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Full Length Research Paper

Diatom distribution in the surficial sediments of Lake Fuxian, Yunnan Plateau, China

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Examination of surficial sediments at 14 sites shows minor, but consistent differences in the numbers and kinds of diatom assemblages in different regions of Lake Fuxian. Diatom assemblages in the surficial sediments at all sites were dominated by *Cyclotella ocellata*, *Cyclotella rhomboideo-elliptica*, *Stephanodiscus hantzschii*, *Fragilaria crotonensis Cyclostephanos dubius* and *Stephanodiscus minutulus Aulacoseira granulata Achnanthes minutissima*. A detrended correspondence analysis (DCA) defined two groups of sites generally corresponding to the two main parts of the Lake Fuxian basin. They reflected the two geomorphological regions of the lake basin, which basin in the northern were wider and deeper than that in the southern basin and the corresponding differences in hydrochemistry. It was characterized by lower diatom abundance in the southern part of the lake where there was main inflow water with high nutrient concentrations flows from the eutrophic Lake Xingyun. The total diatom abundance was 4.8 × 10^7 valves g^{-1} and 3.6 × 10^7 valves g^{-1} in northern and southern part of the lake, respectively. It was characterized by higher abundance of *S. minutulus* in the northern part of the lake (18.2%); there were some phosphorus post-mines which led to higher total phosphorus concentration than that in southern part. The most outstanding characteristic of diatom assemblages from Lake Fuxian lost the extreme degree of endemism with increasing trophic levels. Endemic diatoms species are not the most abundant component of assemblages at all sites. Small abundances of benthic diatoms were found in all samples. Although low abundances were present in sediments, the benthic diatom flora was very diverse. Species diversity was increased in Lake Fuxian, which may be related to natural influences of nutrient loads and local anthropogenic effects.

Key words: Lake Fuxian, diatom, distribution, surficial sediments, China.

INTRODUCTION

Lake Fuxian (24°17’-37'N, 102°49'-57'E, altitude 1721 m) is a subtropical deep lake with a volume of 189 × 10^8 m^3. It (212 km^2 in surface area) is located in the central Yunnan Province; it is a oligotrophic freshwater lake. It is the second deepest lake in China, with a maximum and average depth of 155 and 89.7 m, respectively (Nanjing Institute of Geography and Limnology, 1989). The average annual rainfall is 951.4 mm. In general, rainy season occurs from May to October, and dry season from November to April. The lake shows long water retention time of 167 years (Wang and Dou, 1998). The main inflow is Gehe Watergate through which high nutrient water flows from the eutrophic Xingyun Lake (Nanjing Institute of Geography and Limnology, 1990). Nutrient contents showed a steady increase during the past decades in Lake Fuxian (Li et al., 2003). There have been few studies on diatoms from Lake Fuxian in 1957 and 1989 when diatom assemblages of Lake Fuxian were dominated by *Cyclotella rhomboideo-elliptica* (Zhu and Chen, 1994). However, there was no study with increasing trophic levels in the recent 20 years.

In some lakes that have been subject to different degrees and histories of perturbation, there are large within system differences in response, as measured by qualitative and quantitative anges in sedimentary diatom assemblages

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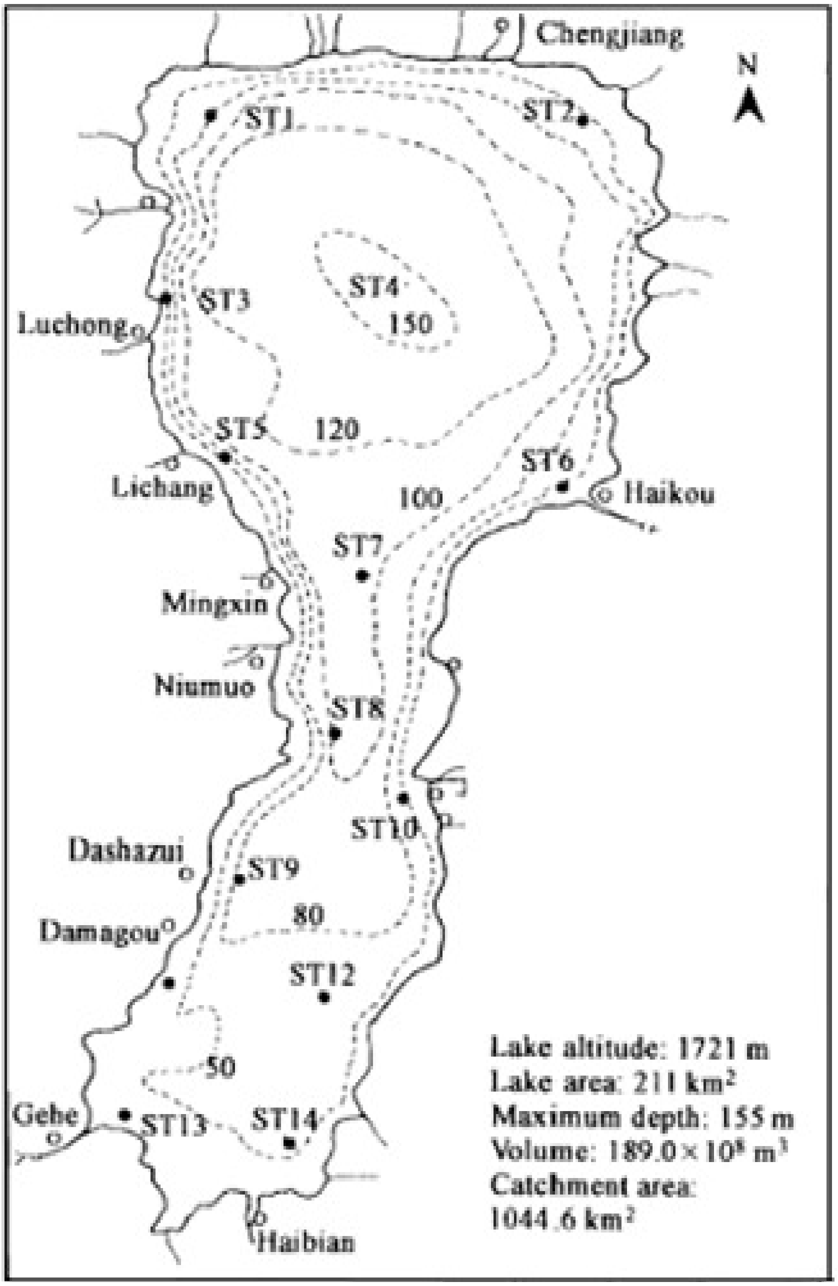

Figure 1. Outline map of Lake Fuxian, showing site locations.

(Stoermer et al., 1993, 1995). Chernyaeva (1970) showed considerable qualitative differences in diatom assemblages deposited at different depths and distances from shore in the northern basin of Lake Baikal. Previous studies have indicated regional differences in phytoplankton abundance (Deng and Xu, 1996; Zhang et al., 2005) in Lake Fuxian. However there have been only very limited information on diatom assemblage in the surficial sediments of the lake so far. The purposes of this research were to describe the present status of diatom assemblage through surficial sediment, and if modern diatom deposition has been grossly modified by anthropogenic effects.

MATERIALS AND METHODS

Three 20 cm sediment cores were collected each from of 14 sites in different depth of the lake using a Kajak gravity corer with a 60 mm-diameter coring tube on May 16, 2005 when it was sunny, and windless. These cores were extruded in 0.5 cm disks using a specially built core extrusion device and stored the top 0.5 cm sections of sediments in bags. The 14 sites are shown in Figure 1. Diatom samples (0.2 g) were treated using HCl and H_2O_2 (Battarbee, 1986). Four replicate sub-samples were potentially available from each sample. Diatom valves were enumerated on each of two prepared slides from each sample, resulting in two replicate abundance estimates. Diatoms were identified using oil immersion at 1000× magnification under the Olympus microscope (BX51).

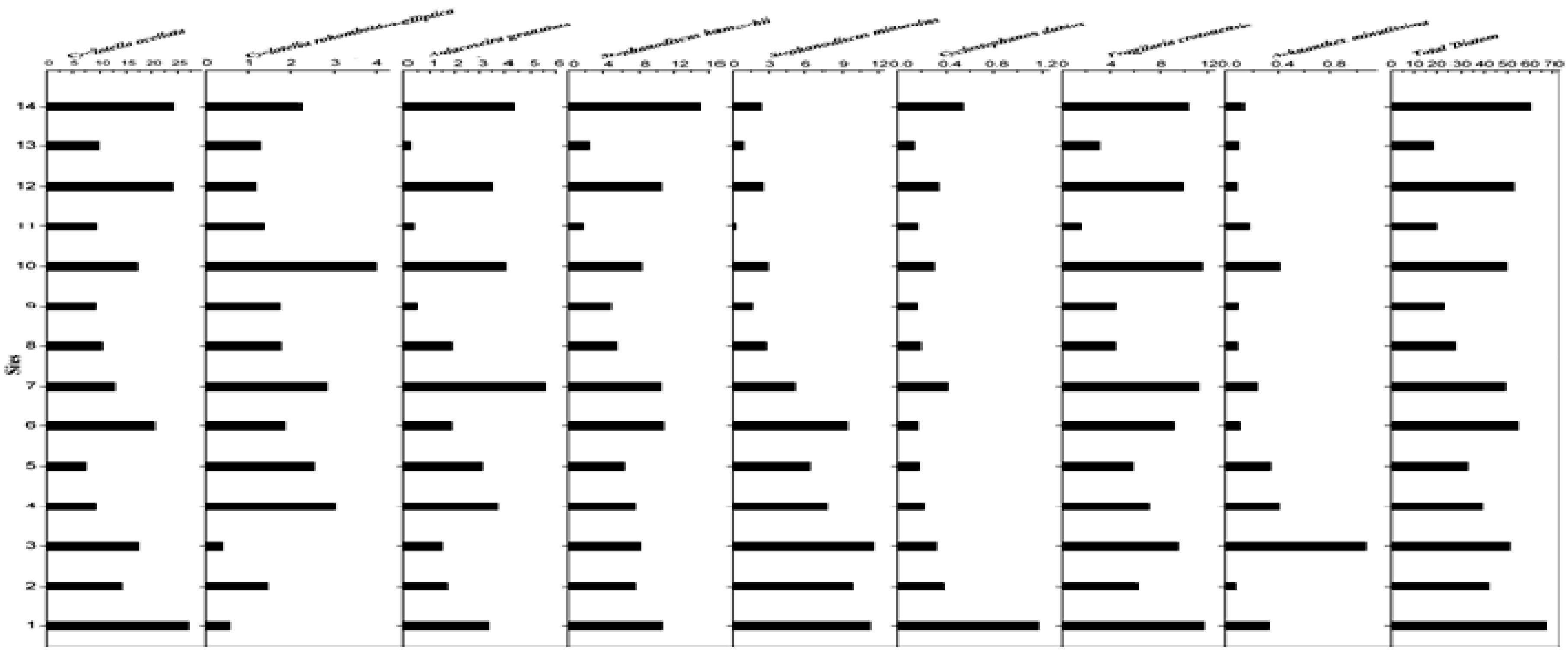

Figure 2. Abundance (x10^6 valves/g) of most common diatom taxa in surface sediment of stations sampled in Lake Fuxian.

Identification was performed using the manuals such as: Krammer and Lange-Bertalot (1988, 1991), Krammer (1997a, b, 2000, 2002, 2003), Rumrich et al. (2000), Zhu and Chen (2000), Lange-Bertalot (2001).

Ordination analyses of diatom assemblages were performed using CANOCO (Ter Braak and Smilauer, 1998). Detrended correspondence analysis (DCA) was used to elucidate main patterns in diatom assemblage and to assess similarity among different sites of Lake Fuxian in terms of assemblage composition.

RESULTS

Diatom assemblages in the surficial sediments at all sites were dominated by *C. ocellata*, *C. rhomboideo-elliptica*, *S. hantzschii*, *F. crotonensis, Cyclostephanos dubius* and *S. minutulus Aulacoseira granulate, Achnanthes minutissima*. The eight most abundant diatom taxa contributed on the average 96.9% (min 74.2%, max 99.3%) to the total diatom abundance in surficial samples. Relative frequency of *C. ocellata* was highest (52.9%) at site 13. Relative frequency of *S. hantzschii* ranges from 8.6 to 25% of assemblages. Relative frequency of *F. crotonensis* ranges from 7.8 to 27.8% of assemblages. Relative frequency of *S. minutulus* ranges from 1.1 to 23.5% of assemblages. Relative frequencies of *C. rhomboideo-elliptica*, *C. dubius*, *A. granulata*, *A. minutissima* were less than 11.4% of assemblages. Though the four species were minor, they were still found in all sites. The diatom abundances per gram dry weight sediment vary between 18.4 × 10^6 and 66.9 × 10^6 valves (Figure 2). Abundances per gram dry weight of the eight most abundant diatom taxa are shown in Figure 3.

The DCA diagram shows centroids of ecoregions in the ordination space of the first axes. The DCA diagram separates all sites along the first axis into two groups based on diatom species composition.

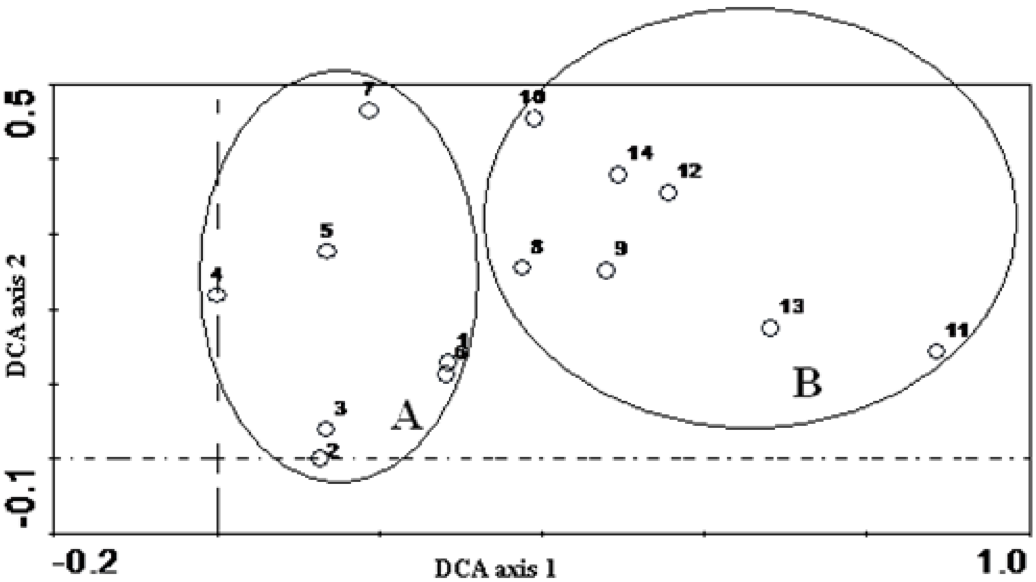

Figure 3. DCA diagram showing centroids of samples for each site. Group A consists of sites from the northern part of the Lake Fuxian basin, whereas group B contains sites from the southern part of the Lake Fuxian basin.

Group A in the left side of the DCA diagram consists of sites from the northern part of the Lake. Group B in the right side of the DCA diagram consists of sites from the southern part of the Lake (Figure 3). Diatom assemblages in group A were dominated by *C. ocellata*, *S. hantzschii*, *F. crotonensis* and *S. minutulus* (Table 1). Diatom assemblages were dominated by *C. ocellata*, *S. hantzschii* and *F. crotonensis* in group B (Table 1). Abundance of the total diatom was significantly higher in group A than group B (Figure 4). Abundance of the total diatom was 4.8×10^7 valves g^{-1} and 3.6×10^7 valves g^{-1} in northern and southern part of the lake, respectively (Figure 4). Comparisons between groups A and B for diatom assemblages showed difference (Table 1). In the northern part of the lake there were 38 taxa, and 63 taxa in the southern part of the lake.

DISCUSSION

In our study, two main groups of sites were identified. They reflected the two geomorphological regions of the lake basin, which basin in the northern were wider and deeper than that in the southern basin and corresponding differences in hydrochemistry (Zhang et al., 2005). In the northern sub-basin, average depth was 94 m, and chlorophyll a concentration was 2.5 μg L^{-1}, whereas in the southern basin, average depth was 68 m, and chlorophyll a concentration was 2.7 μg L^{-1}. This was reflected by differences in diatom assemblages with 38 taxa occurring in the north and 63 taxa in the south. This study indicates that local features of catchments can influence hydrochemistry and distribution pattern of the diatom assemblages. For example, in the southern part of the lake there was main inflow water with high nutrient concentrations flows from the eutrophic Lake Xingyun (Nanjing Institute of Geography and Limnology, 1990). Maximum of total nitrogen in the southern and northern part of the lake in one year was 0.38 and 0.31 mg L^{-1}, respectively (Zhang et al., 2005). It was characterized by lower diatom abundance and higher chlorophyll a concentration than those in the northern sub-basin. In the northern part of the lake there were some phosphorus post-mines which led to higher total phosphorus concentration than that in southern part (Feng et al., 2008). Maximum of total phosphorus in the southern and northern part of the lake in one year was 0.03 and 0.35 mg L^{-1}, respectively (Zhang et al., 2005). It was characterized by higher abundance of *S. minutulus* in north than those in south. *S. minutulus* needs a plentiful supply of phosphorus, and it had a relatively high total phosphorus optimum (Jacques et al., 2000).

The most outstanding characteristic of diatom assemblages from Lake Fuxian was losing the extreme degree of endemism. *C. rhomboideo-elliptica* (endemic to Lake Fuxian) was dominant in Lake Fuxian in 1957, 1983 and 1989 (Xing, 1984; Zhu and Chen, 1994). So far as the diatom flora was concerned, endemic plankton species, *C. rhomboideo-elliptica* was minor at all stations sampled. Significant quantities of apparently non-endemic diatom species completely dominated the flora at all stations sampled. Although these taxa (*S. hantzschii*, *C. dubius* and *S. minutulus*) resemble forms found in the lakes of Yangtze River (Qi, 1995; Yang et al., 2005). Considering the species involved, if we assume they are the same, or ecologically similar to forms from the lakes of Yangtze

Table1. Distribution and relative abundance of diatom taxa in north and south of Lake Fuxian.

Species	North	South	Species	North	South
Achnanthes clevei		+	*Geissleria aff. acceptata*		+
Achnanthes exiguua	+		*Gomphonema minutum*	+	
Achnanthes minutissima	0.7 (0.2-2.1)	0.5 (0.2-0.9)	*Gysigma acuminatum*	+	+
Achnanthes pusilla		+	*Hantzschia amphoixys*	+	
Amphora affinis		+	*Hantzschia elongta*		+
Amphora libyca	+	+	*Navicula angusta*		+
Amphora ovalis		+	*Navicula aunora*		+
Amphora pediculus	+	+	*Navicula cryptocephala*	+	+
Aneumastus rostratus	+	+	*Navicula cryptotenella*	+	+
Aulacoseira granulata	5.6 (2.7-11.4)	4.9 (1.2-8.2)	*Navicula densilineolata*		+
Caloneis bacillum		+	*Navicula hasta*	+	+
Cocconeis placeneta	+	+	*Navicula phylleptosoma*		+
Cocconeis sp.	+		*Navicula pygma*	+	+
Cyclostephanos dubius	0.8 (0.3-1.7)	0.7 (0.6-0.9)	*Navicula radioa*		+
Cyclotella menginana	+	+	*Navicula turris*		+
Cyclotella ocellata	32 (23.3-40.5)	42.5 (35-52.9)	*Navicula* sp1	+	+
C. rohomboideo-elliptica	4.0 (0.8-7.7)	6.0 (2.3-8.0)	*Navicula* sp2		+
Cymatopleura elliptica		+	*Navicula* sp3		+
C. elliptica var. *consticta*		+	*Navicula* sp4		+
Cymbella affinis	+		*Navicula* sp5		+
Cymbella ehrenbergi	+		*Navicula* sp6		+
Cymbella proxima	+		*Naviculadicta chilensis*		+
Cymbella sinensis	+	+	*Nitzschia amphioxys*		+
Diploneis ovalis	+		*Nitzschia angusta*	+	+
D. smithii var. *rhombica*	+		*Nitzschia frustula*		+
Diploneis sp.		+	*Nitzschia paleo*		+
Diploneis subovalis	+	+	*Nitzschia vermicularoides*	+	+
Encyonema minuta		+	*Planothidium minutissima*		+
Encyonema perminuta		+	*Rhopalodia gibba*		+
Encyonema silesiaca	+		*Sellaphora* sp.1		+
Epithema sorex	+		*Sellaphora* sp.2		+
Fragialria capunica	+	+	*Sellaphora* sp. 3		+
Fragilaria breviatum	+		*Stenopterobia densistriata*		+
Fragilaria crotonensis	20 (14.8-27.8)	17 (7.8-23.2)	*Stephanodiscus hantzschii*	18.3 (16-21.4)	17.8 (9-25)
Fragilaria leptostarum		+	*Stephanodiscus minutulus*	18.2 (11-23.5)	5.4 (1.1-10)
Fragilaria pinnuta		+	*Surirrella robusta*		+
Fragilaria tenera		+	*Surirrella subsalsa*		+
Gomphonema constrictum	+		*Synedra acus*	+	+

+, Relative abundance less than 0.5%.

River, their occurrence can be interpreted as indicative of a higher state of eutrophication in recent history of Lake Fuxian. Whether these results from the natural influences of nutrient loads from Lake Xingyun, or if it results from local anthropogenic effects, or some combination of the two, cannot be satisfactorily addressed on the basis of results from this study. Detailed comparisons of cores from the regions of interest will help to resolve the relative importance of anthropogenic effects.

Another striking characteristic of diatom assemblages in Lake Fuxian was increasing species diversity. In our study, we found 76 species in Lake Fuxian, while Zhu and Chen (1994) reported 18 and 49 taxa from Lake Fuxian in 1957 and 1989, respectively. The benthic diatom flora represented in our study was exceedingly diverse, but abundance of the benthic taxa was so low. Zhu and Chen (1994) showed that number of benthic diatom was 14 and 39 in 1957 and 1989, respectively. In our study, there were 68 benthic diatoms. It may be related to natural influences of nutrient loads and local anthropogenic effects.

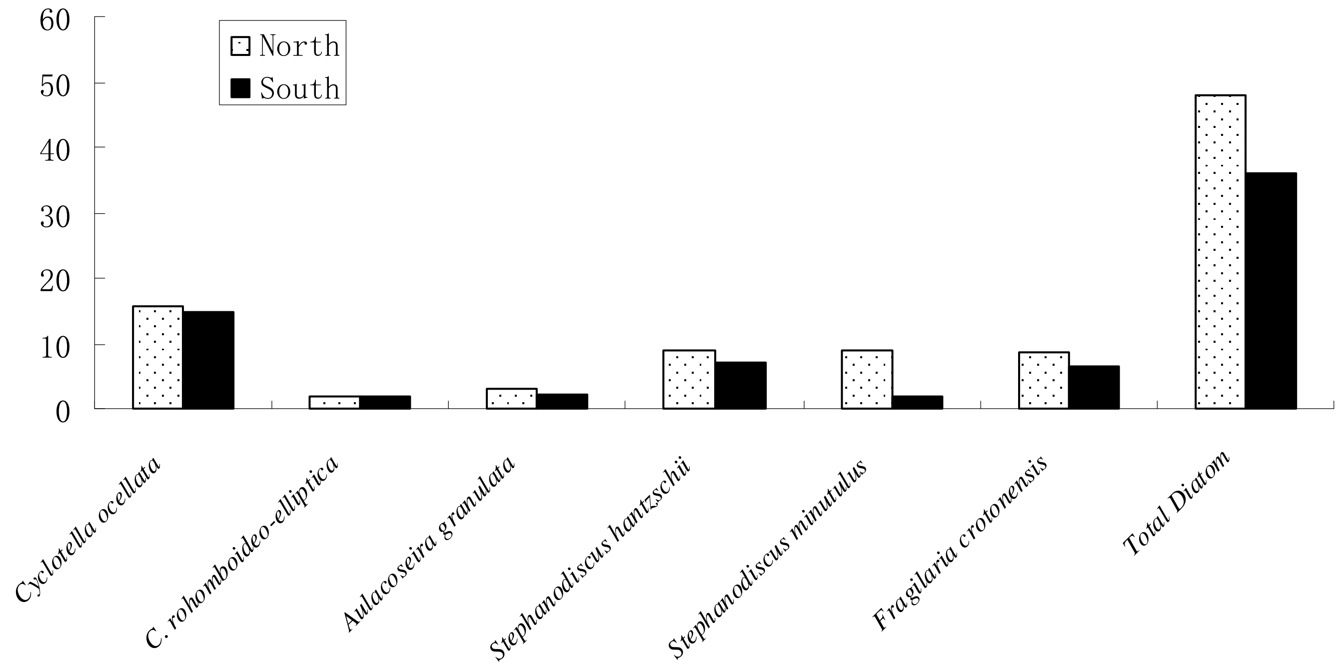

Figure 4. Abundance (x10^6 valves/g) of dominant species in north and south of Lake Fuxian.

In Lake Fuxian, total nitrogen and total phosphorus showed substantial increases from 1983 to 2005, and they range from 120 to 278µg/L, and 9 to 20.7 µg/L (Li et al., 2003; Zhang et al., 2005; Xiong, 2006). In addition, invasive fish were introduced to Lake Fuxian in 1960s, 1980s and 2000 (Yang et al., 1994; Xie and Chen, 2001; Qin, 2005). These factors were important disturbances to aquatic ecosystems, especially to oligotrophic plateau lakes that are generally considered to be very vulnerable ecosystems.

Our study thus indicates that there were measurable differences in abundance and composition of surface sediment diatom assemblages in different regions of modern Lake Fuxian. It should be understood that this difference was in sediment composition, which was a function of production, preservation, and dilution by allochthonous material. Ryves et al. (2003) have already shown that some frustule dissolution, such as *Synedra acus*, takes place in the water column, and further dissolution of more robust taxa occurs at surface sediment-water interface. Diatom dissolution was a significant process in Lake Fuxian occurring in the water column for some taxa, such as *S. acus* which was found in water column and was not found in the surface; preservation was not good at all stations. Although quantitative differences were small, some species appear to be restricted to certain parts of the lake. For example, *Hantzschia elongta Sellaphora* sp.1, *Navicula* sp.2, and *Navicula* sp.3 only appeared at site 11. It may be related to micro-ecological factors. Macro- and micro-ecological factors determine both the composition and numbers of taxa in a diatom sample (Flower, 2005). It is well known that the diatom diversity is affected by micro-ecological factors (Mann, 1999). There was a small island near site 11, which may have an effect on distribution of diatom. Most such taxa do not appear to be recent introductions (Lei et al., 1963; Nanjing Institute of Geography and Limnology, 1990; Zhu and Chen, 1994), although some, notably *S. hantzschii*, *C. dubius* and *S. minutulus*, were present in samples from lake of the middle and lower of the Yangtze River (Yang et al., 2005). We infer that occurrence of a number of these species in Lake Fuxian is a first response to environmental modification. This, in turn, implies that Lake Fuxian is a very sensitively poised system, that should be responsive to small changes in regional conditions as they affect nutrient loading to the lake and physical factors which affect distribution of external nutrient loads within the lake.

To understand the past environmental changes of Lake Fuxian, more comprehensive study of sedimentary diatom assemblages are needed.

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