Int. J. Environ. Res., 5(1):167-176, Winter 2011
ISSN: 1735-6865

Phytoplankton Community and the Relationship with the Environment in Nansi Lake, China

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Received 12 Oct. 2009; Revised 17 Jan. 2010; Accepted 25 Aug. 2010

ABSTRACT: This study was carried out from June to October 2008 in Nansi Lake. Based on the data collected from five sampling stations, phytoplankton taxonomic composition, abundance, temporal variations and spatial distribution were examined. About 94 species, including 48 species of Chlorophyta, 22 species of Bacillariophyta, and 1 water bloom causative species were identified. Average phytoplankton diversity index and evenness values were 1.59 and 0.58, respectively, revealing moderate biodiversity of phytoplankton biocoenosis. The phytoplankton abundance averaged 1.52×10^7 cells/L, and was much higher than previous investigation carried out in the same months in 1995. The species of Chlorophyta, Bacillariophyta dominated phytoplankton community. The main dominant species were *Scenedesmus dimorphus, Chlorella vulgaris, Synedra acus, Aulacoseira granulata, Merismopedia tenuissima* and *Monallantus brevicylindrus*. Concerning nutrient stoichiometry, it was suggested that the higher TN: TP ratio indicated potential P-limitation for phytoplankton growth in Nansi Lake. The environmental conditions of water quality and phytoplankton community composition indicated that Nansi Lake was eutrophic in summer.

Key words: Phytoplankton, Composition, abundance, Species, Environmental factors, Nansi Lake

INTRODUCTION

South-to-North Water Diversion Project in China is the largest project to meet the increasing demand for water resources in northern China and it is composed by three routes: the east, center and west route (Shan *et al*., 2007). The construction of the project is designed to solve the water shortage problem and sustain economic and social development in the water receiving areas. The fact is that water pollution along the east route is more serious than the other two routes (Wang *et al*., 2006a). Nansi Lake is located in the north of the Huai River Basin (34°27' ~35° 20 ' N, 116°34' ~117°21' E), and it drains an area of 3.17×10^4 km^2, belonging to 32 counties of Jiangsu, Shandong, Henan and Anhui Provinces. The total water area is 1266 km^2 with an average water depth of 1.5 m. As a long narrow lake running from north to south, Nansi Lake is separated into an upper lake and a lower lake by a dam and made up of four connected lakes named Nanyang, Dushan, Zhaoyang and Weishan. Nansi Lake contains abundant biodiversity, including numerous species of phytoplankton, zooplankton, plants, fish and birds, which are among the most important wetland resources in China (Zhao, 2005). At present, Nansi Lake is being utilized for flood control, irrigation, water supply, aquatic breeding, navigation and tourism, etc (Luo *et al*., 2005). Nutrient load from the drainage area has increased dramatically in the last two decades due to sewage discharge, industrial effluents and overuse of agriculture fertilizer (Chen *et al*., 2007). Being employed in the east route of the South-to-North Water Diversion Project for accommodating water storage and reversing the natural north-to-south flow direction by setting up pump stations, Nansi Lake is a potential drinking water source for the water diversion project (Wang *et al*., 2006b). To meet the required water quality, a series of measures have been taken by the local government to improve water quality in Nansi Lake.

In recent decades eutrophication has become one of the most serious environmental problems all over the world (Hein, 2006; Kuo *et al*., 2008; Lundberg *et al*., 2009). There will be an outbreak of water bloom when eutrophicated water bodies are exposed to appropriate water temperature, air temperature, flow rate, light and other external conditions (Sarkar & Chattopadhayay, 2003; Jickells, 2005; Heisler *et al*., 2008). The cyanotoxins (hepatotoxins and neurotox-

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ins) produced by bloom-forming cyanobacteria have been the cause of human and animal health hazards and even death (Sangolkar *et al.*, 2009). Lake eutrophication problems have received considerable attention in China, especially because they relate to the quality of drinking water. As the largest freshwater lake in northern China and the channel of South-to-North Water Diversion Project, the trophic state, phytoplankton species composition and abundance, and the possibility of the outbreak of water bloom have raised serious concern.

Investigations of phytoplankton are an important aspect in studying water quality and eutrophication of shallow lakes (Maria, 1993; Ptacnik *et al.*, 2008). Phytoplankton community composition responds sensitively to changes in water quality, making phytoplankton a useful biological quality parameter for lake monitoring (Reynolds, 1980). It would be better to analyze the basic information of the phytoplankton in order to improve water quality and prevent the occurrence of water bloom (O'Farrell *et al.*, 2002; Webber *et al.*, 2005). The spatial distributions of phytoplankton, species composition and biomass in Nansi Lake have not been studied intensively for the last 20 years. Liu *et al.* (1997) found that the species of Euglenophyta were dominant and Shuai *et al.* (2006) indicated that *Merismopdia glauca* was preponderant in phytoplankton community on May 2002. Both of these earlier studies sampled only once and not much attention has been paid on the spatial distribution and temporal variations.

The main objectives of this paper are to describe the phytoplankton community composition, species diversity and evenness, the spatial distribution and temporal variations in abundance, dominant species, and to characterize the relationship between phytoplankton and environmental factors in Nansi Lake.

MATERIALS & METHODS

This study was carried out from June to October 2008 and the samples were collected monthly from five sampling stations (S1, S2, S3, S4 and S5), which are the national control monitoring sections. Nansi Lake and the sampling stations are shown in Fig.1. Stations S1 and S2 were located in Nanyang Lake and Dushan Lake, both of which belong to the upper lake. Station S3 was located near the dam which divides Nansi Lake into an upper lake and a lower lake. S4 and S5 were located in Zhaoyang Lake and Weishan Lake, both of which belong to the lower lake. According to the water depth, water samples were collected with a Ruttner water sampler (Hydrobios, Germany, 1000mL) at the depth of 0.5 m below the surface. The samples were kept cool and dark

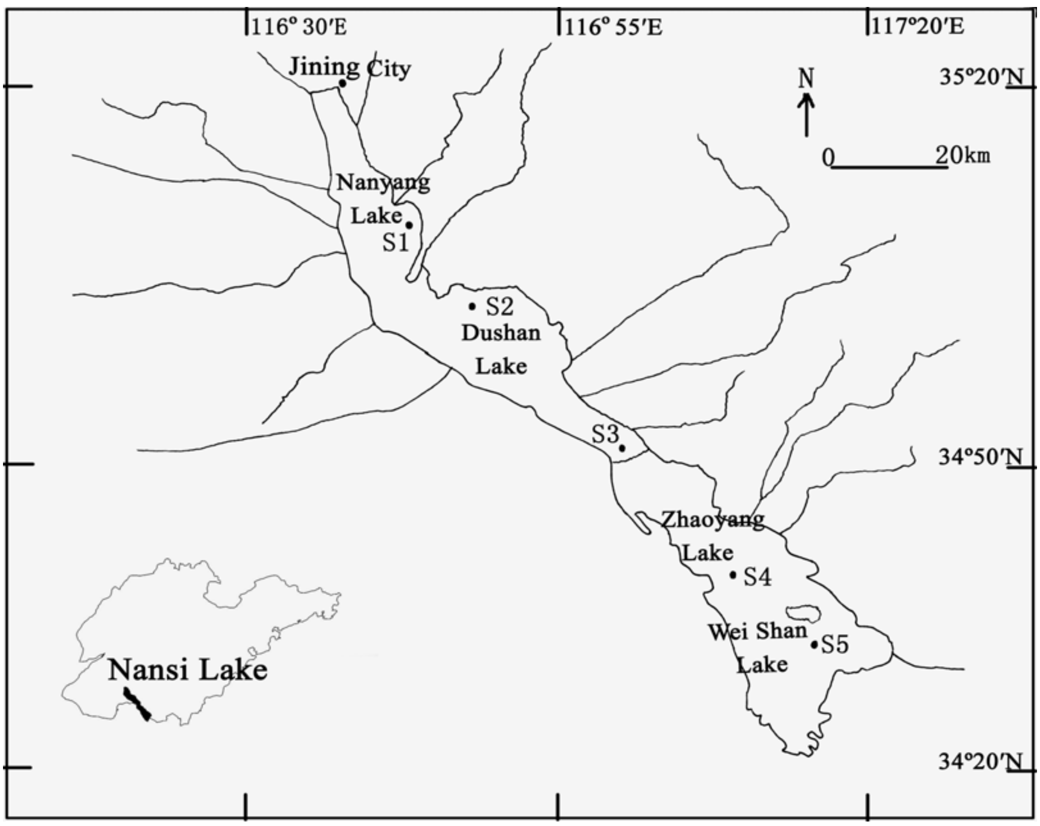

Fig. 1. Location of sampling stations in Nansi Lake

and carried to laboratory for analysis.

The physical and chemical parameters such as water temperature, pH, transparency and dissolved oxygen (DO) were determined using in situ instruments with a thermometer (TES1316, Shanghai Precision Instruments Co., China), portable acidity meter (PH-HJ90 MODELB, Aerospace Computer Company, China), Secchi disk (20 cm), portable dissolved oxygen meter (YSI59, YSI Corporation in China, China), respectively. Total phosphorus (TP) and total nitrogen (TN) were determined by the methods of molybdate blue procedure and persulfate oxidation spectrometry (EPAC, 2002). As a photosynthetic pigment present in all species of phytoplankton, chlorophyll *a* is a reliable and commonly used proxy for total phytoplankton biomass (Gregor & Maršálek, 2004). For chlorophyll *a*, 250 or 500mL of water samples was filtered immediately after collecting through acetic cellulose filters of 0.45 μm pore size. The materials left in the filters were extracted with acetone (90% *V/V*) in the dark for 6～8 h at 4°C. The extracting solution was measured by a spectrophotometer (UV-2450, SHIMADZU, Japan) and the concentration of chlorophyll *a* was calculated by the standard method (EPAC, 2002).

A sedimentation method was used for counting and species identification. The phytoplankton samples were kept in brown glass bottles of 1000mL immediately preserved by adding 15mL of Lugol's iodine solution and stored at 4°C. To optimize the counting process, the samples preserved in Lugol's solution were checked for high densities of phytoplankton, and the subsamples of water were settled 48h for enumeration using microscope technique (CX31, OLYMPUS, Japan) (EPAC, 2002). The supernatant was siphoned off, resulting in a 25–100× concentration of the sample. In total, a volume of 10-40mL of the sample was investigated for analysis, according to total phytoplankton abundance.

The species diversity and evenness were accounted according to Shannon and Pielou (Shannon & Wiener, 1949; Pielou, 1966). The biological diversity (H') and evenness (J) were calculated according to the following equations:

$$H' = -\sum_{i=1}^{S} P_i \log_2 P_i \qquad (1)$$

$$P_i = N_i / N \qquad (2)$$

$$J = H' / \log_2 S \qquad (3)$$

where N_i is respective abundance of the phytoplankton species; N is total individual abundance; S is total species. The number of species evaluated was based on the sum of all species observed in the sample. Relationships between environmental factors and phytoplankton abundance, diversity indices and evenness were estimated by simple linear correlation analysis (SPSS 13). All calculations were performed for n = 25 observations.

RESULTS & DISCUSSION

Water temperature ranged from 17.0°C in October to 27.8°C in August, varying significantly with time, but not with station. Horizontal differences in water temperature ranging from 0.0 to 1.5°C can be explained by the synoptic conditions at different sampling stations, but not by the large distance from south to north in Nansi Lake. The lake water was weak alkaline as the pH ranging from 7.20 to 7.89. DO concentrations varied indistinctively with time and ranged from 4.8 to 9.6 mg/L with an average of 7.70 mg/L. The maximal concentration was monitored at station S1 in August and the minimal at station S5 in October. Water transparency maintained at low level ranging from 40 to 65cm (Fig. 2a). The TN and TP concentrations changed monthly with a range of 0.34 to 9.48 mg/L (Fig. 2b), 48 to 715 μg /L (Fig. 2c), respectively. The chlorophyll a concentrations (Fig. 2d) ranged from 2.55 to 158.36μg/L and fluctuated with high values in June and August and low values in other months. The highest concentrations of DO, TN, TP, and chlorophyll *a* were detected simultaneously at station S1 in August.

A total number of 7 phyla, 46 genera, 94 species were identified in the phytoplankton community. The total number was composed by 48 species of Chlorophyta, 22 species of Bacillariophyta, 17 species of Cyanophyta, 3 species of Euglenophyta, 2 species of Cryptophyta, 1 species of Xanthophyta, 1 species of Pyrrophyta (Table 1). Chlorophyta was the most important group in terms of species number (51.06%), followed by Bacillariophyta (23.40%), Cyanophyta (18.09%), and by the others 7.45%. The ratio of Chlorophyta species number to the total number of phytoplankton species observed in all samples had a range of 40.9% to 57.9%, with an average of 48.5%.

The species number detected at 5 monitoring stations ranged from 55 to 65 (Fig. 3) by each month. The species numbers of Chlorophyta were always abundant, and there was a peak in temporal distributions, which was similar to that of total species number. In August, the species number of Chlorophyta, Bacillariophyta and Cyanophyta were 32, 15 and 11, respectively.The species of Chlorophyta, Bacillariophyta and Cyanophyta were the most abundant phytoplankton communities in Nansi Lake.

The phytoplankton abundance in Nansi Lake exhibited distinct differences by each station. The aver-

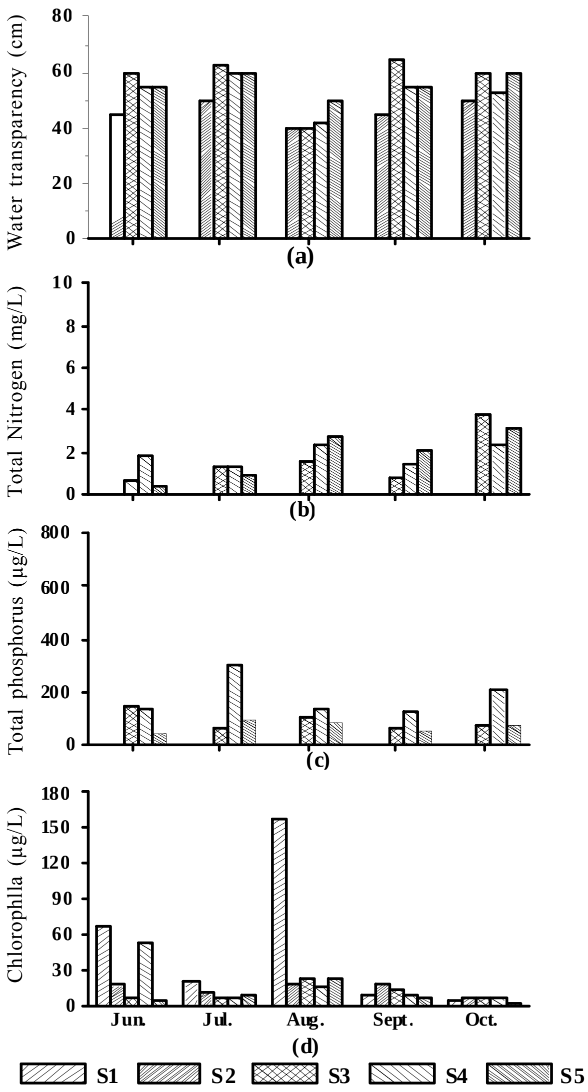

Fig. 2. Temporal variations of Water transparency (a), TN (b), TP (c) and Chlorophyll *a* (d) from June to October in 2008

age phytoplankton abundance was 1.52×10^7 cells/L, with a range of 1.33×10^6-5.50×10^7 cells/L (Fig. 4). The maximum abundance appeared at the station S1 in August and the station S5 had a minimum abundance in October, which was lower than one tenth of the highest record. A peak in abundance occurred in August at all monitoring sections, with an average of 3.16×10^7 cells/L. As a whole, phytoplankton abundance decreased in a downstream direction. The average phytoplankton abundance in upper lake (stations S1 and S2) was 1.97×10^7 cells/L which was higher than lower lake (stations S4 and S5), with an average of 1.03×10^7 cells/L.

Diversity indices calculated for Nansi Lake were performed on cell abundance. The diversity indices varied from 0.70 to 2.31, and evenness from 0.19 to 0.83 (Fig. 5). The results showed an average diversity index and evenness of 1.59 and 0.58, respectively. The highest diversity index was recorded at station S3 in June and the lowest registered at station S1 with a lower evenness in September. The phytoplankton diversity indices took on relatively higher values (>2.0) and the distribution of phytoplankton species was even in different regions in June and July. The lower diversity indices values mainly appeared in August, September and October, with distinct differences between sampling stations.

Fig. 6 shows the species abundance ranked top three among all the species from June to October. These dominant species were selected according to total abundance of all sampling stations. The principal phytoplankton species were *Chlorella vulgaris, Scenedesmus dimorphus, Synedra acus, Aulacoseira granulata, Merismopedia tenuissima, Monallantus brevicylindrus,* and *Navicula simplex*. The proportion of each dominant specie's abundance accounted for total phytoplankton abundance ranged from 6.5% to 36.0%. *Scenedesmus dimorphus* was abundant and

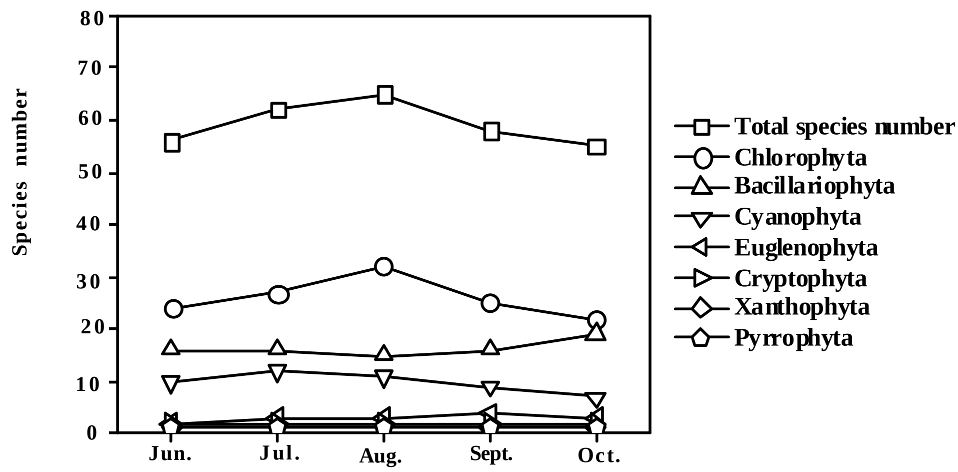

Fig. 3. Temporal variations of phytoplankton species in Nansi Lake

Table 1. The list of Phytoplankton species identified in Nansi Lake

Phyla	Genera	Species
Chlorophyta	*Actinastrum*	*A. hantzschii*
	Ankistrodesmus	*A. acicularis, A. angustus, A. falcatus, A. falcatus var. mirabilis*
	Asterococcus	*A. superbus*
	Characium	*C. limneticum*
	Chlamydomonas	*C. microsphaera, C. simplex*
	Chlorella	*C. ellipsoidea, C. pyrenoidosa, C. vulgaris*
	Coelastrum	*C. microporum*
	Cosmarium	*C. obtusatum*
	Crucigenia	*C. quadrata, C. tertrapedia*
	Gloeocystis	*G. ampla*
	Micractinium	*M. pussillum*
	Microspora	*M. stagnorum*
	Pediastrum	*P. boryanum, P. duplex, P. duplex var. gracillimum*
	Planktosphaeria	*P. gelotinosa*
	Scenedesmus	*S. acuminatus, S. denticulatus, S. dimorphus, S. javaensis, S. obliquus, S. quadricauda*
	Schroederia	*S. mizschioides, S. robusta, S. setigera, S. spiralis*
	Selenastrum	*S. bibraianum, S. westii*
	Sphaerocystis	*S. schroeteri*
	Tetraëdron	*T. caudatum, T. trigonum, T. trilobulatum, T. tumidulum*
	Tetrastrum	*T. staurogeniae forme*
	Ulothrix	*U. aequalis, U. implexa, U. moniliformis, U. oscillarina, U.variabilis*
	Westella	*W. botryoides*
	Westellopsis	*W. linearis*
Bacillariophyta	*Asterionella*	*A, formosa*
	Aulacoseira	*A. granulata, A. granulata var. angustissima*
	Cyclotella	*C. bodanica, C. comta, C. meneghiniana, C. stelligera*
	Cymbella	*C. microcephala, C. tumida*
	Diatoma	*D. vulagare*
	Fragilaria	*F. brevistriata, F. capucina*
	Navicula	*N. graciloides, N. radiosa, N. simplex, N. viridula*
	Pinnularia	*P. interrupta, P. microstauron*
	Synedra	*S. acus, S. affinis, S. amphicephala, S. ulna*
Cyanophyta	*Chroococcus*	*C. minor, C. minutus, C. tenax*
	Gloeocapsa	*G. magma*
	Lyngbya	*L. contarata , L. limnetica, L. major*
	Merismopedia	*M. elegans, M. glauca, M. punctata, M. sinica, M. tenuissima*
	Microcystis	*M. incerta*
	Oscillatoria	*O. princeps, O. tenuis*
	Phorimidium	*P. tenus*
	Raphidiopsis	*R. curvata*
Euglenophyta	*Euglena*	*E.geniculata, E. viridis*
	Phacus	*P. tortus*
Cryptophyta	*Chroomonas*	*C. acuta*
	Cryptomonas	*C. ovata*
Xanthophyta	*Monallantus*	*M. brevicylindrus*
Pyrrophyta	*Peridinium*	*P. zonatum*

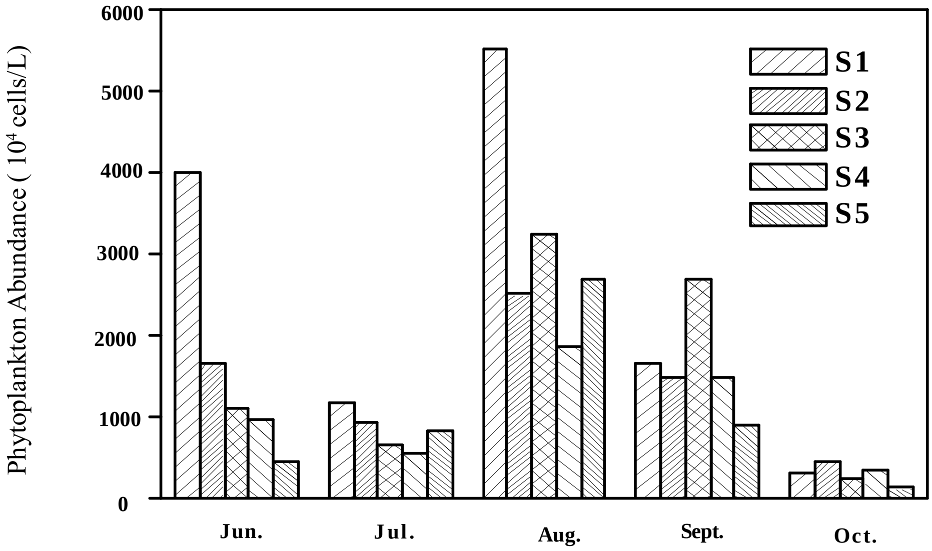

Fig. 4. Temporal Variations of phytoplankton abundance at five sampling stations

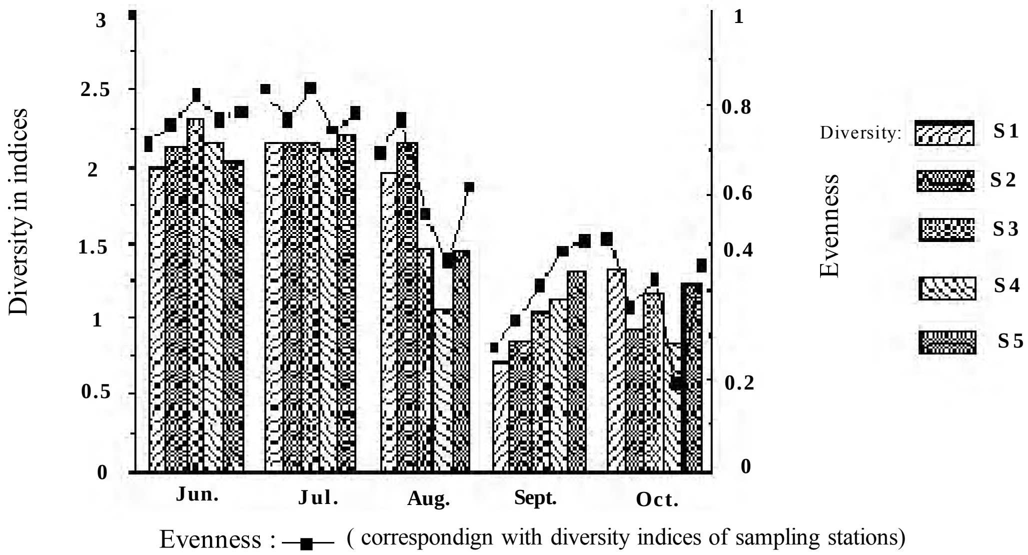

Fig. 5. Spatial and Temporal Variations of phytoplankton diversity indices and evenness

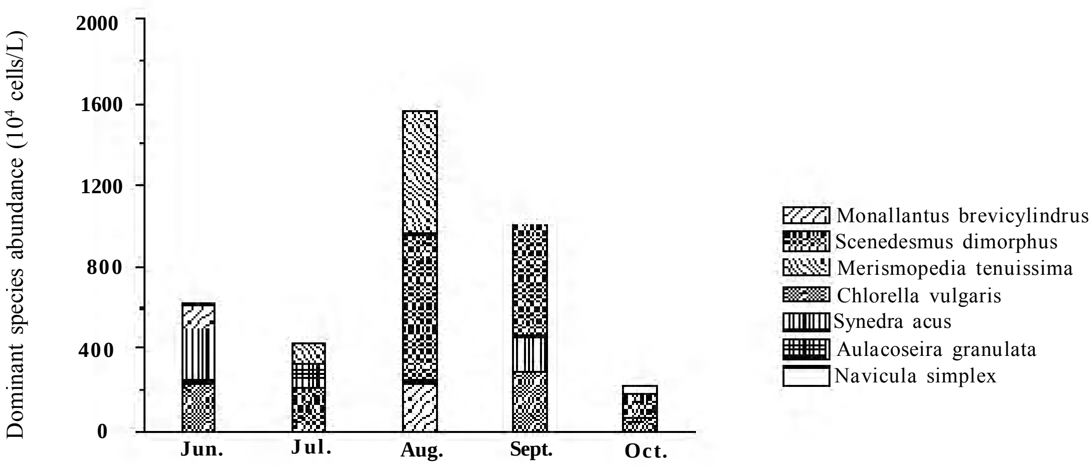

Fig. 6. Dominant species abundance ranked top three among all the species

(The species were selected according to total abundance of five sampling stations)

dominated each month at all stations, especially at station S1. *Merismopedia tenuissima* was abundant in July and August. *Chlorella vulgaris* was also abundant, but the highest abundance was observed in September. The distribution of *Monallantus brevicylindrus* was similar to that of *Chlorella vulgaris*. At stations S1 and S2, *Merismopedia tenuissima* and *Monallantus brevicylindrus* were abundant. By contrast, *Aulacoseira granulata* was abundant at stations S3-S5. The dominant taxa of green algae and diatoms were *Chlorella vulgaris*, and *Synedra acus*, respectively. There were no colony-forming cyanobacteria, such as *Micocystis*, *Anbaena*, and *Aphanocapsa*, dominating phytoplankton community.

As one of the most important environmental factors for the growth of phytoplankton, water temperature of all samples had significant correlation ($r=0.64$; $n=25$; $p<0.01$) with phytoplankton abundance in Nansi Lake. The phytoplankton abundance in October was poor and almost less than one tenth of that in August at all sampling stations (Fig. 4). Water transparency was used to describe water clarity and the ecological quality of shallow lakes could be predicted quite well from water transparency (Perdrozo *et al.*, 2008; Peeters *et al.*, 2009). The low water transparencies (less than 70cm) recorded during all the months in Nansi Lake could not entirely due to poor ecological conditions as there were frequent mixing of the entire water column and re-suspension of unconsolidated sediments in shallow lakes (Ishikawa & Tanaka, 1993). In addition to suspended solids, phytoplankton, zooplankton and dissolved organic matters (DOM) also have an impact on the water transparency (Torremorell *et al.*, 2007). There was weakly positive correlation ($r=0.32$; $n=25$; $p<0.01$) between DO and phytoplankton abundance in Nansi Lake. The DO concentrations increased slowly with the phytoplankton abundance, which might be the reason that the oxygen production rate in the course of phytoplankton growing exceeded the consumption by the oxygen consuming substances in lake waters.

Redfield (1958) reported the optimal N/P ratio for phytoplankton growth, known as the Redfield Ratio, is 16:1 (based on molecular concentrations). Large differences from 16 at low N/P ratios can be an indication for potential nitrogen limitation and at high N/P ratios, potential phosphorus limitation of the primary production of phytoplankton. Concerning nutrient stoichiometry, from the 25 sampling occasions, it was observed that in Nansi Lake most of the TN/TP ratios (mol/mol) were around 16 in early summer and all of the ratios were higher than 16 in late summer (Fig. 7). Nutrient availability and monthly fluctuations in nutrient supplies, which also happened in Nansi Lake, have often been cited as a principal factor controlling phytoplankton abundance in freshwater (McCarthy *et al.*, 2009). The higher TN: TP ratio in Nansi Lake would indicate potential P-limitation for phytoplankton growth. Furthermore, increased TN: TP supply ratios might reduce phytoplankton diversity by favoring those relatively few species with strong competitive abilities for using P (Elser *et al.*, 2009). This agreed with the results obtained in Nansi Lake as the variations of diversity indices and TN: TP ratios demonstrated the opposite trend (Fig. 5 and Fig.7).

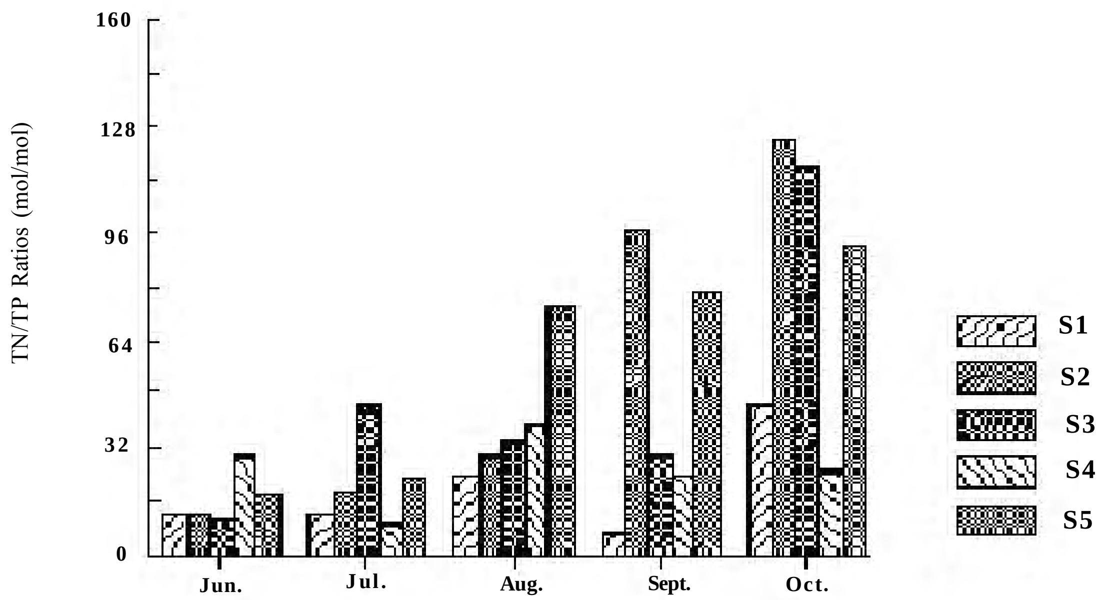

Fig. 7. TN/TP rations (mol/mol) at different sampling stations

There was a decreasing abundance gradient from early summer to late summer and from the stations close to city of Jining to the stations further from freshwater influences for all phytoplankton groups. It seemed that the nutrients load from drainage area around Jining City was a reason for higher phytoplankton abundance in the upper lake (stations S1 and S2). Dense populations and factories around Jining City produced large quantities of pollutants discharged into the river and eventually enter Nansi Lake. Cropland runoff, livestock and aquaculture wastes were the main water pollution sources in lower lake (stations S4 and S5). It is probably related to better water quality that the phytoplankton abundance of station S5 around Weishan Island was lower than the other stations, as shown in Fig.2. The average phytoplankton abundance detected in 2008 was higher than that collected in the same season 1988, with a range of 2.0-4.0×10^6 cells/L during June to October (Jin & Liu, 1995). Previous studies indicated that the growth of phytoplankton was closely correlated with nutrients and N: P ratios, as well as with micro-quantity elements such as Fe, Mg, etc (Sedwick *et al*., 2002; Quiblier *et al*., 2008). The peak phytoplankton abundance in August would indicate the lake water containing most of the nutrients required to the phytoplankton growth.

The spatial and temporal distribution of phytoplankton diversity indices was uneven in Nansi Lake. The distribution patterns of evenness were similar to that of diversity index (Fig. 6). Phytoplankton diversity indices and evenness presented small modifications during June and July. The lower values of diversity indices and evenness were detected at late summer and early August. Many researches indicated that the correlation between evenness (J) and Shannon-Wiener index (H') is positive and strong (Stirling & Wilsey, 2001; Ricotta & Avena, 2003). Analysis showed that there was highly significant positive correlation ($r=0.0.97$; $n=25$; $p<0.01$) between phytoplankton diversity indices and evenness in Nansi Lake. The monthly change of phytoplankton species numbers was not marked. Thus, the diversity indices would more affected by evenness than by number of species (Maria, 1993). Diversity indices of phytoplankton have been used as an indicator of the water quality (Karydis & Tsirtsis, 1996; Kitsiou & Karydis, 2000). Biologists proposed a different scale of pollution in terms of phytoplankton community diversity index, which states a negative correlation between Shannon and Wiener index and pollution: of 0.0-1.0 for heavy pollution, 1.0-2.0 for moderate pollution, 2.0-3.0 for light pollution, 3.0-4.5 for slight pollution (Shanthala *et al*., 2009). It was established that the diversity index value of a phytoplankton community in less polluted waters would be higher. The diversity indices in September and October were much lower than that in June and July, whereas the water quality was not obviously worse (Fig. 2). Furthermore, station S1 in August with high nutrients concentrations (TN, 9.8mg/L; TP, 715μg/L) showed high phytoplankton diversity index simultaneously (Fig. 5). Therefore, the phytoplankton composition and diversity indices also depend on mechanisms besides water quality (Karydis & Tsirtsis, 1996; Danilov & Ekelund, 1999). Wehr and Descy (1998) assert that variations in water chemistry may alter relative proportions of a few dominant taxa but often have little effect on the overall assemblage. Moreover, with the increasing phytoplankton abundance, the impact of predation of fish on the phytoplankton becomes stronger and a serious topdown control of the phytoplankton assemblage exists (Komarkova, 1998). On the other hand, the relation between phytoplankton and macrophytes is complex, as interacting with light climate and nutrient cycle through their biomass (Asaeda *et al*., 2001). From that, it can be concluded that the high diversity of Nansi Lake does not necessary indicate good water quality for this lake. Although a disturbance is a variable consisting of many components, changes in phytoplankton diversity indices seem to be mainly controlled by physical forces since nutrients concentrations were always available in Nansi Lake.

The most important environmental factor affecting phytoplankton biomass and community composition is eutrophication (Tremel, 1996). The phytoplankton biomass level corresponded to the nutrient level of the lake types (Chen *et al*., 2003). Most phytoplankton taxa observed in the present study were also frequently found in other freshwater lakes. For example, *Aulacoseira granulata* and *Chlorella vulgaris* were also numerous in eutrophic lakes (Lepistö & Rosenström, 1998). *Pediastrum duplex* is a green alga showing many modifications, as exemplified by *P. duplex* v. *gracillimum*, due to changes in its environment. It was also identified from almost all eutrophic lake samples and it is known as a species indicative of eutrophy (Järnefelt, 1952), in natural eutrophied lakes (Mantere & Heinonen, 1983). Cyanobacteria were a prominent phytoplankton group in eutrophic lakes. For instance, *Microcystis aeruginosa* was identified in all the eutrophic lakes and from every single sample in the Hypereutrophic lakes (Chen *et al*., 2003). 17 species of cyanobacteria were found in the samples based on data collected in 5 months. *Merismopedia tenuissima* was the dominant species of cyanobacteria community at all stations. One water bloom causative species (*Microcystis incerta*) was identified, which made a minor contribution to the whole phytoplankton abundance.

CONCLUSION

Based on a monthly sampling, 7 phyla, 46 genera and 94 species of phytoplankton community were identified from June to October of 2008 in Nansi Lake. The average phytoplankton abundance was 1.52×10^7 cells/L, ranging from 1.33×10^6-5.50×10^7 cells/L. The phytoplankton abundance was much higher in August than other months and the phytoplankton biocoenosis revealed high biodiversity during June and July. The changes in phytoplankton diversity indices seem to be mainly controlled by physical forces since nutrients were always available. The high TN: TP ratios would indicate potential P-limitation for phytoplankton growth in late summer. The main dominant species were *Scenedesmus dimorphus*, *Chlorella vulgaris*, *Synedra acus, Aulacoseira granulata*, *Merismopedia tenuissima* and *Monallantus brevicylindrus*. The species of Chlorophyta and Bacillariophyta rather than cyanobacteria causing water bloom dominated phytoplankton community. Further research is needed to predict quantitatively the effect of phytoplankton on the environmental and ecological characteristics in Nansi Lake.

ACKNOWLEDGEMENTS

The authors thank the staff of Shandong Environmental Monitoring Central Station and Jining Environmental Monitoring Station for the sampling program. This study was supported by International Cooperation research of Shandong Province (2008GJHZ20601), Australia-China Special Foundation (2006DFA93110) and Policy and Technology Research Center of South-to-North Diversion Project Office, State Council.

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