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Negative effects of *Microcystis* blooms on the crustacean plankton in an enclosure experiment in the subtropical China

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Abstract: Effects of *Microcystis* blooms on the crustacean plankton were studied using enclosure experiments during July—September, 2000. Eight enclosures were set in the hypereutrophic Donghu Lake. Different nutrient concentrations through additional nutrient and sediment in enclosures were expected to result in different abundance of *Microcystis*. From July to early August, the phytoplankton community was dominated by Chlorophyta, Cryptophyta, Bacillariophyta and Cyanophyta other than *Microcystis aeruginosa*. *M. aeruginosa* showed a rapid increase during early August in all enclosures and predominated. Crustacean plankton was dominated by the herbivorous *Moina micrura*, *Diaphanosoma brachyurum* and *Ceriodaphnia cornuta*, and the predaceous *Mesocyclops* sp. and *Thermocyclops taihokuensis*. During the pre-bloom period, the dynamics of *M. micrura* population appeared to be mainly affected by the predaceous cyclopoids. With the development of *Microcystis* blooms, such interaction between *M. micrura* and cyclopoids seemed weakened, especially when the *Microcystis* biomass was high. But there was no apparent influence on the interaction between *Leptodora kindti* and its zooplanktonic prey. The density of two cyclopoids decreased with the enhancement of *Microcystis*. The density decline of *M. micrura* was caused by both predation and inhibition by *Microcystis*. The low food availability of other edible phytoplankton during the blooms led to low densities of both *C. cornuta* and *D. brachyurum* by late August. It appears that dense *Microcystis* blooms exert strong negative effects on the herbivorous cladocerans and the predaceous cyclopoids.

Keywords: crustacean plankton; cladocerans; cyclopoids; food availability; *Microcystis* bloom

Introduction

Cyanobacteria(i.e. *Microcystis aeruginosa*) blooms are frequently associated with changes of zooplankton community. Few zooplanktons can use bloom-forming *Microcystis* directly because of nutritional deficiencies (Arnold, 1971), inedibility(Webster, 1978) and toxin production(Fulton, 1987). It has frequently been shown that toxic *Microcystis* is lethal to zooplankton in laboratory experiment(Ferrão-Filho, 2000). But Haney(Haney, 1987) ever pointed out that there is less or no direct evidence for lethal effects of toxic cyanobacteria on crustacean plankton in the field. The negative effect of *Microcystis* on zooplankton has been probably attributed to feeding inhibition or the lack of alternative food. During *Microcystis* blooms, zooplankton can use other phytoplankton, small-sized *Microcystis*, bacteria or detritus(e.g. decomposed *Microcystis*) as food(Hanazato, 1987; Chen, 2003). Because of filtering inhibition from colonial *Microcystis*, it is difficult for zooplankton, especially large-sized *Daphnia*, to get other phytoplankton as food. On the contrary, some small-sized species suffer, to some extent, less inhibition from *Microcystis* blooms and ingested small-sized *Microcystis* colonials(Fulton, 1987). But it is confirmed that zooplankton is impossible to get enough necessary nutrition from *Microcystis* alone owing to the lack of poly-unsaturated fatty acid(PUFA), sterols or other essential elements(Von Elert, 2001). Only green alga mixed with colonial *Microcystis* could improve the growth rates of zooplankton population (Chen, 2003). Once colonial *Microcystis* are ingested, colonial mucilaginous and adhered bacteria can be used by zooplankton as complentary foods (Infante, 1984). When *Microcystis* decomposes, some herbivorous zooplankton can use it while others cannot (Hanazato, 1987; Chen, 2003). In spite of carefully-designed laboratory experiments, it is still difficult to judge which factors in nature from cyanobacteria, including physical inhibition, toxicity, and the scarcity of nutritious algae, are most important in influencing zooplankton growth (Infante, 1985).

Cyclopoids have a wide food spectrum(Hopp, 1997; Kumar, 1999; Xie, 2000) and prefer to select animal food (Kumar, 1999). Also, they could discriminate between toxic and nontoxic clones of cyanobacteria(DeMott, 1991). So during the *Microcystis* bloom, cyclopoid can use different prey although dense blooms could possibly reduce, to some extent, feeding on animal prey. Thus, their brood size of per female and population size would decrease during the bloom.

Donghu Lake is a subtrophic shallow lake in east China. From the 1970s to 1985, heavy cyanobacteria blooms(mainly *Microcystis*, *Anabeana* and *Oscillatoria*) occurred in the summer of each year, but the blooms have disappeared completely since 1985(Wang, 1991; Xie, 2001), due to high density of filter-feeding fish (*Hypophthalmichthys molitrix* and *Aristichthys nobilis*)(Xie, 1996). Nutrient concentration in lake seemed to have no impact on cyanobacteria blooms(Xie, 1996). Therefore during July-September 2000, *in situ* enclosure experiments were conducted to study the influences of cyanobacteria blooms on zooplankton abundance. The main purposes of this paper are to document the dynamics of both herbivorous and predaceous crustacean plankton and to assess the effects of the *Microcystis* bloom on the crustacean plankton community with emphasis on food availability and prey-predator interactions.

1 Materials and methods

1.1 Experimental design

The enclosure experiment was conducted from July 15 to September 21 in 2000. Eight polyethylene enclosures(each 2.5 m × 2.5 m by 2 m depth), installed in the Shuiguohu, the most euthrophic in Donghu Lake, were attached to steel

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pipes which were mounted at the bottom. The enclosures were open to the air above and sealed off from sediment at bottom. About 12.5 m^3 lake water near enclosures was pumped directly into each enclosure without screening on July 15. Since microscopic examination showed that the pump did not damage the plankton, we did not add more zooplankton to the enclosures. The enclosures were free of fish.

Four treatments with sediment and/or nutrients were set in order to create differently artificial concentration gradients in different enclosures. P + S treatment was added 5 cm sediment, KH_2PO_4 and lake water. N + S treatment was added 5 cm sediment, KNO_3 and lake water. S treatment was added 5 cm sediment and lake water. NS treatment was only added lake water. Each treatment had two replicates. Sediment from Shuiguohu, a bay of Guozhenghu was added into the corresponding enclosures on July 16. Nutrient additions were performed once on July 21, which created initial N:P ratios of 5 and 30 respectively in the P + S and N + S treatments. Thus, the concentrations of total nitrogen and total phosphorous were the highest respectively in the N + S and P + S treatments during the experiment. Average concentrations during the experiment in P + S, N + S, S and NS treatments were 2.07, 4.51, 2.38 and 2.00 mg/L in TN, 0.49, 0.36, 0.39 and 0.24 mg/L in TP. Different nutrient concentrations were expected to result in different abundance of *Microcystis*.

1.2 Sampling and analysis

All sample were collected at 07 : 00—08 : 00 in the morning. Stratification in enclosures was weak during the sampling time. Water temperature (0.5 m depth) measurements were made with a thermometer. To measure the concentration of chlorophyll-*a*, phytoplankton was fractionated into three size classes(< 18 μm, 18—60 μm, >60 μm) with plankton nets based on the result of Burn (Burn, 1994). The phytoplankton was collected with Whatman GF/C filters, and the chlorophyll-*a* was extracted with 90% acetone solution for 24—36 h, and then was determined by HPLC. Phytoplankton samples for microscopic counting were obtained by taking 1 L subsample from the 5 L pooled sample collected from the surface to the bottom of the enclosures at 0.5 m intervals. The subsamples were preserved with Lugol ' s iodine and formaldehyde and sedimented more than 24 h. Then the supernatant was removed and the residue was collected. After complete mixing, 0.1 ml concentrated samples were counted directly through a 0.1 ml counting chamber using a Leitz microscope at 40 × 10 magnification. When the *Microcystis* bloom occurred, 30 ml sample was directly obtained from the 5 L mixture. The *Microcystis* colonies were broken into unicellular form by ultrasonic wave, and then the unicellular *Microcystis* was counted as described above. Algal biomass was estimated from the closest geometric shape of each taxon.

Crustacean plankton was sampled at a 4—5 d interval using a 5 L modified Patalas bottle sampler. Samples were obtained by straining 15 L of the water collected from the surface to the bottom at 0.5 m intervals through a 64 μm mesh plankton net and were preserved in a 4% formaldehyde-sucrose solution (Haney, 1973). Crustacean plankton were identified according to Chiang (Chiang, 1979), Sheng (Sheng, 1979) and Xie(Xie, 1997), and counted under 10 × 6.3 magnification. Fresh weights of crustaceans were estimated according to the equations of Huang (Huang, 1999).

A repeated measure ANOVA, with the treatments as the fixed factor and the different samples through time as the repeated measures, was used to investigate the effect of the different treatments on the density of the different taxa. All data analysis was conducted in Stactistics.

2 Results

2.1 Biomass of phytoplankton, chlorophyll-*a* concentration and water temperature

The dominant group of phytoplankton was Cryptophyta (*Crypomonas* sp.) at the beginning of the experiment, and then shifted to Chlorophyta. Meanwhile, the proportion of Cyanophyta and Bacillariophyta mainly composed of *Oscillatoria*, *Spirulina* and *Melosira*, increased steadily. In early August, biomass of *M. aeruginosa* showed a rapid increase and formed a bloom(Fig.1). By mid-August, *M. aeruginosa* comprised more than 90% of the total

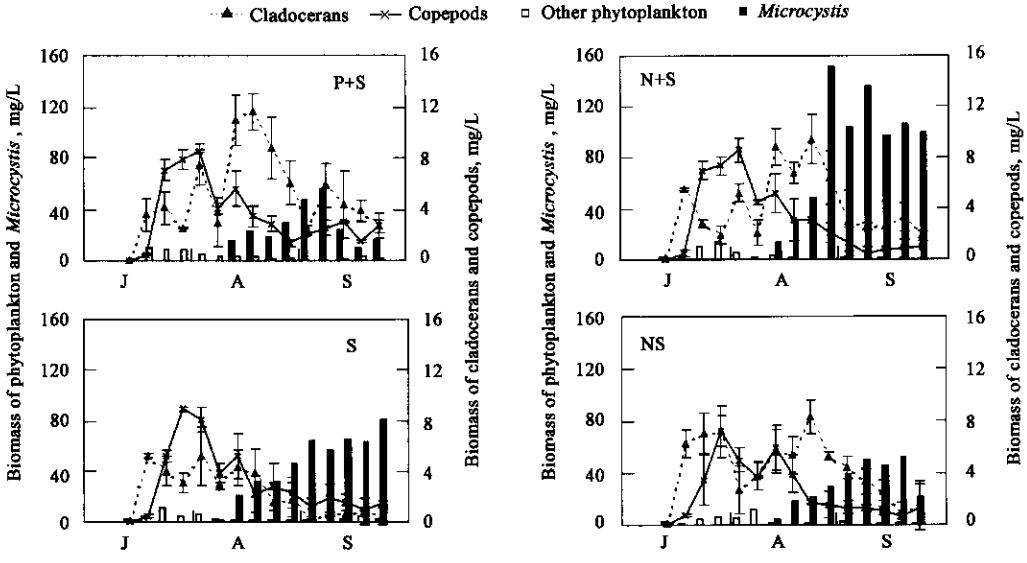

Fig.1 Changes in the biomass of crustacean zooplankton and phytoplankton in the enclosures during the experiment
Because large-sized *Leptodora kindti* could affect the biomass relation between other cladocerans and copepod, its biomass was excluded in the S treatment; Vertical bars represent Standard Deviation; J: July; A: August; S: September

phytoplankton biomass in all the enclosures except for the P + S treatment where an obvious decline was observed near the end of the experiment. Biomass of *Microcystis* was much higher in the N + S treatment than in the other treatments. The mean biomass of *M. aeruginosa* during the bloom period were 23.5 mg/L(P + S), 78.6 mg/L(N + S), 46.0 mg/L (N) and 27.8 mg/L(NS). In the four treatments, the mean biomass of other phytoplankton were the highest in July (3.51—7.15 mg/L) and lower in September(0.37—1.23 mg/L) than in August (1.80—2.81 mg/L). During the *Microcystis* bloom, the mean biomass of other phytoplankton were in the order of P + S > S > NS > N + S.

Fig.2 shows the changes in size-fractionated chlorophyll-*a* concentration in the enclosures. The proportion of chlorophyll-*a* in phytoplankton < 18 μm remained at a relatively higher level(18%—78%) in July as compared to the following two months (4%—53%). In the P + S treatment, the mean chlorophyll-*a* in the phytoplankton < 18 μm was higher in August(8.93 μg/L) than in September (5.78 μg/L), while in the N + S, S and NS treatments, the mean chlorophyll-*a* in the phytoplankton < 18 μm was lower in August(9.08, 8.72, 4.68 μg/L, respectively) than in September(15.61, 11.48, 7.95 μg/L, respectively). In all the treatments, the proportion of chlorophyll-*a* in the < 18 μm fraction remained at a low level during the bloom period in comparison to the pre-bloom period.

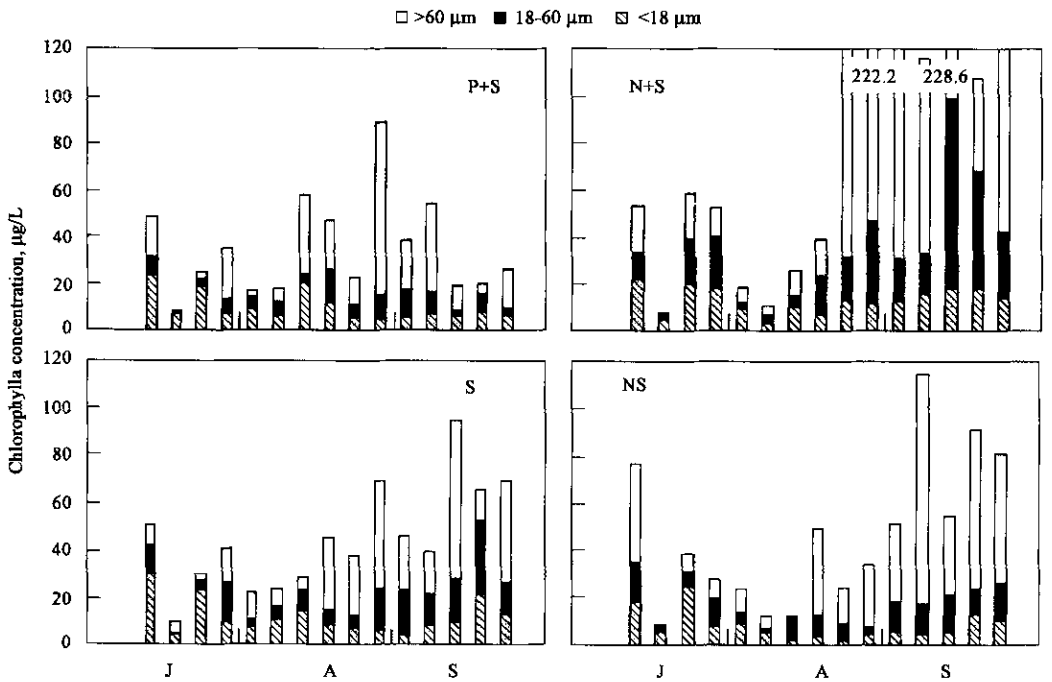

Fig.2 Dynamics of size-fractionated chlorophyll-*a* concentrations in the enclosures during the experiment
J: July; A: August; S: September

The large-sized(> 18 μm) phytoplankton remained at a relatively low level before the appearance of *Microcystis* bloom. Larger phytoplankton began to dominate the phytoplankton community and contributed greatly to total chlorophyll-*a* concentration during the *Microcystis* bloom. The average concentration was lower in the P + S treatment (31.2 μg/L) than in the other treatments(70—102 μg/L). In the N + S treatment, the maximum chlorophyll-*a* concentration in phytoplankton > 18 μm reached as high as 210 μg/L. Near the end of the experiment, the chlorophyll-*a* concentration of total phytoplankton showed steady decline in the P + S treatments, but remained high in the other treatments.

The water temperature varied from 24.5℃ to 32.5℃ during the experiment. It was above 30℃ before August 22, and then declined gradually.

2.2 Density dynamics of crustacean plankton

The cladocerans, *Moina micrura*, *Diaphanosoma brachyurum* and *Ceriodahpnia cornuta*, and the copepods *Mesocyclops* sp. and *Thermocyclops taihokuensis* dominated the crustacean plankton community during the experiment (Fig.3).

With the exception of the S treatment, the density of *M. micrura* in the other enclosures showed two peaks: a larger one in mid-July and a smaller one in late August. In late July, the density became so low that *M. micrura* was barely detected. Then it rose up slowly. The average densities during August 17-August 22 ranged between 33.0—144.5 ind./L in the three treatments and were in the order of NS > P + S > N + S. There was a rapid density decline to < 1 ind./L in N + S treatments in early September. In the P + S and NS treatment, the densities decreased slowly and were 15.1 and 21.5 ind./L respectively at the end of experiment. In the S treatment, the density showed one peak in mid-July and declined sharply with average density only 5.2 ind./L (0.5—9.5 ind./L) afterwards.

Generally, the density of *D. brachyurum* showed a marked increase coinciding with the rapid density decline of *M. micrura*. In the NS treatment, it decreased from late July to early August, and then remained at a lower level (3.0-80.0 ind./L). The sharp density decline in the N + S treatment occurred in late August and remained very low in September(0.1—3.3 ind./L). In the other two treatments, a low density remained during the course of the bloom. The

average density in the P + S treatment was higher in September(48.6 ind./L) than in August(30.9 ind./L) when *Microcystis bloom* began to decrease.

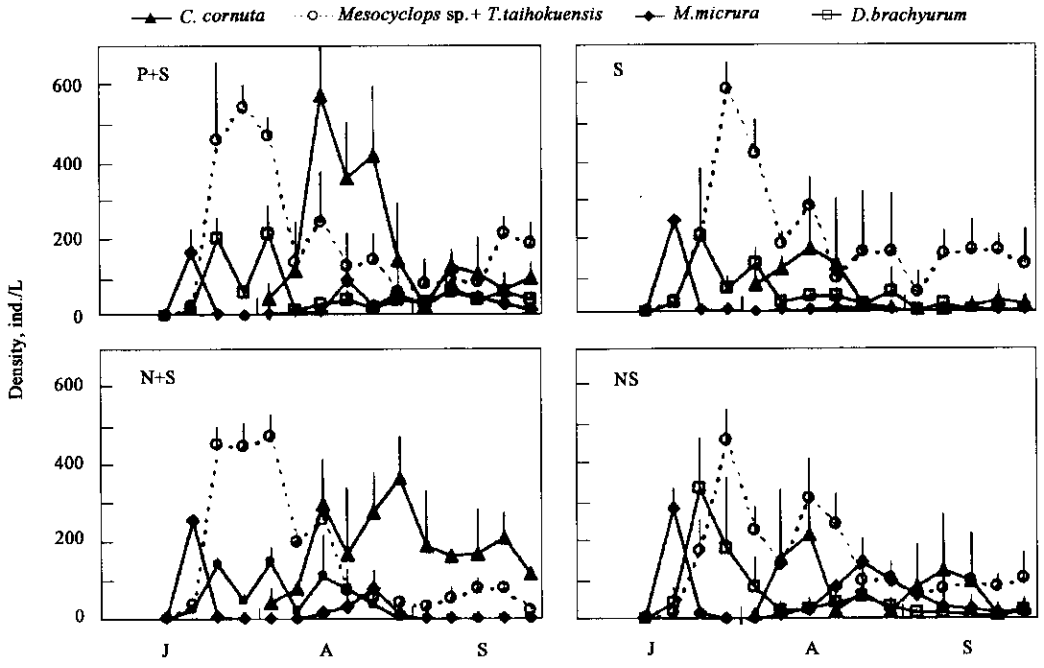

Fig.3 Density dynamics of *Moina micrura*, *Ceriodaphnia cornuta*, *Diaphanosom brachyurum*, *Mesocyclops* sp. and *Thermocyclops taihokuensis* in the enclosures during the experiment; J: July; A: August; S: September

C. cornuta appeared in August. Its population enhancement was marked in all the treatments in early August, especially in the P + S and N + S treatment with the maximum density of 569 and 296 ind./L, respectively. In the treatments except the N + S treatment, the density declined since late August, with smaller peak in the P + S and NS treatments (maximum density 132.2 and 122.4 ind./L, respectively) in mid-September. In the N + S treatment, the density reached another peak (360.5 ind./L) in late August, then declined and kept a relatively density stable (113.5—205.5 ind./L) in September.

Mesocyclops sp. and *T. taihokuensis* reached their density peak in late July and then began to decrease with a low density level after mid August. Fig. 4 shows the correlation between the predaceous cyclopoids and the herbivorous cladocerans *M. micrura* during the pre-bloom period. Pooled data from all enclosures showed that the correlation between the density of *M. micrura* and two cyclopoids were significantly negative during July 18 - August 2(*M. notius*: $r = -0.9323$, $n = 16$, $P < 0.01$; *T. taihokuensis*: $r = -0.8446$, $n = 16$, $P < 0.01$) but not during the bloom period. No significant correlation in densities was found between cyclopoids and another two cladocerans during the pre-bloom and bloom periods.

Leptodora kindti only appeared in the S treatment from August 22 until the end of experiment with a maximum density of 5.5 ind./L on September 21 (Fig.5). None was found in the samples on September 17. Its mean length ranged between 1.73—4.38 mm.

ANOVA analysis showed that there was no difference between the four treatments in densities of *D. brachyurum* ($F = 1.06$, $P = 0.3688$) and the predaceous *Mesocyclops* sp. and *T. taihokuensis* ($F = 1.44$, $P = 0.2390$), but significant difference in densities of *M. micrura* and *C.*

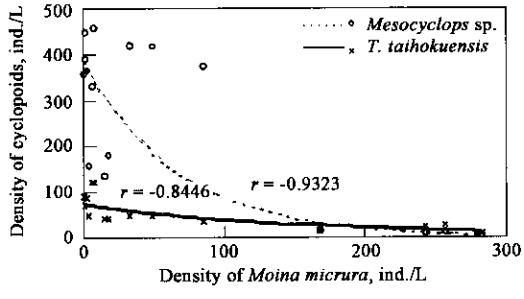

Fig.4 Correlations between the mean densities of the predaceous cyclopoids and the herbivorous cladocerans during the pre-bloom period (from July 18 to August 2, $n = 16$)

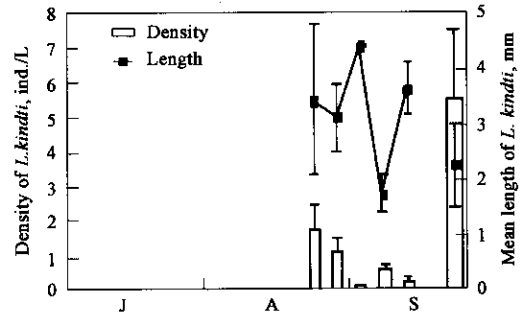

Fig.5 Density and mean length of *Leptodora kindti* from August 22 to the end of experiment; J: July; A: August; S: September

cornuta ($F = 7.59$, $P < 0.001$). From August 22 to the end of the experiment, the mean densities of *M. micrura* and *C. cornuta* were lower in the S treatments(5.2 and 14.8 ind./L) than in the other treatments (13.5—57.4 and 60.6—208.6 ind./L). The mean density of *D. brachyurum* was 15.7 ind./L. Its densities in the NS(21.4 ind./L) and P + S(43.7 ind./L) treatments were higher than in the N + S

treatment(5.7 ind./L).

2.3 Relation between crustacean plankton and phytoplankton biomass

The proportion of cladocerans (*M. micrura*, *D. brachyurum* and *C. cornuta*) in total curstaceans changed greatly with the variation of the *Microcystis* biomass during the experiment(Fig.6). Generally, the proportion was higher at the beginning of the experiment, and declined sharply before the *Microcystis* bloom. With the increase of *Microcystis* in total phytoplankton, the proportion of cladocerans went beyond the copepod gradually. In the N + S treatment, the proportion of cladoceran was above 50% from August 12 to the end and in the P + S and NS treatments, the value was above or near 50% from August 7 to September 11, and then declined to less than 50%. On the contrary, the proportion of cladoceran in the S treatment was almost always below 50% during the *Microcystis* bloom.

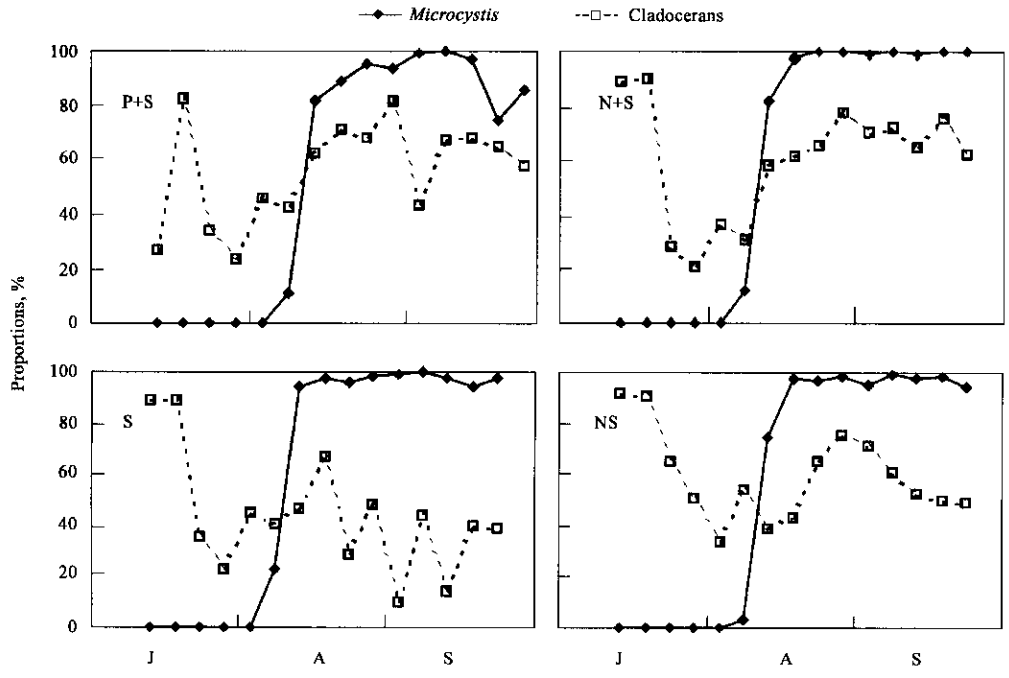

Fig.6 Changes in density proportion of cladoceran in total crustaceans and changes in biomass proportion of *Microcystis* in total phytoplankton during the experiment. Nauplii were excluded from the total crustacean density in order to show the relative density of cyclopoids in capable of predation

During the bloom period, there was a significant positive correlation between the biomass of other phytoplankton and the densities of *C. cornuta*, *D. brachyurum* and two cyclopoids, but no correlation in *M. micrura*. Significant negative correlations were found between the biomass of *Microcystis* and the biomass of crustaceans, and the densities of *M. micrura* and copepods.

2.4 Impact of *Microcystis* blooms on brood size of dominant cladocerans

Before the *Microcystis* bloom, mean brood sizes per egg-bearing female of *M. micrura*, *D. brachyurum*, *Mesocyclops* sp. and *T. taihokuensis* were 8.2, 3.3, 50.0 and 37.0, respectively. However, it declined respectively to 3.1, 2.0, 35.0 and 20.7 during the bloom period. There was significant difference (*M. micrura*: $P < 0.01$; other three: $P < 0.05$) between the two periods.

3 Discussion

In the present study, *Mesocyclops* sp., *T. taihokuensis* and *L. kindti* were the main predators of the cladocerans. The significant negative relationship between cyclopoids (*Mesocyclops* sp. and *T. taihokuensis*) and *M. micrura* before the *Microcystis* bloom suggests that the density declines in July were probably caused by the predation of the cyclopoids. Yang (Yang, 1998) also found a negative relationship between the *Mesocyclops* sp. and *M. micrura* and *D. brachyurum*. Just before the *Microcystis* bloom, an extremely high-density peak of *C. cornuta* appeared. However, the density peak of the two predaceous cyclopoids did not follow again. Laboratory experiment showed that *Mesocyclops* sp. was more favor in selecting *M. micrura* as food when mixed *Daphnia carinata* or *Ceriodaphnia cornuta* (Chen F. Z., unpublished data). Although there was no significant correlation between the densities of the three cladocerans and the two cyclopoids during the *Microcystis* bloom, it was interesting that significant correlation ($r = -0.3903$, $n = 48$, $p < 0.01$) was shown between the densities of *M. micrura* and *Mesocyclops* sp. when the data for the biomass of *Microcystis* > 50 mg/L were detected. It accorded with the relation between *M. micrura* and *Mesocyclops* sp. under colonial *Microcystis* in laboratory experiment (Chen, 2004). So it appears that the marked density declines of *M. micrura* in the P + S, N + S and NS treatments in August could not completely be attributed to the predation by the cyclopoids. Other reasons could result in the low density of *M. micrura* during the period under the biomass of *Microcystis* > 50 mg/L and of *D. brachyurum* and *C. cornuta* during the bloom period. The negative correlation between the densities of cyclopoids and the biomass of *Microcystis* suggests that the pre-predator relationship between the cyclopoids and the cladocerans becomes weakened. Chen (Chen, 2004) found the predation ability of *Mesocyclops* sp.

was inhibited by high concentration of colonial *Microcystis* spp. For *Mesocyclops* and *Thermocyclops*, if only feed on algae, their brood sizes were very small in comparison to the animal food (Kumar, 1999). Brood sizes of two cyclopoids were significantly lower during the bloom period than during the pre-bloom period in the present study. This suggests that cyclopoids could not get enough animal food for reproduction although the biomass of cladocerans was higher than the one of cyclopoids during the bloom period in the enclosures except for the S treatment. Hanazato (Hanazato, 1991) and Kim (Kim, 2001) found similar phenomena during the *Microcystis* bloom. The possible reason was that dense *Microcystis* bloom prevented cyclopoids from predating on animal food.

L. kindti only occurred in the S treatment in late August. Because cladocerans are the main food items for *L. kindti* (Branstrator, 1991), the rough estimation as the method of Xie (Xie, 2000) indicated that the ration of the daily food consumption by *L. kindti* to the cladocerans abundance was relatively high (2%—39%). The low densities of the three cladocerans in late August and September mainly attributed to the selective predation by *L. kindti*, which resulted in the biomass of cladocerans less than that of copepods only in the S treatment. In spite of relatively higher biomass of *Microcystis*, it appears that the blooms could not influence the predation of *L. kindti* on its prey.

The brood sizes of *M. micrura* and *D. brachyurum* showed significant decrease during the *Microcystis* bloom, which was more marked for *M. micrura* than for *D. brachyurum*. The brood size of *M. micrura* in the present study corresponded with a low food level (Amarasinghe, 1997), indicating that the low population of *M. micrura* under the high biomass of *Microcystis* (> 50 mg/L) was probably due to low food availability during the *Microcystis* bloom. Three mechanisms might be involved.

3.1 Interference by large-sized phytoplankton

In the P + S, N + S and NS treatments, large-sized phytoplankton (> 18 μm) became dominant with the development of *Microcystis* bloom. Laboratory experiments showed that *M. micrura* had low filtration rates and low growth and reproduction rate when fed on edible-sized *Microcystis* particles (Jarvis, 1987; Hanazato, 1987) or even with the mixture algae including *Microcystis* (Ferrão-Filho, 2000). However, field studies show different results: *M. micrura* coexisted well with *Microcystis* blooms in some lakes (Ferrão-Filho, 2000). It seems that *M. micrura* has some selective mechanism for edible food in the field. In the present study, the density of *M. micrura* declined with the biomass enhancement of *Microcystis* according to the exponential decrease, especially in the N + S treatment where the density of *M. micrura* declined to < 1 ind./L when the biomass of *Microcystis* was very high (> 50 mg/L). Thus, it seems to partly attribute the density decline of *M. micrura* during the bloom period to the filtering inhibition by *Microcystis*.

3.2 Decline in quantity of other edible algae

In many eutrophic waterbodies, although there is high primary production during the warm seasons, suitable food for cladoderans may be relatively scarce because of the predominance of large-sized phytoplankton (e. g., Xie, 1998). In the present study, there was no correlation between the biomass of other phytoplankton and the density of *M. micrura* during the bloom period. Thus, our analysis of phytoplankton provides no evidence that the low density of *M. micrura* during the bloom was due to a scarcity of alternative food. In some lakes, the decomposing *Microcystis* could become the food resource for *M. micrura* during the *Microcystis* bloom (Hanazato, 1987), but this was not the case in our study. We did not measure the concentration of decomposed *Microcystis*. Because neonates of *M. micrura* could not completely develop to adult if only feeding decomposed *Microcystis* (Chen, 2003), *M. micrura* was still in the condition of lack of food.

3.3 Interspecific competition for food

The three cladocerans may compete for limited food resources. However, *D. brachyurum* remained at lower density in August and September and the density of *C. cornuta* was also low in September. During the course of *Microcystis* bloom, two potential competitors, the rotifers and nauplii, also decreased in abundance (Liu, 2002). Therefore, interspecific competition does not seem to cause the rapid decline of *M. micrura* in late August. It is reported that *D. brachyurum* consumes very little colonial *M. aeruginosa*, but its feeding on *Chlamydomonas reinhardi* is little inhibited by colonial *M. aeruginosa* (Fulton, 1987). The positive correlation between this species and the biomass of other phytoplankton suggests that low food availability might also be the reason for the low density during the *Microcystis* blooms as indicated by the lower brood size.

C. cornuta is less sensitive to *Microcystis* and exists in the lake covered with the *Microcystis* bloom (Nandini, 2000; Ferrão-Filho, 2000). It is suggested in the present study that low food availability might also be the reason for the low density during the *Microcystis* blooms through the positive correlation between this species and the biomass of other phytoplankton. Laboratory experiment also identified the positive correlation between the population growth rate of *C. cornuta* and concentration of *Scenedesmus obliquus* (Chen, 2003).

In addition to the influence of low food quantity, fatty acid deficiencies in *Microcystis* can also affect the development and reproduction of cladocerans (Von Elert, 2001). In the present study, the smaller particles of *Microcystis* were probably ingested by cladocerans. The content of polyunsatutated fatty acid (PUFA) in algae could directly impact the abundance of cladocerans (Müller-Navarra, 1995). Cao (Cao, 1997) found that content of PUFA (especial ω3PUFA and ω6PUFA) in *Microcystis* was very low. Phytoplankton PUFA content was also significantly correlated with herbivorous zooplankton production (Brett, 1997). Beside the PUFA, lack of other lipid (e.g. sterol) in *Microcystis* would limit the growth of cladoceran (Von Elert, 2001). So for the cladocerans in the present study, lack of the above element would be possible to impact their abundance.

In conclusion, in the pre-bloom period of the experiment, the dynamics of *M. micrura* seemed to be mainly affected by the predaceous cyclopoids. With the development of *Microcystis* blooms, such interaction was weakened, especially when the biomass of *Microcystis* was great. The density decline of *M. micrura* may have been

caused by both predation and *Microcystis* inhibition. The low food availability of other edible phytoplankton during the blooms led to the low density of both *C. cornuta* and *D. brachyurum*. It appears that dense *Microcystis* blooms exert strong negative effects on the herbivorous cladocerans and the predaceous cyclopoids.

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