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The Rotifer Assemblage in a Shallow, Eutrophic Chinese Lake and Its Relationships with Cyanobacterial Blooms and Crustacean Zooplankton

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ABSTRACT

Rotifer assemblage in the subtropical eutrophic Lake Chaohu was investigated monthly from September 2002 to August 2003. Forty-nine species belonging to 18 genera and 14 families were recorded. The highest densities of rotifer were observed during summer when there were heavy cyanobacterial blooms. There was a significant positive correlation between total rotifer density and the biomass of cyanobacteria. However, no correlations were found between the densities of rotifer and crustacean zooplankton, possibly owing to the paucity of large-bodied planktonic crustaceans. It is likely that the occurrence of cyanobacterial blooms not only caused the shift of dominant crustacean zooplankton from large species to smaller ones but also weakened the negative interaction between crustaceans and rotifers.

INTRODUCTION

Lake Chaohu (770 km^2 in surface area), located in the central of Anhui Province, is one of the five largest freshwater lakes in China. The lake is extensively used as water sources for drinking and irrigation and as a fishery. In the recent decades, eutrophication of the lake has taken place as indicated by the regular outbreak of heavy cyanobacterial blooms over the whole lake, resulting in significantly negative ecological, healthy, social, and economic effects (Jin et al. 1995). So far, most concerns have been on the aspect of chemistry (see Xu et al. 2003 and the references there), but little is known about the changes of other components (i.e., plankton assemblages) after eutrophication of the lake.

Rotifera is an important component of freshwater zooplankton and is not only important food for many fishes but also used as an indicator of water quality (Sládeček 1983). However, there has been very limited information on rotifers in Lake Chaohu. Investigations in 1981 indicated the presence of 22 species of rotifers with an annual mean density 17.52 ind./L (Fisheries Management Committee of Lake Chaohu 1981). The relationship between phytoplankton and zooplankton is rather complex. It is known that cyanobacteria are generally less detrimental to rotifers and small cladocerans than to large cladocerans. There are several possible hypotheses for this. Firstly, large colonial or filamentous cyanobacteria may be too large for rotifers to ingest, and hence, the inhibitory effect of *Microcystis aeruginosa* endotoxin could be lessened (Gilbert 1990, Sartonov 1995). Secondly, in nature other potentially nutritious food sources are closely associated with *M. aeruginosa* colonies, including bacteria, protozoans (Paerl 1984b), and eukaryotic algae (Kilham et al. 1986) which can be consumed by rotifers. Thirdly, some species of rotifer (e.g., *Brachionus calyciflorus*, *B. rubens*) can utilize cyanobacteria as a supplementary food source (Fulton and Parel 1987a, Rothhaupt 1991). However, until now, there has been little field evidence to support this. The purposes of this work were to describe the species composition and seasonal dynamics of the rotifer assemblages in Lake Chaohu and to expose the relationships between rotifer abundance and cyanobacterial biomass and crustacean zooplankton density.

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MATERIALS AND METHODS

Lake Chaohu was sampled monthly from September 2002 to August 2003 at nine locations, four of which were located in the western and more eutrophic region of the lake (Sites I-IV). Sites V-IX were in the eastern area. Each water sample was a mixture of two sub-samples — one from 0.5 m below the surface and one from 0.5 m above the bottom.

Water temperature was recorded by a WMY-01 digital thermometer in the field. Dissolved oxygen (DO) and pH were determined with an Orion 810 dissolved oxygen meter and PHB-4PH meter, respectively. Conductivity and transparency were measured by DDB-303A meter and a Secchi disk.

Orthophosphate (PO_4-P) was analyzed by the ammonium molybdate method. Total phosphorus (TP) and total dissolved phosphorus (TDP) were measured by colorimetry after digestion with H_2SO_4 (Ebina et al. 1983). Total nitrogen (TN) and total dissolved nitrogen (TDN) were determined by the Kjeldahl method. Nitrate (NO_3-N) was analyzed using the automated Korolev/cadmium reduction method. Ammonium (NH_4-N) was determined by the Nessler method, and nitrite (NO_2-N) by the α-naphthylamine method (Apha et al. 1992).

To count rotifers, 1 L of water was fixed with 5% formalin and was concentrated to 30 ml after sedimentation for 48 hours. Sub-samples were counted under 100× magnification. Trophi were isolated, whenever necessary, by dissolving the soft tissue with 5% NaOH (Koste 1978). Identification was according to Koste (1978). For phytoplankton estimation, 1 L of water was preserved with 1% acidified Lugol's iodine solution and concentrated to 30 ml after sedimention for 48 hours. Sub-samples were counted under 400× magnification. Taxonomic identification was according to Hu et al. (1979), and biomass was estimated from approximate geometric volumes of each taxon. Meanwhile, 15 L of water were filtered through a 60 μm plankton net to collect crustaceans, which were identified according to Chiang and Du (1979) and Sheng (1979) and counted under a magnification of 63×.

The relationships between rotifer abundance and cyanobacterial biomass and crustacean zooplankton density were evaluated by using correlation analysis.

Table 1. Annual means and ranges of physical and chemical parameters in Lake Chaohu during the study period.

Parameter	Mean	Range
Temperature (°C)	17.02	4.1-27.32
Conductivity (μS/cm)	26.16	16.7-37.89
DO content (mg/L)	11.49	6.88-15.29
pH	7.81	5.81-9.12
Water depth (m)	3.11	2.18-5.51
Transparency (cm)	49.86	32.33-63.56
NH_4-N (mg/L)	0.527	0.155-0.980
NO_3-N (mg/L)	1.506	0.576-2.749
NO_2-N (mg/L)	0.029	0.0013-0.075
TN (mg/L)	3.23	1.58-4.48
TDN (mg/L)	2.55	1.03-4.09
PO_4-P (mg/L)	0.019	0.0033-0.0336
TP (mg/L)	0.11	0.079-0.142
TDP (mg/L)	0.031	0.0165-0.044

RESULTS

The lake ecosystem characteristically had a large variation in water level, low transparency, and abundant nutrients (Table 1). According to OECD (1982), Lake Chaohu is in a eutrophic-hypereutrophic state.

The phytoplankton community was dominated by *M. aeruginosa*, *Anabaena spiroides*, *Cyclotella* sp., *Pediastrum* sp., *Scenedesmus* sp. and *Chroomonas acuta*. Heavy cyanobacterial surface blooms appeared in the warm months, mainly consisting of *M. aeruginosa* and *A. spiroides*. The annual mean phytoplankton biomass was 9.9 mg/L. In the crustacean zooplankton community, the cladocerans *Bosmina* sp. and *Ceriodaphnia* sp. and the cyclopoid copepod *Limnoithona* sp. were dominant throughout the study period. The annual average density of crustaceans was as high as 114.8 ind./L.

Forty-nine rotifer species belonging to 18 genera and 14 families were recorded (Table 2). The family Brachionidae was the richest in species number (14) followed by Trichocercidae (12). Spatially, the maximum number of species was observed at Site III, and the minimum at Site VI. Seasonally, the species richness reached the maximum in summer (38) and the minimum in winter (19). In terms of annual mean density, the most dominant rotifers were *Cephalodella catellina* (19.0%), *Polyarthra vulgaris* (16.3%), *Conochilus unicornis* (11.3%), *B. calyciflorus* (6.8%), *Keratella quadrate* (6.7%), *K. cochlearis* (4.6%), *Trichoerca brachyura* (4.5%), and *Lecan hornemanni* (3.9%).

The highest densities of rotifer were observed during summer when there were heavy cyanobacterial blooms. The annual mean of the rotifer density was 453.6 ind./L. The highest density peak was in July when there were a large number of *C. catellina* (Fig. 1). The average densities of the more eutrophic Sites I-IV (662.3 ind./L) were relatively higher than those of the less eutrophic Sites V-IX (286.7 ind./L).

There were significant positive correlations between total rotifer density and total algal and cyanobacterial biomass. However, there was no significant correlation between rotifer abundance and the density of crustacean zooplankton (Fig. 2).

Table 2. Rotifer taxa recorded at nine sites of Lake Chaohu from September 2002 to August 2003.

	I	II	III	IV	V	VI	VII	VIII	IX
Asplanchnidae									
Asplanchna priodonta Gosse, 1850	+	+	+	+	+	+	+	+	+
Brachionidae									
Anuraeopsis fissa (Gosse, 1851)	+	+	+	+	-	-	-	-	-
A. navicula Rousselet, 1910	-	-	+	-	-	-	-	-	-
Brachionus angularis Gosse, 1851	+	+	+	+	+	-	+	-	+
B.calyciflorus Pallas, 1766	+	+	+	+	+	+	+	+	-
B. forficula Wierzejski, 1891	-	+	+	-	-	-	+	-	-
B. leydigi Cohn, 1862	+	+	-	-	-	-	-	-	-
B. patulus (Müller, 1786)	-	-	-	+	-	-	-	-	-
B. quadridentatus Hermann, 1783	-	+	-	-	-	-	-	-	-
B. urceolaris (Müller, 1773)	+	+	+	-	+	-	-	-	-
Keratella cochlearis (Gosse, 1851)	+	+	+	+	+	+	+	+	+
K. quadrata (Müller, 1786)	+	+	+	+	+	+	+	+	+
K. testudo (Ehrb., 1832)	-	-	-	-	-	+	-	-	+
K. valga (Ehrb., 1834)	+	+	+	+	+	+	+	+	+
Platyias quadricornis (Ehrb., 1832)	-	+	-	-	-	-	-	-	-
Colurellidae									
Lepadella ovalis (Müller, 1786)	-	-	+	-	-	-	-	-	-
L. patella (Müller, 1786)	+	+	+	+	+	-	-	-	-

(continued)

Table 2. Continued

	I	II	III	IV	V	VI	VII	VIII	IX
Euchlanidae									
Euchlanus dilatata Ehrb., 1832	+	+	+	+	+	+	+	+	+
Gastropodidae									
Ascomorpha ovalis (Bergendahl, 1892)	-	-	-	-	-	-	-	-	+
Lecanidae									
Lecane hornemanni (Ehrb., 1834)	+	+	+	+	+	+	+	+	+
L. luna (Müller, 1776)	-	-	+	-	-	-	-	-	-
L. sympoda Hauer, 1929	-	-	+	-	-	-	-	-	-
Notommatidae									
Cephalodella catellina (Müller, 1786)	+	+	+	+	-	+	-	+	+
Cephalodella sp.	-	+	+	+	-	+	-	-	+
Synchaetidae									
Polyarthra dolichoptera Idelson, 1925	+	+	+	+	+	+	+	+	+
P. euryptera (Wierzejski, 1893)	-	-	-	-	+	-	-	-	-
P. remata (Skorikov, 1896)	-	+	+	+	+	+	+	+	+
P. vulgaris Carlin, 1943	+	+	+	+	+	+	+	+	+
Synchaeta oblonga Ehrb.,1831	+	+	+	-	+	-	-	-	-
Trichocercidae									
Trichocerca brachyura (Gosse, 1851)	-	+	+	+	+	+	+	+	+
T. capucina (Wierzejski and Zacharias, 1893)	-	+	+	-	-	+	-	+	+
T. cylindrica (Imhof, 1891)	-	+	+	+	+	+	+	+	+
T. dixon-nuttalli Jennings, 1903	-	+	-	+	-	-	-	-	-
T. elongata (Gosse, 1886)	+	-	-	+	+	-	-	-	-
T. gracilis (Tessin, 1890)	+	-	-	-	-	-	+	+	+
T. pusilla (Lauterborn, 1898)	+	+	+	+	+	+	+	+	+
T. rousseleti (Voigt, 1902)	-	-	+	-	+	-	+	-	+
T. similis (Wierzejski, 1893)	+	-	+	-	-	+	-	+	+
T. stylata (Gosse, 1851)	-	-	-	-	+	-	+	+	+
T. weberi Jennings, 1903	-	-	+	-	-	-	-	-	-
Collothecidae									
Collotheca balatonis Varga, 1936	-	-	-	-	-	-	+	+	-
C.pelagia (Rousselet, 1893)	-	-	-	+	+	+	+	+	+
Conochilidae									
Conochilus unicornis Rousselet, 1892	+	+	+	+	+	+	+	+	+
Filiniidae									
Filinia cornuta (Weisse, 1847)	+	+	-	-	-	-	-	-	-
F. opoliensis (Zacharias, 1898)	-	+	+	-	-	-	-	-	-
F. passa (Müller, 1786)	-	-	-	+	-	-	-	-	-
F. terminalis (Plate, 1886)	+	+	+	+	+	-	+	+	-
Hexarthriidae									
Hexarthra mira (Hudson, 1871)	-	+	-	-	+	+	+	+	+
Testudinellidae									
Pompholyx sulcata (Hudson, 1885)	-	+	+	+	+	+	+	+	+

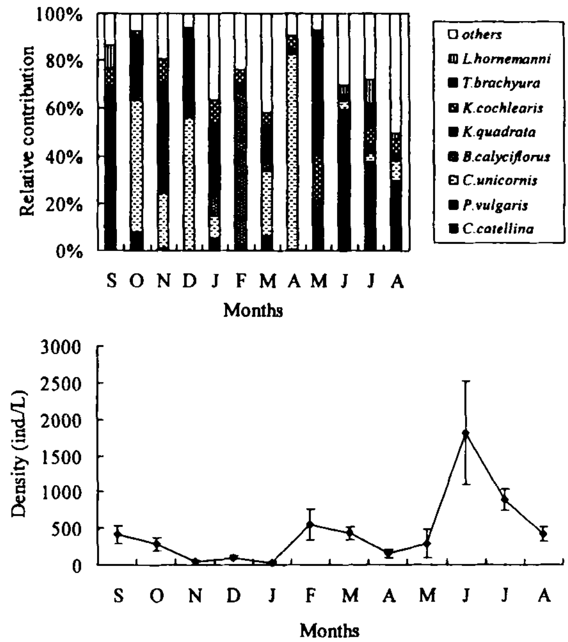

Figure 1. Temporal variations in total density of rotifers and in the relative percentage abundance of the dominant species of rotifers.

DISCUSSION

Rotifers respond quickly to environmental changes and are considered good indicators of water quality and trophic conditions because of their short generation time and fast population renewal (Sládeček 1983). Generally, the indicators of eutrophic lakes are *Brachionus* spp., *Anuraeopsis fissa*, *Pompholyx sulcata*, *P. complanata*, *T. cylindrica*, *T. pusilla*, *Filinia longiseta*, *K. cochlearis*, *K. quadrata*, and *P. euryptera* (Radwan 1976, Gannon and Stemberger 1978, Sládeček 1983, Hacerman 1998). In our study, eight of the above ten species were recorded in Lake Chaohu, among which three were dominant. Previous investigation indicated the presence of some oligotrophic species such as *Ploesoma hudsoni* and *Gastropus hyptopus*, a sub-dominant species in Lake Chaohu in the 1960s. However, at present, these rotifers have disappeared from the lake, indicating a significant increase in the trophic level of the lake water since the 1960s.

The present study indicated that there was a significantly positive correlation between total rotifer density and the biomass of cyanobacteria (i.e., both *C. catellina* and *K. cochlearis* reached maximum densities in summer when there were heavy cyanobacterial blooms). In an enclosure experiment, Liu et al. (2002) reported that *K. cochlearis* was less affected by *M. aeruginosa* blooms and that the *M. aeruginosa* blooms favored the development of *C. catellina* and *Proales* sp. In a laboratory experiment, Gilbert and Durand (1990) found that *Aphanizomenon flos-aquae* filaments had little effect on the ability of *K. cochlearis* to exploit edible food. It is suggested that these small-sized rotifers may be less susceptible to cyanotoxins (Gilbert 1990) and have relatively low food thresholds (Stemberger and Gilbert 1985, MacIsaac and Gilbert 1989, Kirk and Gilbert 1990).

Many studies have revealed the inverse abundance relationship between crustaceans and rotifers in natural environments (Gilbert 1985, 1988, 1989, Fussmann 1996). Most rotifers and crustaceans are primarily algivorous, with highly overlapping food niches, even though rotifers are much smaller in size; large cladocerans, especially *Daphnia* sp., can severely suppress rotifers through mechanical interference, through exploitative competition for food resources, or through both (Gilbert 1985, 1988, 1989, Fussmann 1996, Sarnelle 1997). However, no correlations were found between the densities of rotifer and crustacean zooplankton during our study. The possible mechanism for this may be due to the paucity of large-bodied planktonic crustaceans in the lake. The planktonic crustaceans were dominated by small-sized cladocerans (*Bosmina* sp., *Ceriodaphnia* sp.) and the cyclopoid copepod *Limnoithona* sp. Laboratory culture experiments have indicated that these small-sized crustaceans can coexist with rotifers (Infane and Riehl 1984, Gilbert 1988, Gilbert and MacIsaac 1989). It is likely that the occurrence of heavy cyanobacterial blooms has not only caused the shift of dominant crustacean zooplankton from larger species to smaller ones as indicated by numerous previous studies (Edmondson and Litt 1982, Infante and Riehl 1984, Fulton and Parel 1987a and 1988b, Gilbert 1990, Fulton and Jones 1991) but also weakened the negative interaction between crustaceans and rotifers.

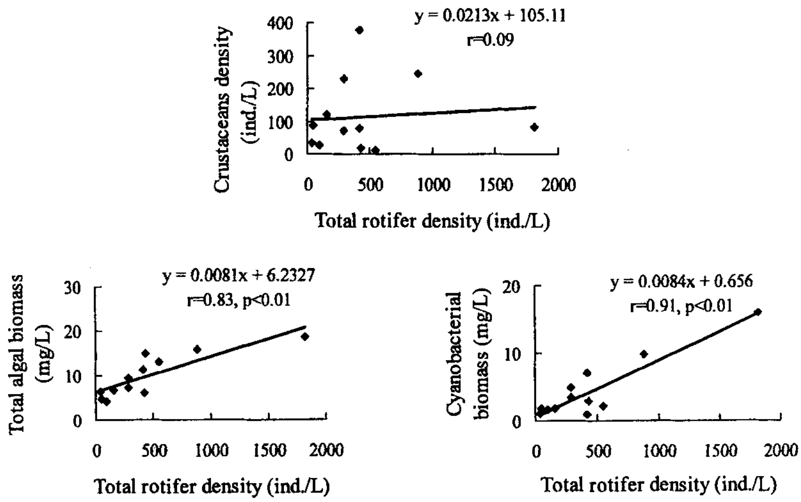

Figure 2. The relationships between total rotifer density and biomass of total algae and cyanobacteria as well as the crustaceans density.

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