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Spatio-temporal variation of microcystins and its relationship to biotic and abiotic factors in Hongze Lake, China

Qingju Xue [a], Richard R. Rediske [b], Zhijun Gong [a], Xiaomei Su [a,c], Hao Xu [a], Yongjiu Cai [a], Yanyan Zhao [a], Liqiang Xie [a,]*

[a] State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Number 73 Beijing East Road, Nanjing 210008, China
[b] Annis Water Resources Institute, Grand Valley State University, 740 West Shoreline Drive, Muskegon, MI 49441, USA
[c] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

An investigation of three particle-associated microcystin (MC) congeners (MC-LR, MC-RR, and MC-YR) was performed in 2013 from August to November in Hongze Lake, China. All MCs congeners exhibited significant spatial and temporal variability. Particle-associated MCs were commonly found in this lake, but MC-LR was present at low levels (0.075–1.252 μg/L). All three MC congeners were found to be significantly correlated with non-toxic phytoplankton (e.g., chlorophyte, cryptophyte and diatoms), while only MC-YR and total MC were correlated with cyanobacteria biomass. Copepods, rotifers and three genera of Cladocera were positively correlated with MC concentrations, but feeding habits of these zooplankton species might have different effects on different MC congeners and total MC distributions. Linear mixed effects (LME) model results showed that the interactions between cyanobacteria and other non-toxic phytoplankton or zooplankton species may drive MCs dynamics. Physiochemical parameters also may affect MC congener variability individually or through their effects on toxic cyanobacteria. The results of this study suggested that MCs distribution in Hongze Lake was site-specific and could be influenced by biotic and abiotic factors both individually and through their interactions.

Introduction

Cyanobacteria blooms can cause many water quality issues, including cyanotoxin production, odors and scums (Xie et al., 2011). It is known that the probability of a cyanobacteria bloom being toxic to humans is more than 50% (Utkilen and Gjølme, 1992). In particular, toxic cyanobacteria blooms in freshwater systems around the world have increased in frequency and severity in recent years (Boopathi and Ki, 2014). Various genera of cyanobacteria, such as *Microcystis*, *Planktothrix*, *Nostoc*, and *Anabaena*, are known to produce microcystins (MCs), which are cyclic hepatotoxic peptides that may cause death and illness in humans and animals (Joung et al., 2011). There exist at least 248 MC congeners (Spoof and Catherine, 2017), but only MC-LR and MC-RR have received significant attention.

MC production is influenced by several interacting environmental factors (Lee et al., 2014). Numerous field and laboratory studies have examined the effects of environmental parameters on MC concentration, among which total nitrogen (TN), total phosphorus (TP), water temperature, light intensity, turbidity and phytoplankton biomass were found to be the most important. Previous studies suggested that MC concentration was positively correlated with water temperature (Joung et al., 2011; Yu et al., 2014), whereas the relationship between MC concentration and Secchi depth (SD) was negative (Graham et al., 2004). In most studies, TP was found to be strongly correlated with MC concentration (Joung et al., 2011; Kotak et al., 2000; Krüger et al., 2012). However, studies examining the relationship between nitrogen and MC concentration often produced variable results. Excessive nitrogen loads could promote non-N_2 fixing cyanobacteria and expand blooms of the toxin producing genera (Paerl, 2008). Nitrogen limitation was shown to increase MC production by enhancing the transcription of the *mcy* gene (Boopathi and Ki, 2014) whereas Kotak et al. (2000) found MC-LR concentrations were negatively correlated with inorganic nitrogen and the TN:TP ratio. Conversely, Horst et al. (2014) found that nitrogen-limited conditions led to a substantial reduction in MC concentration. In addition, different phytoplankton community characteristics may lead to significant variation in MC concentration (Cerasino et al., 2013; Dolman et al., 2012). Limited studies have examined the interactions of MCs and zooplankton and primarily focused on the eco-physiological effects (Baselga-Cervera et al., 2014; Harke et al., 2017). Due to the complexity of toxin-regulating factors, research concerning the influence of environmental factors on MC concentrations is still evolving.

* Corresponding author.
E-mail address: lqxie@niglas.ac.cn (L. Xie).

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Hongze Lake is the fourth largest freshwater lake in China and covers an area of 1805 km^2 and has a mean water depth of 1.77 m (Huang et al., 2010; Ruan et al., 2008). It is used for transportation, recreation, aquaculture, and a potential drinking-water source for residents around the lake (Ren et al., 2014). To date, only limited studies have been conducted on this lake and investigations have focused on wetland pollution (Gao et al., 2013), water quality (Zhang et al., 2015) and phytoplankton distribution (Ren et al., 2014). Hongze Lake was classified as eutrophic (Carlson trophic status index of 50–55) in 2011 and 2012 (Hu et al., 2014), and more frequent cyanobacteria blooms may occur if the trophic state deteriorates in the future. In consideration of the size, trophic status, and resource significance of Hongze Lake, additional research on the ecosystem dynamics and stressors is important.

The primary purposes of this study were: (1) to investigate the spatial and temporal patterns of phytoplankton and other lake-water environmental parameters; (2) to determine the concentrations and distributions of total MC concentration and different MC congeners; (3) to describe the correlations between MC congener dynamics and environmental parameters; and (4) to identify potential variables that influence MC concentrations. This information will be important for water resource management and the development of strategies to prevent adverse impacts from increased eutrophication.

Materials and methods

Field sampling and lab analysis

Ten sites were sampled monthly in Hongze Lake from August to November in 2013 (Fig. 1). The sites were well distributed throughout the lake. Although the four months sampling could cover the dynamics of MC in this lake from lowest to highest concentration, missing the growth period of cyanobacteria in April/May was a limitation to this study. All water samples were collected at a depth of approximately 0.5 m below the water surface using a 5-L Plexiglas water sampler (WB-PM, Beijing Purity Instrument Co., Ltd., China). Water temperature, specific conductance (Cond), salinity, pH, turbidity (NTU) and dissolved oxygen (DO) were measured in situ with a Yellow Springs instrument (YSI) 6600 V2 multi-sensor sonde (USA). Water depth and SD (Secchi disk depth) were measured using a sonar fathometer (SM-5A, Japan) and a Secchi disk, respectively. Phytoplankton samples were preserved with 1% acidic Lugol's solution in 500-mL plastic bottles. A total of 10 L of

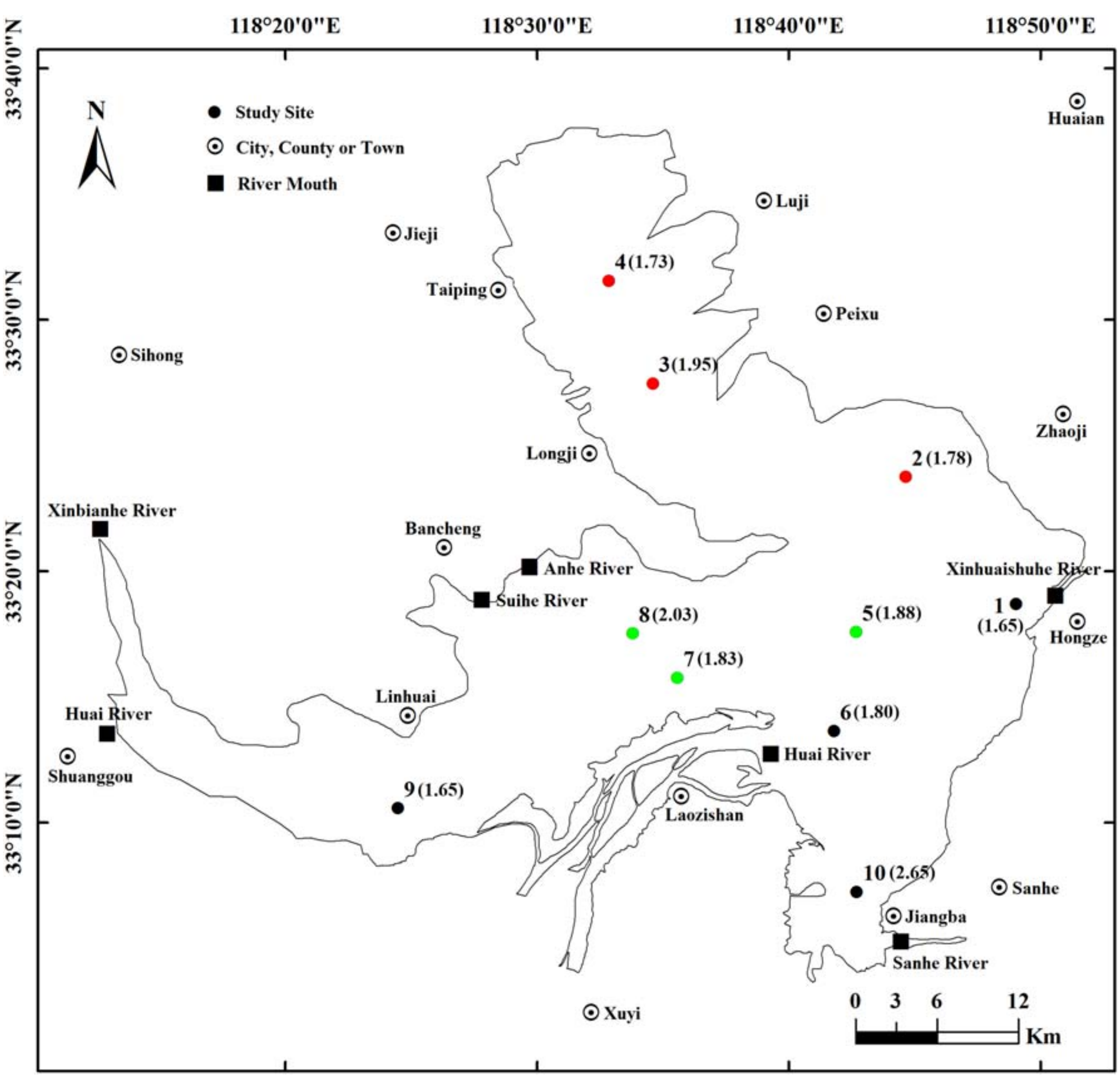

Fig. 1. Sampling site locations on Hongze Lake. Northern region: 2, 3, and 4 (red); central region: 5, 7 and 8 (green); river mouth: 1, 6, 9 and 10 (black). Numbers in parentheses: water depth of this site. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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