the total zooplankton biomass in the lake water was much lower than that of phytoplankton (0.76—1.04, average of 0.93 mg f. w./l).

Examinations of the phytoplankton in the foregut contents of the fishes showed that the proportion of *Cyclotella* to the total phytoplankton biomass was 58—92 (average 73)% for silver carp (much higher than that in the lake water). Thus, the proportion of *Cyclotella* to total phytoplankton collected by the fishes was larger for silver carp than for bighead. Since *Cryptomonas* and *Ochroconas* (which were subdominants in the lake water during the period) are easily destroyed in the guts (even in the foreguts, it was usually very difficult to find their less damaged individuals), the proportions of *Cyclotella* in the food item of the fishes might have been overestimated somewhat. About half or more of the phytoplankton collected by the fishes were *Cyclotella* and the proportion of *Cyclotella* in the food item of the fishes was near to that of *Cyclotella* in the lake water.

The valve diameter of *Cyclotella* in the foregut, hindgut or feces differed little from each other for both bighead and silver carp (Fig. 1, Table 1), and also differed little between the two carps. The average valve diameter of *Cyclotella* in the gut contents or feces showed much temporal changes similar to that in the lake water although it was, on the average, slightly larger (Fig. 1).

The ratio of empty frustule of *Cyclotella* to total *Cyclotella* (E/T ratio) in the foregut contents of both carps taken from the net cage were considerably higher than that in the lake water (Fig. 1, Table 1). It is apparent that when passing through the esophagus, more than half of *Cyclotella* cells were more or less damaged (Table 2). In both carps the E/T

| Table 1 Average valve diameter of *Cyclotella* (L) and average ratio of empty frustule of *Cyclotella* to total *Cyclotella* (E/T) in the lake water, and in the gut contents or feces of the fishes |
|-----------------|-----------------|-----------------|-----------------|
| Period          | March—May a)   |              | 8—17 June b)   |
| Lake water      | L(μm)           | E/T(%)          | L(μm)           | E/T(%)          |
| Silver carp     |                 |                 |                 |
| (foregut)       | 9.9             | 28.0            | 7.3             | 26.2            |
| (hindgut)       | 10.1            | 49.8            | 8.6             | 50.3            |
| (feces)         | 10.5            | 47.3            | 8.5             | 52.0            |
| (feces 60")    | 10.3            | 50.6            |                 |                 |
| Bighead carp    | 10.8            | 52.4            | 8.7             | 56.3            |
| (foregut)       | 10.3            | 58.8            | 8.6             | 56.0            |
| (hindgut)       | 10.3            | 57.7            |                 |                 |
| (feces)         |                 |                 |                 |
| (feces 60")    |                 |                 |                 |

a) fish cultured in the net cage in Donghu Lake.
b) fish cultured in the aquaria.
c) fish cultured in the aquaria with lake water passed through 60 μm mesh plankton net.
ratio in the feces was only slightly higher than that in the foregut contents (Fig. 1, Table 1), indicating that when passing from the first loop of the intestine (in some cases, slightly beyond the curvature) to the anus, only a small number of *Cyclotella* were digested to empty frustules appearing mainly in the esophagus.

But, this does not mean that the digestion rate of *Cyclotella* in the intestine was very low, since our microscopic observations show that actually, more cells were seriously damaged (only residual protoplasm present in the cell) in the feces than in the foregut (Table 2).

The average E/T ratio in the gut contents or feces of silver carp was slightly higher than in those of bighead, respectively (Table 1), while the proportion of undamaged cells showed a reverse tendency (Table 2).
Table 2  Average proportion (%) of various-typed cells of *Cyclotella* (*A*—undamaged cells; *B*—protoplast partly destroyed but frustule undamaged; *C*—fragments of frustules with protoplast; *D*—fragments of empty frustules; *E*—undamaged empty frustule in the lake water, and in the gut contents or feces of the fishes

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<th>8–17 June</th>
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<td></td>
<td>A</td>
<td>B</td>
</tr>
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<tr>
<td>(feces 60 μm)</td>
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<tr>
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<td>(feces 60 μm)</td>
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a) fish cultured in the net cage in Donghu Lake.
b) fish cultured in the aquarium.
c) fish cultured in the aquarium with lake water passed through 60 μm mesh plankton net.

2. Aquarium experiment

During June, 8–17 the water temperature varied between 26.0–29.5 °C, the total phytoplankton biomass in the lake water varied between 4.3–11.6 (average 7.5) mg f.w./l, of which *Cyclotella* comprised 29.8–59.5 (average 43.6)%, and *Cryptomonas* 2.8–29.4 (average 17.1)%, and the average zooplankton biomass was 1.53 mg f.w./l.

In June, the average valve diameter of *Cyclotella* in the lake water declined markedly below that in March–May (Figs. 1, 2, Table 1). The fishes cultured in the aquaria chose larger cells rather than smaller ones when the average valve diameter of *Cyclotella* in the lake water was about 7–8 μm (Fig. 2, Table 1).

The exclusion of zooplankton (by straining the lake water through a plankton net) influenced little the valve diameter of *Cyclotella* and the E/T ratio in the feces of both carps (Fig. 2, Table 1), indicating *Cyclotella* cells found in the feces of both carps were collected by themselves and not by zooplankton ingested by the fishes.

The E/T ratio in the feces of both carps was consistently higher than that in the lake water. Since the average E/T ratio was 1.9–2.2 times higher in their feces than in the original food, about half of the *Cyclotella* cells in the lake water were digested into empty frustules after passing through the alimentary canal of the fishes.

Similar to those fishes cultured in the net cage, the average E/T ratio in the feces of bighead was slightly higher than that in feces of silver carp (Table 1). The E/T ratios in the feces of both carps cultured in the aquaria were unexpectedly very close to those in the feces of the fishes cultured in the net cage (Table 1), although food items were more abundantly available in the net cage.
DISCUSSION

Since past the fish intestine the average valve diameter of *Cyclotella* changed little,

![Graph](image)

the size distribution of *Cyclotella* in the feces is representative of that in the foregut contents. Actually, frustules of *Cyclotella* digested by the fishes were very scanty in number, since our microscopic examinations showed very few frustule fragments, even in the feces (Table 2). The inability of the fish to digest diatoms greatly facilitates determination
(by merely examining the feces) of the size distribution of diatoms collected by the fishes.

The average ratio of empty frustule of *Cyclotella* to total *Cyclotella* in the foregut contents of both carps taken from the net cage were 1.8–1.9 times higher than that in the lake water, but changed little from foregut to feces (Table 1). Dong(1992) also reported that when fed on cultured *Scenedesmus*, the percentage of cracked cells of *Scenedesmus* in the foregut content of silver carp comprised 18.8, which was 2.9 times that of the percentage in the original food (6.48), but increased only little in the hindgut content (22.0), suggesting that grinding action of the pharyngeal teeth of the silver carp had a key function in digesting algae with cellulose cell wall. Our results suggested a similar mechanism.

In the present study, the aquarium experiment showed that both bighead (ca. 100 g in body weight) and silver carp (ca. 70 g) could collect particles as small as 8–10 μm (Fig. 2 and Table 1), and the examination of the gut contents of the fishes cultured in the net cage in Donghu Lake showed that the majority of the phytoplankton found in the intestines were 8–20 μm. Smith (1989) reported that when feeding at 20°C on spherical particles (yeast, micronic beads and pollen), filtration rate (FR) of 32 g silver carp for particles between 10–50 μm was described by the equation \( FR = -20.8 + 21.7 \times \log \text{of particle diameter} \). His study also showed that the fish could filter particles of ca. 10 μm although the filtration rate was low, but there was no measured filtration for particles as small as 5.7 μm. Iwata (1976) also showed that 0.65–0.80 g silver carp could filter a small green alga (*Selenastrum* sp., 10 μm in length), although the ingestion rate was lower than feeding on a large green alga (*Closterium moniliferum*, 300 μm). All these results indicate that both bighead and silver carp can collect particles as small as 8–10 μm.

The distances between gill rakers (DGR) of bighead and silver carp were studied by some workers. Hampl et al., (1983) reported that DGR of silver carp was ca. 12 μm at the narrowest and ca. 26 μm at the widest, which did not change with age. Liu (1981) reported that DGR of silver carp was 15–25 μm when the fish length was 1.5–10 cm, and 34–41 μm when the fish length was 34–47 cm; and that of bighead was 30–35 μm when the fish length was 1.5–3 cm, and 30–72 μm when the fish length was larger than 3.5 cm. Spataru et al. (1983) found that DGR of silver carp was 36 (33.9–37.2) μm and that of bighead carp was 84 (83.9–86.8) μm when body lengths of the fishes were ca. 15–30 cm. These observations indicate that the distance between gill rakers of silver carp is larger than 15 μm and that of bighead is larger than 30 μm.

Apparently, both bighead and silver carp can collect particles smaller than their filtering net meshes. The mechanism is still not understood. Probably, secretion of mucus plays an important role in collecting such small particles.

In the present study, the majority of the phytoplankton collected by the bighead and silver carp (cultured in both net cage and aquaria) were 8–20 μm, and were also the major components of the phytoplankton community in the lake water. Cremer and Smitherman (1980) reported that food particles found in the intestines of bighead carp

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were 17–3,000 μm (when the majority of phytoplankton was 50–100 μm) and 8–100 μm (when the majority of phytoplankton was 17–50 μm) in intestines of silver carp (both carp were cultured in small ponds). Their results agreed well with the observed distances between gill rakers. Thus, it seems that collection of food particles by the fishes is largely dependent on the food availability in the environment, i.e., when most of the food items are small, they can collect food particles even smaller than the distances between their gill rakers; when most of the food items are large, they collect mainly those food particles larger than the distances between their gill rakers. In this case, divergency in trophic niche occurs between these two carps, i.e., the food particles collected by bighead carp are usually larger than those collected by silver carp.

In the enclosure experiments conducted in 1989/90 and 1992 in Donghu Lake, it was found that a dense stocking of the fishes not only decreased the quantity of the food item, but also changed their dominants, i.e., large-sized species were replaced by small-sized ones.

In other words, the dominance of small-sized food items in the environment usually suggests that food availability for the fishes had worsened, and that the fish production was approaching the carrying capacity of the lake ecosystem. The present situation in Donghu Lake seems to be just like this, i.e., the dominance of Cyclotella and Cryptomonas suggests a worsening food availability for the fishes.

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References


