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Phosphorus release from cyanobacterial blooms in Meiliang Bay of Lake Taihu, China

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ABSTRACT

To investigate the relationship between cyanobacterial density and phosphorus release into a lake aquatic environment, in situ experiments with 2.5 L microcosms were conducted in Meiliang Bay, located in the northern part of Lake Taihu, China. The effects of different environmental factors on phosphorus release and the ways changes of water quality indexes are involved in phosphorus release were further examined. It was found that total dissolved phosphorus (TDP) concentration kept to low levels (around 0.488 mg L^{-1}) in the microcosm with the low cyanobacterial density (8.85×10^7 cell L^{-1}) throughout the experimental period, whereas first-order kinetics of TDP release was observed in microcosms with intermediate (7.60×10^8 cell L^{-1}) and high cyanobacterial density (3.65×10^9 cell L^{-1}). Accordingly their TDP release rate constants were both approximately 0.8930 d^{-1} in the latter two treatments. The dissolved inorganic phosphorus (DIP) concentrations also increased with the increase of cyanobacterial density in 4 days. However, the DIP decreased from 35.52 mg L^{-1} on day 4 to 6.72 mg L^{-1} on day 6 in microcosm with the high cyanobacterial density during the experiments. Temperature could remarkably improve phosphorus release, while disturbance and illumination had negative effects on it. In addition, both TDP and DIP concentrations were positively correlated with electronic conductivity, salinity and total dissolved solid, but negatively correlated to chlorophyll-a and cyanobacterial density when cyanobacterial density was more than 7.60×108 cell L^{-1}. Thus, more phosphorus can be released from cyanobacterial blooms at higher cyanobacterial densities in Meiliang Bay, which is also determined by high temperature. Higher dissolved phosphorus concentration in cyanobacteria-dominated lakes (regions) is mainly due to the decomposition of cyanobacteria during the outbreak of cyanobacterial bloom in Lake Taihu, especially in Meiliang Bay.

1. Introduction

Phosphorus (P) is a vital biogenic element in freshwater ecosystems such as lakes, reservoirs and rivers (Carlsson and Caron, 2001; Smith et al., 2006; Schlusser et al., 2007; Toothman et al., 2009; Wang and Wang, 2009). Excessive P can eutrophicate freshwater bodies and further bring about harmful algal blooms (Yu, 2000; Glibert et al., 2002; Perkins and Underwood, 2002; Vadeboncoeur et al., 2003; Johnson and Chase, 2004; Smith, 2006; Zhang et al., 2008; Liu et al., 2009). It has been well known that phytoplankton, such as cyanobacteria, play an important role in the biogeochemical cycle of P in freshwater systems (Hecky and Kilham, 1988; Holdren and Montanño, 2002; French and Petticrew, 2007; Havens et al., 2007; Monbet et al., 2007). However, most studies have focused on the cause and extent of algal growth as well as aerobic/anaerobic decomposition of algae (Foree and McCarty, 1970; Jewell and McMarty, 1971; Hessen et al., 2002; Moore et al., 2002; Murrell and Lores, 2004; Smith et al., 2006; Sun et al., 2007). Relatively little attention has been paid to the P release in lakes during the decomposition of bloom-algae.

The P-biogeochemical cycle plays crucial roles in the freshwater ecosystems (Janse et al., 1992; Solidoro et al., 1997; Xu et al., 1999; Hu et al., 2006; Rodrigues et al., 2009), and P release during the decline of bloom-cyanobacteria is one of the most important processes involved. First and second order kinetics of algae decomposition were both observed during the aerobic decomposition of pure phytoplankton cultures or in the presence of bacteria and zooplankton (Jewell and McMarty, 1971). The anaerobic decomposition followed the first order kinetics with the average decay constant of 0.022 d^{-1} (Foree et al., 1970). The regeneration rates

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Table 1
The physicochemical parameters of the water body surrounding microcosms in Meiliang Bay of Lake Taihu during our field experiment.

Parameters	Value	Parameters	Value (mg L^{-1})
Temperature	30.3 °C	TP	0.195
pH	7.81	TDP	0.125
DO	7.02 mg L^{-1}	DIP	0.014
Salinity	0.25%	TN	1.92
TDS	0.345 g L^{-1}	NO_3^--N	0.64
EC	4.08 ms cm^{-1}	NO_2^--N	0.06
Chl-a	9.07 μg L^{-1}	NH_4^+-N	0.46

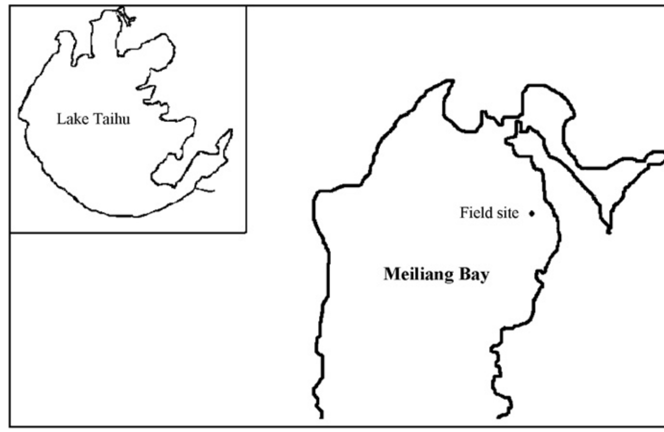

Fig. 1. Location of the experimental sites in the northern Lake Taihu.

of P and nitrogen (N) were first quantified in 1977 (Depinto and Verhoff, 1977). Sun et al. (2007) found that the contents of colloidal P, N and organic carbon (OC) when the cyanobacteria were decomposed were about 5, 9 and 15 times higher than those at the beginning, respectively. The dynamics of water-extractable P during the decomposition of dead *Microcystis aeruginosa* by four bacteria strains were also investigated, which is a more closely related to alkaline phosphatase than acid phosphatase activity (He et al., 2009). Most of these above-mentioned results are from the lab studies or the decomposition of pure algae. Given the dramatic differences in experimental processes between the lab studies and field work (i.e., different environmental factors, water quality parameters, and algal population), the determination of P release from cyanobacterial decomposition via an in situ experiment may be more helpful in our understanding about the P cycles in the aquatic environment.

Lake Taihu is the third largest freshwater lake in China, and has suffered from cyanobacterial blooms in the past few years (Qin et al., 2007; Wang and Chen, 2008). Meiliang Bay, located in the northern areas of Lake Taihu, is one of the areas where cyanobacterial bloom broke out seriously (Qin et al., 2000, 2004; Zhu et al., 2005). Water quality has been deteriorated in Meiliang Bay ever since the early 1980s, switched to the eutrophic state during 1988–1995 and then hyper-eutrophic in recent years (Huang, 2001; Chen et al., 2003; Qin et al., 2004). If P release from the intensive cyanobacteria could increase dissolved P sharply in a short period, the extensive cyanobacterial bloom might make their water quality even worse in Meiliang Bay.

The overall objective of this work is to investigate the in situ release dynamics of P from bloom-cyanobacteria at different cyanobacterial densities in Lake Taihu and the effects of different environmental factors (temperature, illumination and disturbance) and variable parameters, including DO, pH, electronic conductivity (EC), salinity, total dissolved solid (TDS), chlorophyll-a (Chl-a) and cyanobacterial densities, on the P release.

2. Materials and methods

2.1. Experimental site

Meiliang Bay, with an area of 122 km^2, is a typical phytoplankton-dominated lake region that is located in the northern parts of Lake Taihu (Zhu et al., 2007; Xie, 2008). In recent years, serious outbreaks of algal blooms have frequently occurred in this area (Xie, 2008). It was reported that cyanobacteria, especially *Microcystis* spp., are the dominant species of these blooms (Xie, 2008). Cyanobacteria, 91.9% of which was accounted by *Microsystis*, were up to 32.7% of the total phytoplankton biomass in Meiliang Bay.

The environmental parameters of the experimental site were measured as shown in Table 1. The water temperature was about 30.3 °C on average while the pH value changed from 7.61 to 8.61 and DO concentration was in the range of 5.15–8.98 mg L^{-1} throughout the experiment. Other parameters such as EC, salinity and TDS values remained relatively constant (Table 1). Nutrients, including different forms of P such as total phosphorus (TP), total dissolved phosphorus (TDP), dissolved inorganic phosphorus (DIP) and different forms of N including total nitrogen (TN), nitrate nitrogen (NO_3^--N), nitrite nitrogen (NO_2^--N) and ammonium nitrogen (NH_4^+-N) at the field experimental site were also determined during the experimental period.

2.2. Preparation and setting of the experiment

Bloom-cyanobacteria used in this work were collected from Meiliang Bay (31°25′00″N, 120°12′57″E) in July 2009. They were then put aside until decay period when mortality of cyanobacteria was (6.30 ± 0.20%), and then diluted them into different cyanobacterial densities (8.85×10^7 cell L^{-1}, 7.60×10^8 cell L^{-1} and 3.65×10^9 cell L^{-1}) with the lake water taken from the field site (31°28′20.3″N, 120°13′27.6″E). Finally, the 2.5 L bottles as microcosms were placed in the subsurface water body (−20 cm) of Meiliang Bay (31°28′20.3″N, 120°13′27.6″E) where cyanobacteria bloom often broke out from June to October in recent years (Qin et al., 2000, 2004, 2007; Zhu et al., 2005; Fig. 1). All the experiments were conducted with two replicates.

Orthogonal tests with the high cyanobacterial density under three environmental factors were then conducted in the laboratory for 12 days to examine their effects on P release from cyanobacteria. The solutions that containing 2.5 L lake water with cyanobacterial densities of 3.65×10^9 cell L^{-1} were incubated with 5 L flasks in Forma Scientific Orbital Shakers which could control the temperature at 20 °C, 30 °C and the rotational speed at 0 r min^{-1}, 80 r min^{-1}, respectively. When doing the comparisons of illumination, the controlling flasks were packed with aluminum foil and the intensities were quantified by EHSY Lab LX-3621 Digital illuminometer. There were two levels for each factor in replicates as listed in Table 2.

Table 2
Design of orthogonal test of environmental factors.

No.	Environmental factors		
	Temperature (°C)	Disturbance (r min^{-1})	Illumination (lux)
1	20	0	0
2	20	80	2000
3	30	80	0
4	30	0	2000