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Effects of temperature and macronutrients on phytoplankton communities across three largely different lakes identified by a time–space trade-off approach

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ABSTRACT

The impacts of temperature and eutrophication on *Cyanobacteria* blooms were investigated thorugh a time–space trade-off approach. The limnological data of three Lakes, Taihu, Yanghe and Miyun, monitored from 2010 to 2012 were used. After categorising the three lakes by trophic state and water temperature, the study tested: (1) the response of phytoplankton to elevated temperature, by comparing Lakes Taihu and Yanghe, which are different in climate but similar in trophic state; and (2) the response of phytoplankton to higher nutrient concentrations, by comparing Lakes Yanghe and Miyun, which are different in trophic state but similar in climate. Results clearly showed that water temperature was the principle factor contributing to the higher abundance of *Microcystis* in Lake Taihu compared to Lake Yanghe. By contrast, higher abundance of *Microcystis* in Lake Yanghe compared to Lake Miyun could be clearly associated with higher nutrient levels in Lake Yanghe, supported by findings of PO_4-P limitation in Lake Miyun. The study demonstrated that time–space trade-off is a promising approach to manipulate short datasets from different lakes to discover meaningful information.

1. Introduction

Cyanobacteria blooms are globally causing high costs for drinking water treatment and for measures to prevent loss of aquatic biodiversity (Dodds et al., 2008; Yang et al., 2008). There is growing evidence that *Cyanobacteria* blooms are becoming more frequent and widespread, driven by the synergy of eutrophication and global warming (Paerl and Huisman, 2008). Global average surface temperatures have increased by approximately 0.6 °C over the last century and are projected to increase from 1980 to the end of the 21st century by 1.8 °C to 4.0 °C due to the burning of fossil fuels and subsequent rise in atmospheric carbon dioxide (Houghton, 2001; Solomon, 2007). Warming of surface waters promotes longer periods of stratification of the water column, thereby suppressing vertical turbulent mixing, reducing viscosity and shifting the competitive balance between buoyant *Cyanobacteria* and sinking phytoplankton species (Huisman et al., 2006; Paerl and Huisman, 2008; Wilhelm and Adrian, 2008). Generally, *Cyanobacteria*, especially *Microcystis*, dominate at higher water temperatures (>20 °C) and have an optimal temperature for growth above 25 °C (McQueen and Lean, 1987; Robarts and Zohary, 1987). In Lake Steilacoom, Washington, USA, *Cyanobacteria* dominance occurred when surface temperatures exceeded 20 °C (Jacoby et al., 2000). In Lake Nieuwe Meer, the specific growth rate of *Microcystis* showed a higher optimum temperature (≥23 °C) than that of *Bacillariophyta* and *Chlorophyta* (Joehnk et al., 2008). Long-term monitoring records are the best resource to find the dynamics of phytoplankton in response to changes of water temperature and nutrients. However, it is difficult to obtain such long-term monitoring records, in particular phytoplankton species composition data.

This study applies a 'time–space trade-off' approach instead of long-term monitoring records to reveal the impacts of higher temperatures and nutrient concentrations on *Cyanobacteria* growth in the limnological data of three lakes categorized by climate and trophic state. More specifically, it investigated: (1) relationships between the phytoplankton community and water temperature, by comparing Lakes Yanghe and Taihu, which have similar trophic state but different climate; and (2) relationships between phytoplankton community and nutrient concentrations, by comparing Lakes Yanghe and Miyun, which are similar in climate but different in trophic state.

2. Materials and methods

2.1. Studied lakes with different climate and trophic states

Three lakes, Lake Taihu, Lake Yanghe and Lake Miyun, were selected for investigation in this study. The limnological features of these lakes are given in Table 1.

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Table 1
Principle characteristics of Lakes Taihu, Yanghe and Miyun in summer and autumn in 2010–2012.

Index	Parameter	Lake Taihu (Meiliang Bay)	Lake Yanghe	Lake Miyun
Location		31°24′N, 120°13′E	39°59′N, 119°12′E	40°23′N,116°50′E
Climate		Subtropical	Temperate	Temperate
Trophic status		Hypertrophic	Hypertrophic	Mesotrophic
Circulation patterns		Shallow polymictic	Shallow polymictic	Warm monomictic
Surface area (km^2)		129	13	188
Depth (m)	Max	2.6	13.5	43.5
	Mean	1.9	5.7	13.6
Water temperature (°C)	Max	30.0	27.6	27.6
	Min	15.2	9.1	9.1
	Mean ± SD	24.5 ± 4.6	21.2 ± 5.9	21.3 ± 6.0
Irradiation (MJ/m^2)	Max	25.09	23.19	23.19
	Min	9.14	7.32	7.32
	Mean ± SD	19.34 ± 5.06	17.12 ± 5.27	17.12 ± 5.27
Secchi depth (m)	Max	0.39	–	–
	Min	0.30	–	–
	Mean ± SD	0.34 ± 0.03	–	–
pH	Max	9.41	9.49	9.12
	Min	7.86	7.90	7.32
	Mean ± SD	8.58 ± 0.34	8.49 ± 0.49	8.47 ± 0.38
Conductivity (ms/cm)	Max	–	–	5.62
	Min	–	–	3.48
	Mean ± SD	–	–	4.79 ± 0.75
Turbidity (NTU)	Max	–	8.70	3.34
	Min	–	2.10	0.32
	Mean ± SD	–	4.56 ± 2.09	1.26 ± 0.83
TN (mg/L)	Max	4.39	5.92	1.84
	Min	0.72	1.34	0.57
	Mean ± SD	1.94 ± 0.94	3.74 ± 1.33	1.07 ± 0.38
TP (mg/L)	Max	0.1930	0.1861	0.0916
	Min	0.0270	0.0140	0.0059
	Mean ± SD	0.0816 ± 0.0441	0.0742 ± 0.0506	0.0272 ± 0.0248
TN/TP	Max	95	291	149
	Min	7	15	13
	Mean ± SD	34 ± 28	75 ± 63	68 ± 42
NH_3-N (mg/L)	Max	0.17	0.27	0.22
	Min	0.04	0.04	0.03
	Mean ± SD	0.07 ± 0.03	0.13 ± 0.08	0.07 ± 0.04
NO_3-N (mg/L)	Max	3.38	4.96	1.44
	Min	0.04	0.86	0.22
	Mean ± SD	0.70 ± 0.86	2.73 ± 1.24	0.57 ± 0.29
PO_4-P (mg/L)	Max	0.0448	0.0481	0.0297
	Min	0.0021	0.0010	0.0014
	Mean ± SD	0.0090 ± 0.0070	0.0119 ± 0.0106	0.0078 ± 0.0063
Phytoplankton (cells/mL)	Max	210619	53295	10799
	Min	2204	663	136
	Mean ± SD	54,234 ± 54131	15,026 ± 13770	2699 ± 2693

Note: "–" indicates no measurement.

Lake Taihu (31°24′N, 120°13′E) is a hypertrophic, shallow-polymictic lake experiencing a subtropical monsoon climate, with an average water temperature of 15 °C (Fig. 1). Meiliang Bay is situated in the northern part of Lake Taihu. It has a surface area of 129 km^2 and an average depth of 1.9 m (Fig. 1). Due to the economic development in the surrounding region over the past three decades, eutrophication of Lake Taihu has been accelerated. *Cyanobacteria* blooms occurred every year from July to October, whereby *Microcystis* dominated with 85% of phytoplankton biomass (Chen et al., 2003; Liu et al., 2011; Paerl et al., 2011). During this study, water samples at a depth of 0.1–0.5 m were taken monthly at Site A of Meiliang Bay from May to November in 2010–2012. The mean and maximum concentrations of TN were 1.94 mg/L and 4.39 mg/L respectively. The mean and maximum concentrations of TP were 0.082 mg/L and 0.193 mg/L, respectively.

Lake Yanghe (39°59′N, 119°12′E) is a hypertropic, shallow-polymictic lake with an average depth of 5.7 m and surface area of 13 km^2 (Fig. 1). It has a temperate monsoon climate with average water temperature of 12 °C. In 1990–2011, the concentrations of TN and TP presented a rising trend (Wang and Zheng, 2013). The lake has changed from being *Anabaena* dominated in 1990 to *Microcystis* dominated in 2000 (Li et al., 2007). *Microcystis* blooms occurred from August to October every year, with *Microcystis* accounting for 80% of phytoplankton biomass (Zhao et al., 2011). Due to the frozen period in winter, water samples at a depth of 0.1–0.5 m were taken monthly at Site B of Lake Yanghe from June to November in 2010–2012 in this study. The mean and maximum concentrations of TN were 3.74 mg/L and 5.92 mg/L respectively. The mean and maximum concentrations of TP were 0.074 mg/L and 0.186 mg/L, respectively.

Lake Miyun (40°23′N, 116°50′E) is a mesotropic, monomictic lake with a surface area of 188 km^2 and a mean depth of 13.6 m (Fig. 1). It has a temperate monsoon climate and serves as the only drinking water source for Beijing city (Du et al., 2001). Supporting mainly *Diatoms* and *Green algae*, *Microcystis* became dominant only in late summer in recent years (Xue et al., 2012). Due to the frozen period in winter, water samples at a depth of 0.1–0.5 m were taken monthly at Site C of Lake Miyun from June to November in 2010–2012 in this study. The mean and maximum concentrations of TN were 1.07 mg/L and 1.84 mg/L respectively. The mean and maximum concentrations of TP were 0.027 mg/L and 0.092 mg/L, respectively.

2.2. Data collections

At each site, physical and chemical parameters such as water temperature (WT), pH, conductivity (Cond), and turbidity were measured