Ecological characteristics of plankton and aquatic vegetation in Lake Qiluhu

Hu Mingming, Zhou Huaidong, Wang Yuchun, Wang Yingcai, Wang Zhen, Wu Weiju, Zhao Gaofeng, Cheng Yao and Liu Yongding

ABSTRACT

Investigations of the phytoplankton, zooplankton, zoobenthos and aquatic vegetation in Lake Qiluhu were carried out in February, 2009. Over the whole lake, 13 sampling sites were set up for the analysis of phytoplankton and zooplankton, and 22 profiles for the collection of macrophytes and zoobenthos. In the survey, 7 phyla, 65 algae species were identified. The average abundance of phytoplankton was 7.16×10^8 cells/L, and the dominant specie was *Limnothrix redekei*. No obvious surface accumulation of algae was detected. The concentration of Chlorophyll *a* ranged from 85 to 101 μg/L, and the average value was 93 μg/L. Nineteen species of zooplankton were observed, including 4 species of rotifers, 6 species of cladocerans and 9 species of copepods. Copepods were the dominant species, their abundance reaching 68%, whilst Cladocerans took second place with an abundance proportion of 28%. Six species of submerged vegetation were identified: *Potamogeton Pectinatus*, *Myriophyllum*, *Elodea Canadensis*, *Ceratophyllum demersum* and *Potamogeton crispus*. Amongst them, the dominant vegetation was *P. Pectinatus*, the biomass of which was up to 63% of the total biomass. Emerged macrophytes were cluster distributed across the whole lake, mainly consisting of *Scirpus tabernaemontani*, *phragmites communis* and *cane shoots*. Unfortunately, no living zoobenthos were found at the sites. The results indicated that, in Lake Qiluhu, the abundance of phytoplankton was maintained at a high level. The ecological function of submerged vegetation was gradually being lost because of its low standing crop and coverage, and the benthic animal habitat was severely damaged.

Key words | aquatic, Lake Qiluhu, phytoplankton, zooplankton

Hu Mingming
Zhou Huaidong
Wang Yuchun
Zhao Gaofeng
Department of Water Environment,
China Institute of Water Resources and Hydropower Research,
Beijing 100038,
China

Wang Yingcai
Yangtze Valley Water Environment Monitoring Center,
Wuhan 430010, Hubei Province,
China

Wang Zhen
Wu Weiju
Liu Yongding (corresponding author)
Institute of Hydrobiology,
Chinese Academy of Sciences, Wuhan 430072,
China
E-mail: *liuyd@ihb.ac.cn*

Cheng Yao
Hebei University of Engineering,
Handan 056038, Hebei Province,
China

INTRODUCTION

As some of the main organisms in the fresh water ecosystem, phytoplankton and zooplankton play an important role in the process of material recycling and energy conversion. As the primary producers of the water environment, the distribution and composition of the phytoplankton community are significant indicators reflecting the status of that water environment (Liu 1999; Qin *et al.* 2012). Changes of environmental conditions can also directly or indirectly affect the phytoplanktonal community structure (Lepistö *et al.* 2004). Zooplankton is the primary consumer and basic link in the food chain of the aquatic ecosystem. Changes in its quantities and species will affect the distribution and abundance of other aquatic organisms. It is well known that zooplankton and water quality are closely related, and the sensitivity and adaptability of different group to changes in the water environment is various (Gao *et al.* 2009). Aquatic vegetation also plays an important role in the aquatic ecosystem and is an important regulator in maintaining a lake's ecological balance (Ozimek *et al.* 1990; Engel 1998). Previous research has shown that there is a close link between aquatic vegetation and eutrophication or algal bloom (Zheng *et al.* 2007; He *et al.* 2008).

Lake Qiluhu is a eutrophic lake located in Yuxi, in the Yunnan Province of southwestern China. Situated on a plateau, this lake is also one of the nine largest fresh water lakes in Yunnan Province, with a surface area of 35.8 km^2, an average depth of 4 m, a maximum depth of 15 m and a total volume of about 1.5 million m^3. According to the result of an investigation in 1997 (Ma *et al.* 1999), its water quality was fifth class (the National Environmental quality standards for surface water GB3838-88). The features of dynamic change of some

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key pollutants (biochemical oxygen demand (BOD), total phosphorus (TP), total nitrogen (TN)) were also analyzed by means of correlation analysis and double factor variance analysis. As shown in the results, the key pollutants were evenly distributed. The results of a survey in 2009 showed that Lake Qiluhu was mesotrophic (Qin *et al.* 2010). But we know little about the distribution or composition of plankton and aquatic vegetation. In this study, the composition of phytoplankton, zooplankton, zoobenthos and aquatic vegetation were investigated in February, 2009, and the lake's ecological characteristics were analyzed. This study will facilitate comprehension of the ecological status and ecological characteristics of Lake Qiluhu, and also provide some basic information for planning decisions.

METHODS

Sampling

Field investigations were carried out in Lake Qiluhuin in February 2009. Across the whole lake, 13 sampling sites were set up for the analysis of phytoplankton, zooplankton, and the physical and chemical indicators of water, and 21 sites for the collection of macrophytes and zoobenthos (Figure 1). Water temperature, pH, concentration of dissolved oxygen and Secchi Depth (SD) were determined *in situ* with a YSI550A dissolved oxygen meter and a secchi disc. A 1 L water sample was used to analyze the concentrations of TN, TP, ammonia (NH_3-N), nitrate (NO_3-N) and chemical oxygen demand (COD_{Mn}) according to the standard laboratory methods (Chang *et al.* 2010).

Chl *a*, phytoplankton and zooplankton

A 0.5 L water sample was filtered through Whatman GF/C glass fibre filters for Chlorophyll *a* (Chl *a*) measurement. The pigments were extracted by the acetone method in the dark for 24 h at 4 °C. The absorbance of supernatant was measured at 630, 645, 663 and 750 nm, respectively, after being centrifuged at 8,000 rpm for 10 min. A 1 L water sample was fixed with Lugol's iodine solution immediately after sampling and concentrated to about 40 mL after 48 h sedimentation for phytoplankton enumeration (APHA 1992). The species of phytoplankton was identified according to Hu *et al.* (1980) and Yu *et al.* (2007). A 20 L water sample was filtered through a net (112 μm mesh size) and mixed with formaldehyde (10% final concentration) for zooplankton enumeration.

Aquatic vegetation and zoobenthos

Aquatic vegetation was investigated by a grass-cutting machine with an area of 0.168 m^2. Aquatic vegetation was collected stochastically 5–12 times at each station with vegetation, then identified and weighed. The relative abundance, frequentness, relative frequentness and dominance of submerged macrophytes were counted according to the following equations:

(1) relative abundance = the abundance of each species/the total abundance of the community;
(2) frequentness = the frequency of each species/the total frequency of the community;
(3) relative frequentness = the frequentness of each species/the total frequentness of the community;
(4) dominance = (relative abundance + relative frequentness)/2.

Zoobenthos were investigated using a Peterson grab (Baker *et al.* 1977). All the samples of sediment were collected three times, and washed immediately through a mesh net of 225 holes/cm^2. Samples were fixed with formaldehyde (5% final concentration) for zoobenthos enumeration.

RESULTS AND DISCUSSION

Physicochemical characteristics

The nutrient concentrations (TN, TP, NH_3-N, NO_3-N, COD_{Mn}) and water temperature are shown in Table 1. The

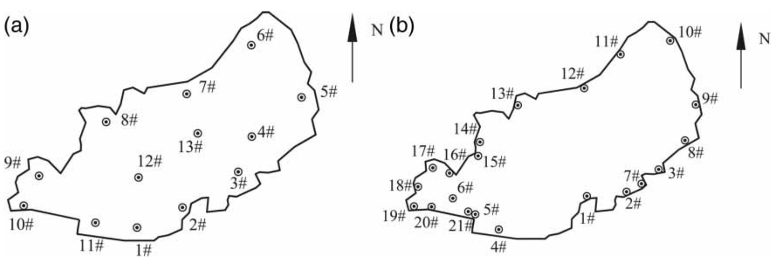

Figure 1 | Location of sampling sites for phytoplankton and zooplankton (a) and macrophytes (b) in Lake Qiluhu.

Table 1 | The characteristics of physicochemical factors in Lake Qiluhu

Sampling sites (Figure 1(a))	T (°C)	pH	DO (mg/L)	SD (cm)	TP (mg/L)	TN (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	COD_{Mn} (mg/L)	Chl a (mg/L)
1#	15.4	8.74	8.7	55	0.065	1.879	0.123	0.290	12.38	0.095
2#	15.3	8.86	8.65	51	0.041	2.738	0.203	0.208	13.21	0.096
3#	15.2	8.85	8.2	46	0.053	1.797	0.138	0.208	12.38	0.093
4#	15.5	8.87	8.33	55	0.049	1.752	0.951	0.290	15.29	0.094
5#	15.5	8.87	7.75	50	0.057	1.708	0.073	0.305	10.96	0.093
6#	15.8	8.8	7.35	42	0.065	1.797	0.217	0.305	19.63	0.101
7#	15.7	8.82	7.56	52	0.053	1.715	0.519	0.223	10.38	0.094
8#	15.7	8.87	7.78	51	0.045	1.603	0.250	0.186	10.08	0.085
9#	15.4	8.89	7.95	46	0.178	3.378	0.309	0.231	12.79	0.098
10#	15.1	8.83	7.69	52	0.045	1.685	0.282	0.178	10.71	0.086
11#	15.2	8.92	8.46	52	0.080	1.476	0.227	0.328	10.38	0.087
12#	15.7	8.93	8.13	55	0.053	1.663	0.187	0.193	10.92	0.087
13#	15.7	8.89	8.11	64	0.049	1.752	0.187	0.193	10.33	0.095

average temperature of the water was 15.5 °C, The highest concentration of TN was detected in sample 9# (3.378 mg/L) and the lowest in sample 11# (1.476 mg/L). The concentration of TP ranged from 0.041 to 0.178 mg/L, with an average value of 0.064 mg/L. The concentration of COD_{Mn} ranged from 10.08 to 15.29 mg/L.

Phytoplankton

In the present study a total of 65 phytoplankton species was identified belonging to seven phyla: *Cyanophyta, Chlorophyta, Bacillariophyta, Pyrrophyta, Chrysophyta, Euglenophyta and Chrysophyta*. *Chlorophyta* were the most diverse group, with *Cyanophyta* in second place. The dominant group was *Cyanophyta*, and *Chlorophyta* was the second. Therefore, Lake Qiluhu is a typical *Cyanophyta–Chlorophyta* pattern lake according to the community structure of phytoplankton.

The average abundance of phytoplankton was 7.16×10^8 cells/L obviously higher than that in March 2006–2008. The concentration of Chl *a* was lower in the north and centre compared to the other areas of the lake, ranging from 0.085 to 0.101 mg/L (Table 1). The highest concentration of Chl *a* was detected in the eastern part of the lake. However, there was no significant difference over the whole lake. Qin *et al.* (2012) reported that the concentration of Chl *a* in Lake Qiluhu ranged from 0.062–0.092 mg/L in January 2010, and the highest concentration was also detected in the eastern part of the Lake. This result was consistent with ours. Ma *et al.* (1999) reported that the key pollutants (TN, TP, BOD) were evenly distributed. As nitrogen and phosphorus are the main nutrition elements affecting the growth of phytoplankton, Ma *et al.*'s result may explain why there was no significant difference of Chl *a* distribution over the whole lake.

In the previous study, there were few results about the community structure of phytoplankton in Lake Qiluhu. According to the results of this survey and the information provided by the local environmental monitoring stations, *Cyanophyta* abundance has increased every year for the past 3 years (Figure 2). In this investigation, *Cyanophyta* represented more than 99% of the abundance of phytoplankton. The main dominant species were *Limnothrix redekei*, *Microcystis* sp., *Aphanizomenon* sp., *Oscillatoria Fragilaria Lyngbya* sp., *Ankistrodesmus* sp. and *Scenedesmus quadricauda*.

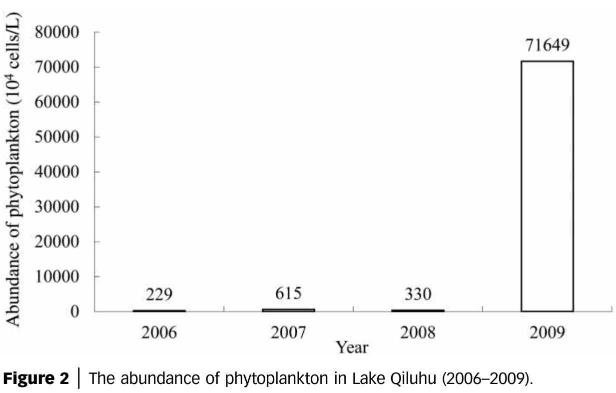

Figure 2 | The abundance of phytoplankton in Lake Qiluhu (2006–2009).

Zooplankton

In total, 19 species of zooplankton were observed in this investigation, consisting of: of four species of *rotifers* (*Asplanchna priodonala*, *Keratella valga*, *Trichocerca longiseta* and *Filinia longiseta*); six species of *Cladocerans* (*Chydorus sphaericus*, *Bosmina longirostris*, *Alona intermedia*, *Pleuroxus trigonellus*, *Camptocercus rectirostris* and *Daphnia longispina*); and nine species of copepods (*Macrocyclops distinctus*, *Macrocyclops albidus*, *Ectocyclops phaleratus*, *Sinodiaptomus sarsi*, *Mesocyclops leuckarti*, *Tropocyclops prasinus*, *Acanthocyclops viridis*, *Cyclops vicinus* and *Sinocalanus dorrii*).

Copepods were the dominant group, and their abundance proportion reached 68%. *Cladocerans* and *rotifers* took second and third place with abundance proportions of 28% and 4%, respectively (Figure 3). The abundance of zooplankton ranged from 0.56×10^4 cells/L to 6.29×10^4 cells/L (Figure 3). *Ectocyclops phaleratus* and *Tropocyclops prasinus* were the dominant species; their densities reached 8,784 and 7,238 cells/m^3, respectively. Previous studies had reported that the abundance of *Copepods* may exceed 1,000 cells/m^3 in a eutrophic environment; *Copepods* prefer living in eutrophic water bodies, and *Cladocerans* also have similar habits (Zheng *et al.* 2007). Thus, the community structure of zooplankton in Lake Qiluhu has the typical characteristics of a eutrophic ecosystem.

Aquatic vegetation

Emerged macrophytes were distributed in clusters across the whole lake, mainly consisting of *Scirpus tabernaemontani*, *Phragmites communis* and *Zizania latifolia*. These species were detected at sites 1#, 13#, 15#, 17#, 18# and 19#. The area of clustered distribution ranged from 10 to 1,000 m^2. The density of emerged macrophytes in site 1# was 39.58 kg/m^2, at sites 13# and 15# it was about 25 kg/m^2, and at sites 17#, 18# and 19# it was about 26.25 kg/m^2. The dominant species at site 1# were *Scirpus tabernaemontani* and cane shoots, at site 13# they were *Phragmites communis* and *Zizania latifolia*, and at site 15# *Scirpus tabernaemontani*. The dominant species of sites 17#, 18# and 19# were *Phragmites communis* and *Zizania latifolia.* This combined site is the most concentrated area of emerged macrophytes, and also the largest site of emerged macrophytes with a total area of approximately 2,500 m^2.

Six species of submerged macrophytes (*Potamogeton malaianus*, *Potamogeton pectinatus*, *Myriophyllum verticillatum*, *Elodea canadensis* Michx, *Ceratophyllum demersum* and *Potamogeton crispus*) were detected in this survey. The dominant species was *P. pectinatus*, representing 63% of the total abundance, and *P. malaianus* was second, representing 19% of the total abundance (Figure 4). Besides abundance, the relative abundance, frequentness, relative

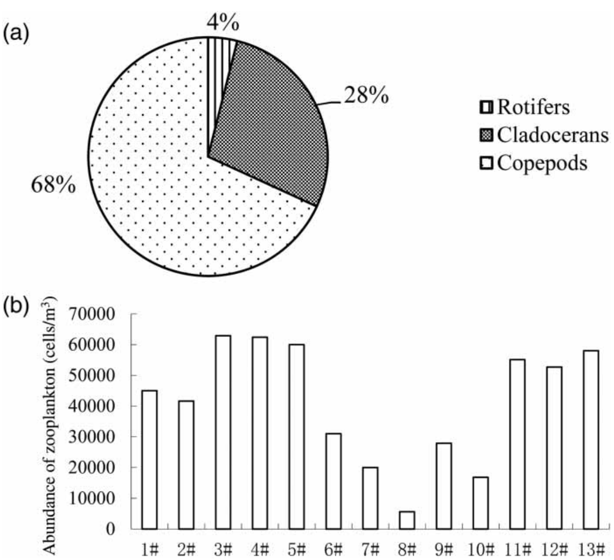

Figure 3 | The structure (species composition) of zooplankton populations (a) and the temporal variation of the zooplankton community (b) in Lake Qiluhu.

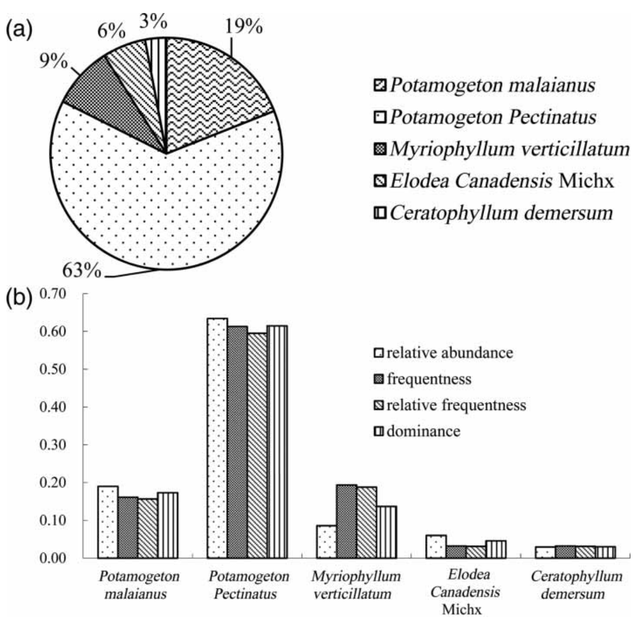

Figure 4 | The structure (species composition) (a), relative abundance, frequentness, relative frequentness and dominance of submerged macrophytes (b) in Lake Qiluhu.

frequentness and dominance of *P. pectinatus* was also significantly higher than other species (Figure 4).

The average density of submerged macrophytes in the whole lake was 0.16 kg/m^2. The density of the different regions is shown in Figure 5, where it can be seen that the density was generally low across the whole lake, with minimum values appearing in the west. One reason might be the widespread appearance of *E. crassipes* in recent years (Dong *et al.* 2011). The invasion of *E. crassipes* has led to the extinction of submerged macrophytes in competition. In this survey, *E. crassipes* still appeared at site 7# with an area of about 2,000 m^2. Another reason might be the Lake's low transparency. In this investigation, the average of transparency in Lake Qiluhu was 0.5 m. Submerged macrophytes greatly decrease as a result of low transparency. This speculation was confirmed by our survey, and a considerable part of the submerged macrophytes collected were dead. By analyzing the monitoring statistics from 1997 to 2001, Wang (2002) reported that the change of algae volume had a significant influence on water transparency. As observed in this survey, the low transparency may have some relation to the high abundance of phytoplankton.

It appears, therefore, that the mass extinction of submerged macrophytes in Lake Qiluhu might be caused by low transparency. The low abundance, low density and disappearance of submerged macrophytes would reduce their ecological functions, such as providing habitats for zoobenthos, stabilizing sediments and reducing the release of endogenous contaminants, as well as the absorption of nitrogen and phosphorus and other nutrients, purifying water, inhibiting the growth of algae and water bloom, improving transparency and so on. The loss of these ecological functions is not beneficial for the ecological restoration of Lake Qiluhu.

Zoobenthos

According to the information on zoobenthos for 2006 and 2007, provided by the local environmental monitoring stations, zoobenthos were only detected in one sampling sites during the survey of March 2007. No zoobenthos were detected in five other investigations. This is consistent with our detailed investigation carried out at the 21 macrophytes sites. No survival of zoobenthos was found. Detailed quantitative investigations were also carried out at the phytoplankton sites 1#, 3#, 5#, 7#, 9# and 13#, where again no survival of zoobenthos was found. The sediment is seriously polluted, and consequently the benthic animal habitat was severely damaged.

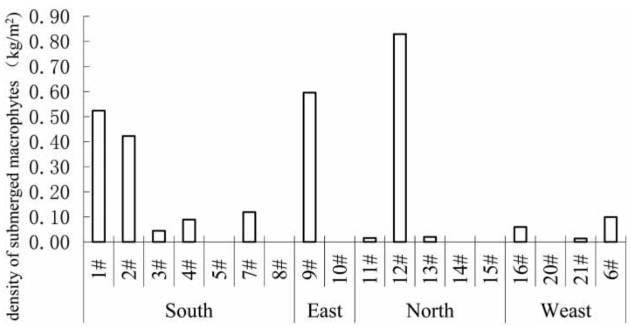

Figure 5 | The temporal variation of submerged macrophytes density in Lake Qiluhu.

CONCLUSIONS

The main results of this investigation of Lake Qiluhu were:

(1) A total of 65 phytoplankton species were identified belonging to seven phyla, with *Cyanophyta* representing more than 99% of the abundance of phytoplankton. The average abundance of phytoplankton was 7.16×10^8 cells/L, and the concentration of Chl *a* ranged from 0.085 to 0.101 mg/L.
(2) A total 19 species of zooplankton were observed in this investigation. Copepods were the dominant group and their abundance proportion reached 68%.
(3) Emerged macrophytes were distributed in clusters in the whole lake, and mainly consisting of *Scirpus tabernaemontani*, *Phragmites communis* and *cane shoots*. The average density of submerged macrophytes in the whole lake was 0.16 kg/m^2. No living zoobenthos was found in this survey.

This was the first comprehensive report about the distribution and composition of phytoplankton, zooplankton, zoobenthos and aquatic vegetation in Lake Qiluhu. The results indicated that, in Lake Qiluhu, the abundance of phytoplankton is maintained at a high level. The community structure of zooplankton was typically characteristic of a eutrophic ecosystem. The ecological function of the submerged vegetation was gradually lost because of its low standing crop and coverage. The sediment was seriously polluted, so that there was no life in the benthic area. Our results suggest that the structure of Lake Qiluhu's ecosystem has been seriously damaged. More comprehensive studies are needed to find: (i) the reason for the sudden change toward eutrophication; and (ii) which ecological restoration measures should be carried out to improve the ecological environment.

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