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Effects of nitrogen and phosphorus on phytoplankton composition and biomass in 15 subtropical, urban shallow lakes in Wuhan, China

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ABSTRACT

This study aims at investigating the composition and biomass of the phytoplankton community in 15 urban shallow eutrophic lakes as well as the effects of main environmental factors, including nutrient concentrations and the ratio of nitrogen to phosphorus, temperature, COD, BOD, water depth, etc. on the phytoplankton community structure. Lake water samples were taken and analyzed on a bimonthly basis during the period from March 2004 to March 2006. The redundancy analysis (RDA) and regression analysis (RA) were performed to identify the effects of nutrients on the phytoplankton community and biomass in these typical urban lakes. The results indicate that most of these urban lakes were hypertrophic due to high concentrations of total phosphorus (TP) and total nitrogen (TN), with mean levels of 490 and 5380 mg m^{-3}, respectively. The phytoplankton community was dominated by *Microcystis aeruginosa* and *Euglena caudate* in summer and *Cryptomonas ovata* and *Cyclotella meneghiniana* in winter. The mean biomass of the phytoplankton reached 456.87 mg L^{-1} in summer months and the annual level was 189.24 mg L^{-1}. Temperature and TP content were found to be the principal limiting factors for phytoplankton growth on an annual basis. On the other hand, the results of RDA and RA demonstrate that the dominant phytoplankton species were not nutrient-limited during summer months. Low TN:TP ratios (<10) were detected accompanied with fewer occurrences of N-fixing cyanobacteria and other filamentous algae in most lakes in summer, which implies that low N:P ratio does not always shifts the dominance of phytoplankton community to the N-fixing cyanobacteria. Moreover, TP always had higher correlation with chlorophyll *a* (Chl-*a*) than TN, even when the TN:TP ratios of most samples were lower than 10. Therefore, it is concluded that the TN:TP ratio is not always a suitable index to determine whether nitrogen or phosphorus limits the phytoplankton biomass in urban shallow eutrophic lakes.

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Introduction

Nutrient enrichment typically stimulates phytoplankton growth in lakes. Some genera of phytoplankton, such as *Microcystis*, *Anabaena*, *Nostoc* and *Aphanizomenon*, usually break out and stand stably, leading to problems with hypoxia, toxins and changes in the structure of biological communities (Carmichael, 2001; Chen et al., 2008).

Understanding the links between nutrient concentration and algal biomass is important in the efforts for eutrophication management. Phosphorus (P) and Nitrogen (N) are often considered as the principal limiting nutrients for aquatic algal production due to their short supply compared to cellular growth requirements. Sakamoto (1966) proposed that the phytoplankton biomass was dependent on total phosphorus (TP) when TN:TP by weight was >17, on total nitrogen (TN) when TN:TP was <10 and both on TN and TP when the ratio of TN to TP was in the range of 10–17. The importance of TN:TP ratio for the relative proportion of cyanobacteria in phytoplankton where TN:TP by weight was <29 has been emphasized by Smith (1982). Paerl et al. (2001) proposed, however, that the "N:P rule" was not suitable for highly eutrophic systems when the loadings of N and P exceed the assimilative capacity of the phytoplankton. Large-scale investigations in the Yangtze shallow lakes indicated that the N:P ratios varied greatly among eutrophic lakes (Wang et al., 2008). Therefore, they proposed that the TN:TP ratio was not an appropriate index to determine whether nitrogen or phosphorus is the limiting nutrient in a lake. In addition, the mesocosm experiment in Lake Donghu indicated that the low TN:TP ratio is rather a result than a cause of *Microcystis* blooms (Xie et al., 2003b). Therefore, further investigations in more lakes, especially in urban shallow eutrophic lakes, are urgently needed to identify the relationship between the phytoplankton population and the threshold of TN:TP ratios.

There are more than one hundred floodplain lakes in the urban area of Wuhan, characterized with low depth and increasingly

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severe eutrophication in recent decades. Most of these lakes were formed from geological subsidence, and were once connected with the Yangtze River before 1950s. Since then, a majority of these lakes were disconnected from the Yangtze River as a result of the construction of flood-control projects, except for a few of lakes being connected with the Yangtze River through man-made ditches and milldams. Since Wuhan City underwent rapid urbanization and industrialization in the 1980s, the remaining lakes have been increasingly exposed to nutrients and organic pollutants generated by untreated domestic and industrial waste-waters (Lu et al., 2007). Thus, these lakes have become more and more eutrophic, showing high N and P levels. Previous research has frequently been focused on the mesocosm experiments in the Lake Donghu, the largest urban shallow lake in Wuhan City (Qiu et al., 2001; Xie and Xie, 2002; Xie et al., 2003a); nevertheless, efforts for the *in situ* investigations into other typical urban eutrophic lakes are rarely made.

The objectives of the study are to investigate the succession of phytoplankton population in these typical urban shallow lakes of Wuhan at different seasons, and to identify the effects of phosphorus and nitrogen on phytoplankton composition and biomass at varying TN:TP ratios.

Methods and materials

Study site

Wuhan, situated in the middle of China (113° 41′ E–115° 05′ E, 29° 58′ N–31° 22′ N), is praised as "a city with hundreds of lakes" owing to its abundance in water resources. The Yangtze River joins the Hanjiang River at the centre of the city, dividing it into three sections. More than one hundred lakes were once scattered in the urban and suburban areas (Fig. 1). Wuhan is located in the humid subtropical monsoon climate zone at an approximate elevation of 23.3 m. The city's 30-year normal precipitation is 1280.9 mm, and rainfall is most frequent between April and October. The average atmospheric temperature is 16.9 °C with an extremum low of −18.1 °C and extremum high of 42.2 °C (Wuhan Water Authority, 2005). Most of the lakes have suffered from overloading of nutrients and organic contaminants, resulting in toxic algal blooms, fish kills and water turbidity.

Samples from fifteen lakes, which belong to nine different drainage basins, were taken in the present study. The lakes of Moshui, Longyang, Sanjiao, Beitaizi and Nantaizi are of the same drainage basin and have been interconnected through artificial ditches since December 2005. Lake Nantaizi was a major receiving water body of wastes generated from such industries as food, automobile and grease manufacturing, which are situated in the Zhuankou Industrial Park. Water depth of the Lake Donghu averages 2.2 m, and displays little seasonal or year-to-year variation. This stability is maintained by pumping water into the lake from a river nearby during the dry season to ensure a continuous water supply (4 million L day^{-1}) for a large steel mill (Havens et al., 2001). Lake Shuiguo is a bay of Lake Donghu with high nutrient loadings. All of the rest studied lakes are seepage lakes and are disconnected with each other. A few kinds of aquatic macrophytes including *Alternanthera philoxeroides*, *Polygonum flaccidum* and *Eichhornia crassipes*, etc., which inhabited in the littoral zone of the studied lakes, have been reported. No macrophyte species has been determined in the lakes of Lianhua, Nantaizi and Hankoubei (Wuhan Water Authority, 2005).

Sampling methods

Field investigations were conducted every two months during the period from March 2004 to March 2006. Samples were collected at a depth about 0.50 m below the surface and mixed with water on the bottom at each location. Quantitative samples of the phytoplankton collected using a 5 L water sampler were divided into 3 portions, and preserved immediately with 1% of acidified *Lugol* iodine solution. Precisely 1 L sample was taken from each portion in the lab and concentrated to 30 mL after sedimentation for 48 h. After complete mixing, the concentrated samples were counted directly in a 0.1 mL counting chamber using a compound microscope (XSP-C202, Shanghai, China; at a magnification of 640×). The mean of all of the three portions was adopted as the final result. Colonial forms were counted by enumerating single cells after separation using an ultrasonic

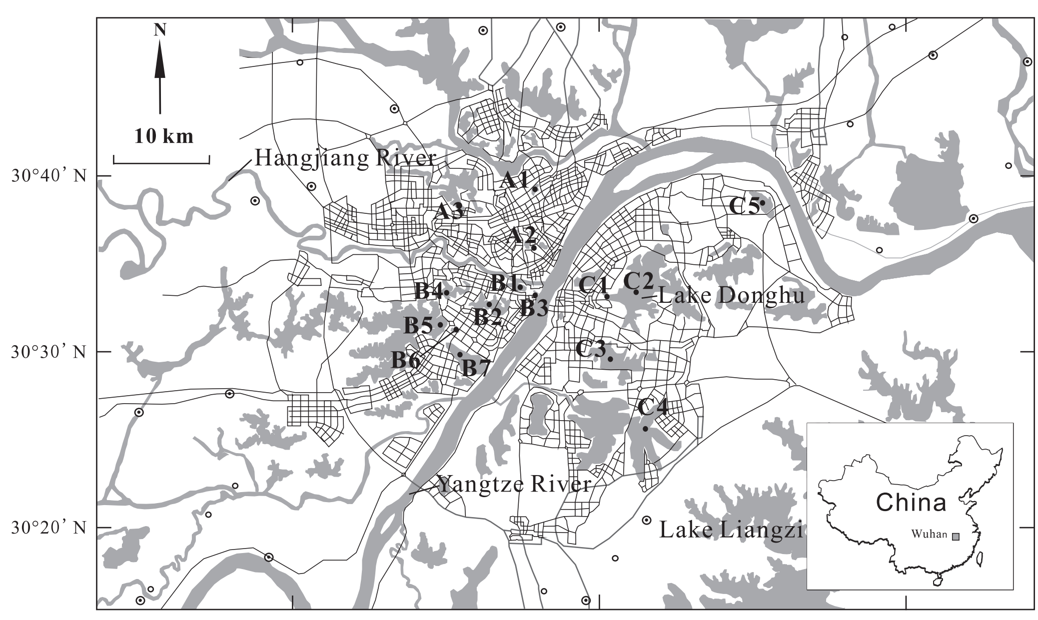

Fig. 1. Sampling stations at 15 lakes, Wuhan, China. A1: Lake Tazi; A2: Lake Hankoubei; A3: Lake Zhangbi; B1: Lake Yuehu; B2: Lake Moshui; B3: Lake Lianhua; B4: Lake Longyang; B5: Lake Sanjiao; B6: Lake Beitaizi; B7: Lake Nantaizi; C1: Lake Shuiguo; C2: Lake Donghu; C3: Lake Nanhu; C4: Lake Tangxun; C5: Lake Qingshanbei.

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