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Full Length Research Paper

Spatio-temporal variations of phytoplankton community composition assayed by morphological observation and photosynthetic pigment analyses in Lake Taihu (China)

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Spatio-temporal variations of phytoplankton were assayed by morphological observation and photosynthetic pigment analyses at four sites in Lake Taihu from September 2007 to June 2008. Results showed that cyanobacteria abundance in water column decreased from autumn to winter but increased in the sediment; in spring, cyanobacteria abundance decreased in sediment but increased in water column. Since phycocyanin in the sediment fluctuated during the year with maxima in March and minima in September, vertical migration and recruitment of cyanobacteria were apparent. Algal abundance and composition changed in the water column. Chlorophytes dominated phytoplankton community initially and were replaced by cyanobacteria especially *Microcystis* spp., which underwent a colony-enlargement process and evolved from colonies with a few cells to those with dozens or hundreds of cells before blooming in late June.

Key words: Colony enlargement, cyanobacteria, Lake Taihu, morphological observation, *Microcystis* spp., photosynthetic pigment.

INTRODUCTION

In eutrophic lakes, cyanobacteria, such as *Microcystis* spp*.,* reinitiate growth in the water column in spring, bloom in summer, then sink to the sediment in autumn (Reynolds et al., 1981; Takamura et al., 1984; Thomas and Walsby, 1986). In winter, *Microcystis* spp. colonies remain in the surface sediment as vegetative cells (Fallon and Brock, 1981; Reynolds et al., 1981; Brunberg and Blomqvist, 2003). These 'resting' colonies are viable and may fuel algal blooms the following year (Preston et al., 1980). In earlier studies, benthic overwintering populations were viewed as an important 'seed bank' in deep lakes (Fallon and Brock, 1981; Reynolds et al., 1981), and findings from these lakes support both significant (Petterson et al., 1990; Barbiero and Welch, 1992; Barbiero and Kann, 1994; Forsell and Petterson, 1995) or insignificant (Livingstone and Reynolds, 1981; Reynolds et al., 1981) inocula for the water column. More recently, *Microcystis* spp. recruitment from surface sediment has been reported from shallow areas of deep lakes (Hansson et al., 1994; Brunberg and Blomqvist, 2003). These benthic cyanobacteria may be important to pelagic growth and development of algal blooms. It is, therefore, important to study benthic algae dynamics and its influences on standing crop in the water column in large, shallow lakes, especially benthic dynamics between annual blooms.

Lake Taihu is the third largest freshwater lake in China, and its northwestern region is highly eutrophic, which threatens fishing and water supply (Chen et al., 2003). It is important to investigate mechanisms of algal blooms development for mitigation and control. Long-term phytoplankton assemblages in Lake Taihu were investigated by

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Abbreviations: Chl *a*; Chlorophyll *a*, **Chl *b*;** chlorophyll *b*, **PC;** phycocyanin.

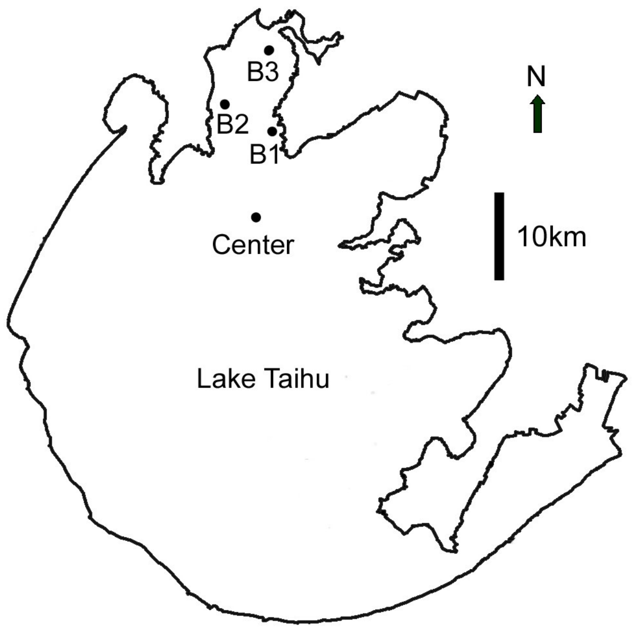

Figure 1. Locations of the four sampling sites in Lake Taihu. Key: B1, bay 1; B2, bay 2; B3, bay 3.

Chen et al. (2003), who concluded that short-term phytoplankton variations were controlled by temperature, wind and turbidity, while long-term abundance dynamics were influenced by nutrients. However, these findings are insufficient to understand phytoplankton dynamics since only pelagic data were considered.

Photosynthetic pigments have been used to study phytoplankton dynamics in water column (Lee et al., 1995; Downes and Hall, 1998; Huang et al., 2000; Asai et al., 2001) and in surface sediment (Soma et al., 1996; Tani et al., 2002; Yan et al., 2004). The objective of this study was to understand spatio-temporal variations of phytoplankton community in sediments versus the water column in Lake Taihu between annual blooms from September 2007 to June 2008, when the bloom first appeared. Phytoplankton succession and community composition were assayed by morphological observation and photosynthetic pigment analyses to understand how algal blooms develop in this large, shallow lake.

MATERIALS AND METHODS

Lake and site descriptions

Lake Taihu is divided into two sections: eastern and western. The eastern section is dominated by macrophytes and has experienced no *Microcystis* blooms, while the western section has few macrophytes and suffers annual *Microcystis* blooms. Meiliang Bay is highly eutrophic and located in the western section. *Microcystis* blooms begin in late May or early June every year. Three sampling sites in Meiliang Bay were named bay 1 (31° 25'53.8"N, 120° 12' 42.5"E), bay 2 (31° 27' 54.7"N, 120° 09' 00.6"E) and bay 3 (31° 30' 20.9"N, 120° 11' 34.8"E) (Figure 1). Water depths at the three sites were 1.6, 2.2 and 2.2 m, respectively. A fourth site, center (31° 20' 59.8"N, 120° 11' 16.7"E; 2.8 m deep), was located near the center of western Lake Taihu.

Analyses of photosynthetic pigments

Integrated water column and upper 0 - 2 cm of sediment were collected at the four sites from September 2007 to June 2008.

For Chl *a* and *b* determinations, 250 ml water was filtered through Whatman's GF/C filters and treated according to Abalde et al. (1998) and Yan et al. (2004). Chl *a* and *b* were determined simultaneously on a spectro-fluorophotometer (RF-5301PC, Shimadzu Corporation, Japan), where Δλ= 258 nm was used for Chl *a* and Δλ= 193 nm for Chl *b* (Huang et al., 1987; Yan et al., 2004), with a scan speed at 60 nmmin^{-1} and band pass at 5 nm. PC was extracted using 0.05 M Tris-HCl buffer (pH= 7.0) and determined at an excitation wave length of 620 nm and emission wave length of 647 nm (Abalde et al., 1998; Yan et al., 2004). All standard pigments were purchased from Sigma (St. Louis, MO, USA).

Microscopic examination of phytoplankton community composition in the sediment and water column

The dominant species of cyanobacteria in Taihu Lake is *Microcystis* spp. (Chen et al., 2003). In winter, most of sedimented algae are concentrated in the upper 2 cm of sediment (Tsujimura et al., 2000). To study the composition of over-wintering phytoplankton in cold and dark environments, sediment was diluted with filtered lake water; the resulting suspension was examined by a microscope (Nikon E-600, Japan). As for the pelagic algae analysis, 1 L integrated water column sample was fixed with Lugol's iodine before morphological observation.

Development pattern of *Microcystis* spp. colony

Meanwhile, microscopic examination was performed to investigate colony enlargement of *Microcystis* spp.. Small colonies (≤ 20 cells) were counted directly, and larger colonies (> 21 cells) were grouped into consecutive groups: >21, >51, >200 and >1000 cells. A total of 300 colonies (including unicells) were counted for each sample from March to June, 2008 before bloom initiation in Lake Taihu. All samples were analyzed in triplicate, data were statistically analysed using the SPSS software (version 11.0), and results were expressed as mean ± standard error.

RESULTS

Phytoplankton community composition in the sediment and water column

Microscopic examinations of sediment and water samples revealed euglenophyta, rhodophyta, and cryptophyta were absent, so it was assumed that Chl *b* represented chlorophytes abundance. *Microcystis* spp. was the overwhelmingly dominant genus in sediment samples (accounting for 98% of total cyanobacteria abundance), but some *Spirulina* sp. and other cyanobacteria were observed in low abundance. Thus, PC could represent cyanobacteria, mostly *Microcystis* spp. Majority of chlorophyta in sediment samples were *Ulothrix* sp., *Scenedesmus obliquus* and *Micractinium pusillum* Diatoms were low in abundance and mostly include

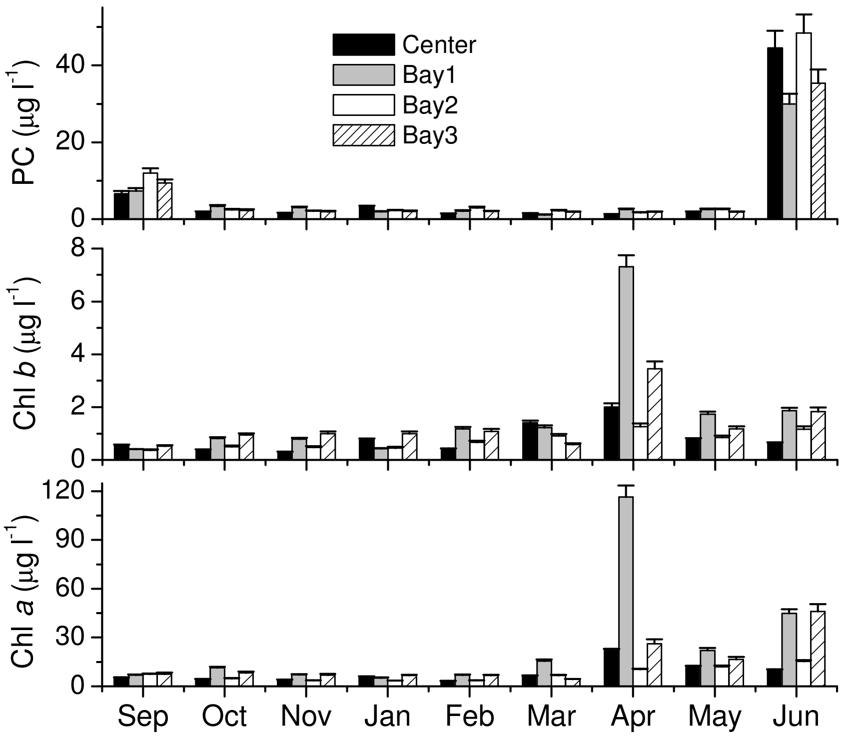

Figure 2. Variations of pelagic phytoplankton at four sites in Lake Taihu. Concentrations of Chl *a, b,* and phycocyanin represent abundances of total phytoplankton, chlorophytes and cyanobacteria, respectively.

Asterionella sp., *Aulacoseira granulate* and *Navicula halophila*.

Variations of phytoplankton community in the water column and sediment

Pelagic algal abundance remained low during the non-bloom period (Figure 2), with each site having different algal abundance (one-way ANOVA, p<0.05). Chl *a* and *b* peaked in April when chlorophytes increased, especially in Meiliang Bay, but did not form visible blooms. After this peak, phytoplankton increased steadily. Relative composition of phytoplankton at each site varied with month. Generally, bays 2 and 3 had higher cyanobacteria standing crops, while bays 1 and 3 had higher standing crops of total phytoplankton and chlorophytes. Despite different algal standing crops among the study sites, no obvious trends were observed. In contrast, PC was low at the four sites but increased dramatically in June before the bloom.

While, phytoplankton in sediment showed a different pattern over time (Figure 3). Center had the lowest abundance and bay 3 the highest among most samples before March. Generally, phytoplankton increased to March 2008 and then declined. Before March 2008, chlorophytes and cyanobacteria increased at all sites, while total phytoplankton declined in November and December and rose from January to March. From April to June, phytoplankton abundance at each site declined. Bay 3 had the highest chlorophyte abundance, and center and bay 2 had the highest total phytoplankton and cyanobacteria. Declining sediment phytoplankton abundance coincided with water column increases, which implied upward inocula to a certain extent. During the same period, relative phytoplankton abundance between sites also changed, as opposed to those before March 2008.

Enlargement of *Microcystis* spp. colony in the water column

With increasing pelagic abundance, *Microcystis* spp. colonies exhibited enlargement (Figure 4). Colonies were small with few cells at the 4 sites in March 2008. Small colonies with less than 4 cells constituted a large portion, and colonies with 4 cells were the most abundant, accounting for 19.5 ± 2.37%, 28.9 ± 2.56%, 19.5 ± 3.01%, and 26.6 ± 2.79% of total colonies at bays 1, 2 , 3 and center, respectively. Colonies remained small, with the largest containing < 20 cells at the end of April at all sites. In May, *Microcystis* spp. grew into larger colonies with > 20 cells. Colonies with > 20 cells respectively comprised 39.7 ± 2.65%, 20.8 ± 2.65%, 22.7 ± 2.68%, and 23.2 ± 3.43% of the total colony. The largest colonies occurred in June, with > 1,000 cells accounting for 2.28 ± 0.32%, 4.89 ± 0.65%, 4.33 ± 0.64%, and 2.90 ± 0.49% of total colonies, respectively.

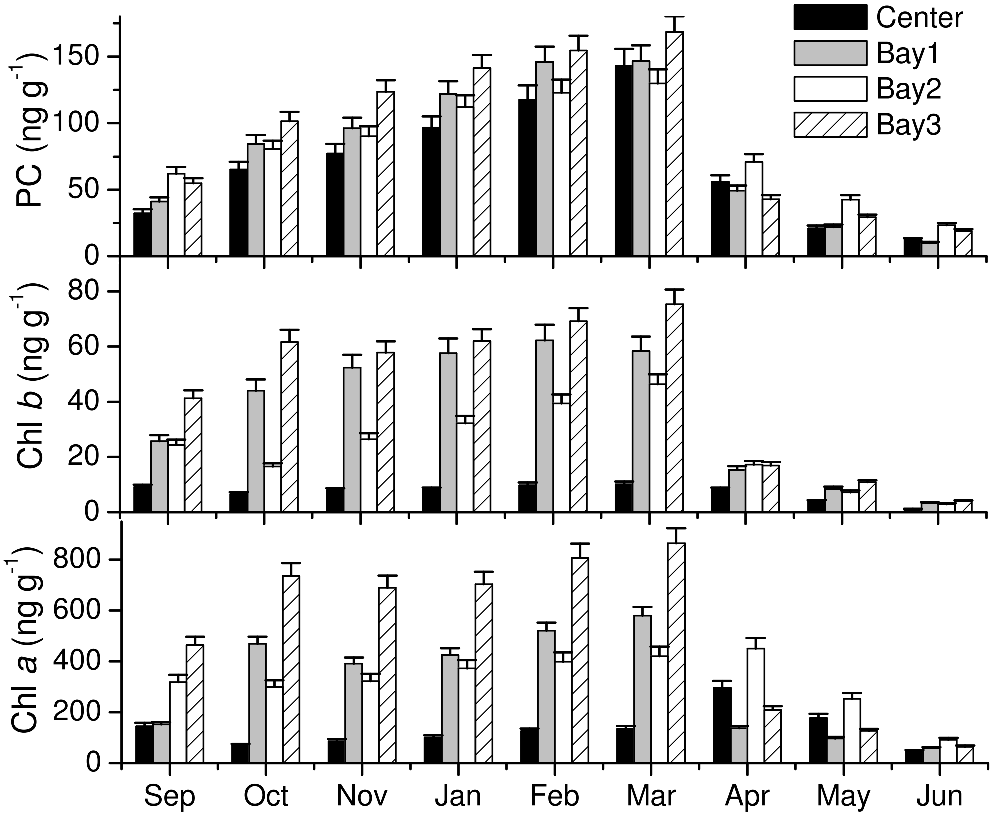

Figure 3. Variations of sediment pigments at four sites in Lake Taihu. Chl *a*, *b*, and phycocyanin represent the abundances of total phytoplankton, chlorophytes and cyanobacteria respectively.

DISCUSSION

Variations of cyanobacteria in surface sediments

Compared to deep lakes, cyanobacteria variations in shallow lakes sediment were less studied. Seasonal variations of *Microcystis aeruginosa* populations in a shallow, polymictic area (south basin; area = 58 km^2; average depth = 4 m) and a deep, monomictic area (north basin; area = 616 km^2; average depth = 43 m) of Lake Biwa, Japan, were reported (Tsujimura et al., 2000). *M. aeruginosa* increased from March to April and decreased until the end of July in the south basin, which is in good agreement with our results. However, *M. aeruginosa* decreased from March to April and increased from May to July at the other south basin site, while for both north basin sites, *M. aeruginosa* increased from March to July in Lake Biwa. Differences in cyanobacteria variations in surface sediments implied that there were different development patterns in various shallow lakes. Benthic inocula of *M. aeruginosa* accounted for a small portion of pelagic abundance in one study (Brunberg and Blomqvist, 2003). In the present study, cyanobacteria decreased in the sediment from April to June, but did not increase in the water column until June. Thus, benthic cyanobacteria may not strongly affect pelagic abundance.

Variations of phytoplankton in the water column

Variations of pelagic phytoplankton showed distinct temporal stages and spatial differences in Lake Taihu. Blooms occurred from June to November, and then declined. *M. aeruginosa* abundance was low until June following recruitment from surface sediments in Lake Mendota (Hansson et al., 1994). Cyanobacteria in epilimnetic populations varied in Esthwaite Water between March and June (Head et al., 1999). In Lake Biwa, pelagic *M. aeruginosa* increased from March to August in the south basin (Tsujimura et al., 2000), while in the north basin, one site showed a decline from June to August. In Lake Taihu, phytoplankton composition and abundance also varied. Chlorophytes were most abundant in April 2008. Afterwards, cyanobacteria, particularly *Microcystis* spp., dominated. Before June, the abundance of total phytoplankton and chlorophytes showed similar trends as chlorophytes were a major group. Afterwards, *Microcystis* spp. became dominant and Chl *a* was mainly from cyanobacteria. Additionally, PC could reflect *Microcystis* spp. blooms, since it constituted a vast majority of cyanobacteria in Lake Taihu. The product of the PC/Chl-ratio and extractive Chl *a* may provide a PC concentration estimate (Vincent et al., 2004); PC values are proportional to absolute phycocyanin content, which were used

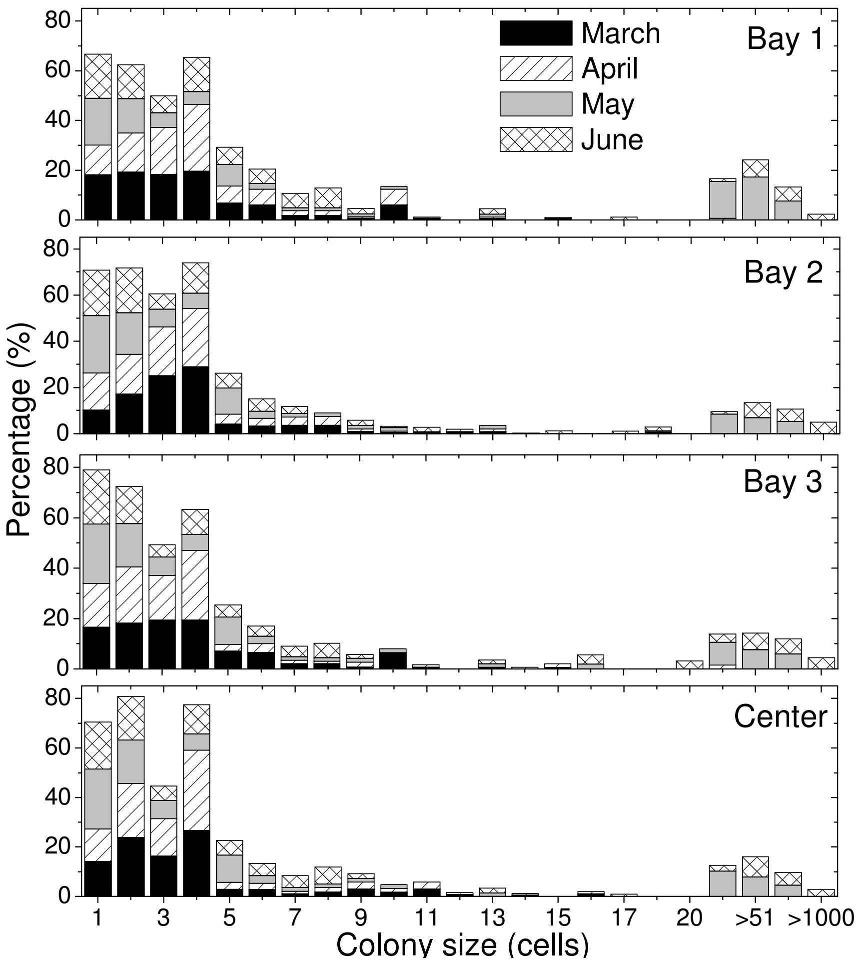

Figure 4. Development of *Microcystis* spp. colony enlargement.

to monitor temporal and spatial cyanobacteria dynamics. For example, in Lake Erie a large bloom was detected by this method by five weeks earlier than reported by local media (Vincent et al., 2004).

Colony enlargement of *Microcystis* spp. in the water column

With phytoplankton succession in the water column, *Microcystis* spp. underwent colony enlargement process, as small colonies consisting of few cells became larger. Recent research (Burkert et al., 2001) used the mixotrophic flagellate *Ochromonas* sp. to induce *M. aeruginosa* colony formation, which resulted in only small colonies. However, *in situ* colony succession has not been studied extensively. In our study, *Microcystis* spp. colony enlargement was related to bloom formation, with a large proportion of colonies larger than 50 cells. However, mechanisms underlying this developmental colony enlargement remain to be understood. These colony developmental patterns and its increase in abundant increase imply that *Microcystis* bloomed as both a result of abundance, accumulation and colony enlargement.

Conclusions

The colony of over-wintering *Microcystis* spp. usually consisted of a single or few cells. As recruitment progressed, colony size increased. Cyanobacteria abundance in the water column decreased from autumn to winter but increased in the sediment. In spring, cyanobacteria decreased in the sediment but increased in the water column. Since PC in the sediment peaked in March and was lowest in September, vertical migration and recruitment were apparent. Algal abundance and composition changed in the water column in relation to algal blooms in Lake Taihu. Chlorophytes dominated the phytoplankton community in spring and was replaced gradually by *Microcystis* spp., which underwent a colony-enlargement process and evolved from colonies with few cells to colonies with dozens or hundreds of cells before blooms appeared in Lake Taihu.

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