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The influence of environmental conditions and hydrologic connectivity on cyanobacteria assemblages in two drowned river mouth lakes

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ABSTRACT

We evaluated the temporal and spatial variability of cyanotoxins, water chemistry, and cyanobacteria communities in two lakes of different trophic status. Bear Lake is a hypereutrophic system that flows into mesotrophic Muskegon Lake. Total microcystins (MC) in Bear Lake (mean, 1.66 μg/L) were composed of multiple structural analogs: 43% MC-LR, 50% MC-RR, and 7% MC-YR. Total microcystins in Muskegon Lake (mean, 0.52 μg/L) consisted of MC-LR (76%), MC-RR (14%), MC-YR (6%), and MC-LA (3%). The lakes were dominated by the cyanobacteria *Microcystis* spp., which accounted for 75% of phytoplankton biovolume in Bear Lake and >90% in Muskegon Lake. Total microcystin concentration was positively correlated with cyanobacteria biovolume and turbidity (Muskegon Lake) and total phosphorus (Bear Lake), while negatively correlated with ammonia (Bear Lake) and nitrate (both lakes). The relationships between microcystins and environmental factors differed between lakes, despite hydrologic connectivity, suggesting that local conditions have a greater influence on toxin production than regional effects. *Cylindrospermopsis raciborskii* was found in both systems; however, the assemblage does not appear to be capable of producing cylindrospermopsin due to the absence of the PKS gene. Although the Bear Lake discharge appears to be the source of *C. raciborskii*, the physical/chemical properties of Muskegon Lake (lower turbidity and temperature, higher nitrate) may constrain the growth of this invasive species. Thus, local conditions in each lake are important in determining which species are capable of maintaining a viable population.

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Introduction

Cyanobacteria blooms are a common nuisance in freshwater ecosystems, resulting in a variety of water quality problems including toxin-production, hypoxia, odors, scums, and potentially unsafe drinking water. Despite their common occurrence, the specific mechanisms that stimulate the growth and toxin production of these blooms are still poorly understood (Paerl, 1988). It is difficult to experimentally induce bloom formation (cf. Wang et al., 2010), which limits our ability to test mechanisms. Observational studies that compare cyanobacterial densities and toxin concentrations in different habitats provide a better understanding of the factors controlling these blooms, which in turn may have important management implications.

Microcystins (MC) are among the most frequently occurring and widely distributed cyanotoxins found in freshwater lakes (Rinta-Kanto et al., 2005; WHO, 2003). The presence of microcystins in water bodies has led to fatalities in wild and domestic animals worldwide, as well as human illness (Metcalf and Codd, 2004). Microcystin production has been correlated with cell growth and toxicity is sometimes higher during cyanobacterial blooms (Long et al., 2001; Rolland et al., 2005). The link between toxin production and growth may explain why many environmental and physiological factors are implicated in microcystin production. In field and laboratory studies, environmental parameters such as water temperature, elevated phosphorus, elevated nitrogen, low stoichiometric ratio of available nitrogen to phosphorus, and high pH (6–9), have been shown to play a role in increasing microcystin production (Johnston and Jacoby, 2003; Oberholster et al., 2004; Paerl, 1988; Rolland et al., 2005; Zurawell et al., 2005).

Cylindrospermopsis raciborskii is a toxin-producing cyanobacterium that thrives in eutrophic to hypereutrophic lakes (Chapman and Schelske, 1997). It can tolerate a wide range of both light and temperature (Varkonyi et al., 2000), accumulates and stores phosphorus efficiently (Istvanovics et al., 2000), and has the capacity to fix atmospheric nitrogen. *C. raciborskii* can produce multiple toxins, and has been implicated in one of Australia's worst cases of human poisoning (Falconer and Humpage, 2001). Due to its potential to produce toxins and its highly adaptable growth, this genus ranks near

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the top of the watch list of toxic cyanobacteria for water managers (WHO, 1999). *C. raciborskii* previously was reported in Muskegon Lake (Hong et al., 2006).

West Michigan contains many eutrophic lakes with histories of cyanobacteria blooms (Hong et al., 2006; Steinman et al., 2008). Studies of cyanotoxins in these lakes have been rare, especially in drowned river mouth systems, despite high levels of recreational use. Muskegon Lake and Bear Lake are both drowned river mouth systems, and are part of the Muskegon Lake Area of Concern (Steinman et al., 2008). The 'Eutrophication or Undesirable Algae' and 'Restrictions on Drinking Water Consumption' Beneficial Use Impairments (BUIs) are listed for both lakes and detailed information concerning the nutrient chemistry, phytoplankton community dynamics, and cyanotoxins are necessary to delist this Area of Concern. The water quality in Muskegon Lake improved after sewage diversion in the mid 1970s (Freedman et al., 1979), but cyanobacteria blooms are still common in the summer (Steinman et al., 2008).

The primary purpose of this research was to provide information on the concentrations of microcystins in pelagic and beach samples taken from Bear and Muskegon Lakes, as well as to analyze their temporal and spatial variability. The secondary purpose was to identify the phytoplankton and cyanobacteria community structure at these sites and to measure corresponding biotic and abiotic factors. Lastly, we examined the total phytoplankton and cyanobacteria communities of both Bear and Muskegon Lakes using non-metric multidimensional scaling techniques to associate microcystin concentrations with environmental factors in each lake. Because Bear Lake discharges into Muskegon Lake through a small navigation channel, our study also allows us to assess the coherence of cyanobacteria community structure and toxin production in two adjacent water bodies.

Materials and methods

Field sampling and lab analysis

Three pelagic sites and three beach locations (Fig. 1) on a public beach were sampled every two weeks in both Bear Lake and Muskegon Lake during July and August 2006 ($n = 56$). Bear Lake is a hypereutrophic, shallow drowned river mouth system with a surface area of 1.66 km^2, an average depth of 2.14 m, and a maximum depth of 3.66 m (Wilson et al., 2005). Bear Lake discharges to Muskegon Lake through a narrow navigation channel at a rate of 0.9 m^3/s and has a mean hydraulic residence time of 30 days (MDNRE, 2008). Muskegon Lake is a mesotrophic/eutrophic, larger drowned river mouth system with a surface area of 16.6 km^2 and an average depth of 7.1 m, with a maximum depth of 23 m (Freedman et al., 1979). Muskegon Lake discharges to Lake Michigan at a rate of 55.5 m^3/s and has a mean hydraulic residence time of 25 days (Freedman et al., 1979). The Muskegon River accounts for 95% of the tributary inputs to Muskegon Lake (Carter et al., 2006). Global Positioning System (GPS) coordinates were taken at each station during the initial sampling survey and used as reference points for subsequent events.

Pelagic samples were collected as integrated epilimnetic one meter water samples, including surface water, using a 1.5 m polycarbonate tube device (Sutherland et al., 1992; Wilson et al., 2005). Beach samples were collected by hand using acid-washed high density polyethylene bottles at a depth of approximately 0.5 m. Samples were immediately placed on ice and returned to the lab for processing.

Samples for toxin analysis were filtered on a 0.7 μm Whatman GF/F glass microfiber filter and stored at −20 °C. Cyanotoxin samples were prepared according to a modified method previously described by

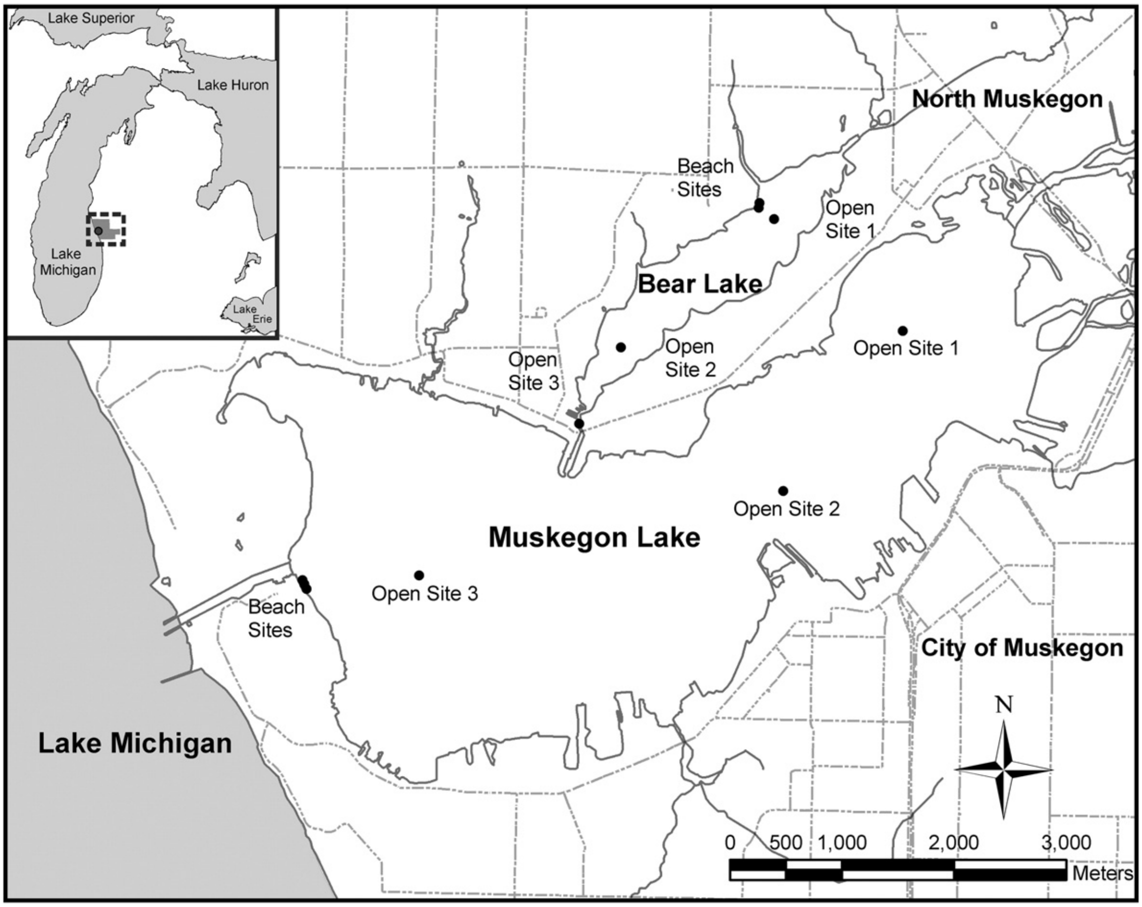

Fig. 1. Bear Lake and Muskegon Lake pelagic and beach sampling locations (2006).

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