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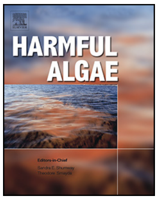

Estimating microcystin levels at recreational sites in western Lake Erie and Ohio

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ABSTRACT

Cyanobacterial harmful algal blooms (cyanoHABs) and associated toxins, such as microcystin, are a major global water-quality issue. Water-resource managers need tools to quickly predict when and where toxin-producing cyanoHABs will occur. This could be done by using site-specific models that estimate the potential for elevated toxin concentrations that cause public health concerns. With this study, samples were collected at three Ohio lakes to identify environmental and water-quality factors to develop linear-regression models to estimate microcystin levels. Measures of the algal community (phycocyanin, cyanobacterial biovolume, and cyanobacterial gene concentrations) and pH were most strongly correlated with microcystin concentrations. Cyanobacterial genes were quantified for general cyanobacteria, general *Microcystis* and *Dolichospermum*, and for microcystin synthetase (*mcyE*) for *Microcystis*, *Dolichospermum*, and *Planktothrix*. For phycocyanin, the relations were different between sites and were different between hand-held measurements on-site and nearby continuous monitor measurements for the same site. Continuous measurements of parameters such as phycocyanin, pH, and temperature over multiple days showed the highest correlations to microcystin concentrations. The development of models with high R^2 values (0.81–0.90), sensitivities (92%), and specificities (100%) for estimating microcystin concentrations above or below the Ohio Recreational Public Health Advisory level of 6 $\mu g\,L^{-1}$ was demonstrated for one site; these statistics may change as more data are collected in subsequent years. This study showed that models could be developed for estimates of exceeding a microcystin threshold concentration at a recreational freshwater lake site, with potential to expand their use to provide relevant public health information to water resource managers and the public for both recreational and drinking waters.

1. Introduction

Cyanobacterial harmful algal blooms (cyanoHABs) cause a multitude of water-quality concerns, including the potential to produce potent toxins in rivers and lakes used for recreation and source-water supplies. These toxins have been implicated in human and animal illness and death in over fifty countries and in at least 36 states in the United States (Graham et al., 2009). The human health risk from cyanoHABs commonly is associated with ingestion or inhalation of toxins during recreational activities (Chorus and Bartram, 1999). Because the incidence of cyanoHABs has been increasing in frequency and severity worldwide (Paerl et al., 2011), water-resource managers need tools to predict when and where toxin-producing cyanoHABs will occur (He et al., 2016). Satellites that collect multispectral data have been used to predict and detect cyanoHABs in lakes and estuaries, including western Lake Erie (Wynne et al., 2013). Satellite data often include estimates of phycocyanin, chlorophyll-a, and cell counts; however, this technology has several challenges because cyanobacterial toxins cannot be directly detected by remote sensing (Lunetta et al., 2015; Stumpf et al., 2016). Although satellite data currently are useful on a broad scale and as an initial warning system for cyanoHAB occurrence, site-specific models are needed to estimate the potential for elevated toxin concentrations that cause public health concerns.

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Microcystins are one of the most frequently detected hepatotoxins in freshwaters and are commonly produced by cyanobacteria in the genera *Microcystis*, *Planktothrix* and *Dolichospermum* (formerly *Anabaena)* (Rantala et al., 2006). Not all strains of these cyanobacterial genera produce toxins, and not all toxin-producing strains continuously produce toxins. Microscopy has been used traditionally to identify and quantify cyanobacteria genera that may produce toxins; however, microscopy cannot identify whether a strain has the ability to produce toxins. Molecular methods, such as quantitative polymerase chain reaction (qPCR), can quantify specific toxin-producing genes from known microcystin-producing cyanobacterial genera. In particular, qPCR can be used to quantify cyanobacteria that contain the microcystin synthetase (*mcy*) gene cluster that is required for microcystin production in the cell.

Currently, toxin measurements require that a sample be collected and analyzed in a laboratory with varying amounts of sample processing and analysis time before results are available. In the interim between sample collection and obtaining results, potential exposures to the public from using or consuming a water source may have already occurred. Models provide the opportunity for public health protection prior to exposure and allow users to be proactive rather than reactive; however, predictions are complicated and likely site specific because of the many factors affecting toxin production.

Many studies have been done worldwide to identify factors that affect cyanoHAB occurrence in freshwater lakes. For those who manage and use a water body for recreation or source-water supply, however, it is important to identify the factors that are related to human and animal health risk—that is, the factors related specifically to toxin concentrations. In a few previous studies, investigators identified factors related to microcystin concentrations on a site-specific level (Joung et al., 2011; Lee et al., 2015; Otten et al., 2012). Other investigators found significant relations between qPCR results for cyanobacteria or cyanobacterial toxin genes and microcystin concentrations (Fortin et al., 2010; Otten et al., 2012; Rinta-Kanto et al., 2009; Conradie and Barnard, 2012; Davis et al., 2009). Optical sensors that provide an indicator of algal pigments (chlorophyll and phycocyanin) have been shown to be promising for providing early warnings of cyanobacterial abundance or elevated microcystin concentrations in recreational waters (Marion et al., 2012) and source-water supplies (Brient et al., 2008; Izydorczyk et al., 2005; McQuaid et al., 2011). Lacking among these previous studies, however, were comprehensive examinations of all types of environmental factors affecting toxin concentrations that could potentially be used in site-specific models.

This study was done to work towards providing water resource managers with models to estimate as quickly as possible the human and animal health risk associated with cyanoHABs. We identified factors that could be used to develop two types of models to estimate microcystin concentrations at freshwater recreational sites. Real-time models include easily- or continuously-measured factors and available environmental data that do not require a sample be collected. Comprehensive models include results from samples collected and analyzed in a laboratory along with real-time factors. The objectives were to (1) identify the environmental and cyanobacterial community composition factors (as measured by microscopy and molecular methods) that were significantly correlated with microcystin concentrations at lake sites and (2) test the feasibility of developing models for estimates of toxin levels. Samples and data were collected at three Ohio lakes, where cyanobacterial proliferation and elevated microcystin concentrations have caused water-resource managers to issue water-quality advisories (Ohio Environmental Protection Agency, 2014).

2. Materials and methods

2.1. Study lakes and sampling frequency

Water-quality and environmental data are presented for samples collected at one site each on three lakes in Ohio, USA (Fig. 1, Buckeye Lake, Harsha Lake, and Lake Erie), that were part of a larger study. Data from the larger study are presented in a companion report that describes weekly to monthly sampling at 11 sites on 8 lakes in Ohio before, during and after the cyanoHAB season during 2013–14 (Francy et al., 2015). The three sites were selected for this article because they were included in the more frequent weekly to semiweekly sampling during 2014.

Buckeye Lake is a man-made lake located approximately 30 miles east of Columbus, Ohio. The Buckeye Lake Onion Island site (39N54′31″, 82W31′00″) was added to the sampling network in 2014 because it is a popular offshore boater swim area. During June–October, 2014, 10 samples were collected at Buckeye Onion Island. William H. Harsha Lake (Harsha Lake) is a reservoir located about 25 miles east of Cincinnati, Ohio. During May–October 2014, 17 samples were collected at an official bathing beach (Harsha Main, 39N01′11″, 84W08′03″) that is part of East Fork State Park. Samples collected in 2013 from Harsha Main were not included in this article because different sondes were used in 2013 and 2014 and the phycocyanin and chlorophyll data could not be verified to be sufficiently homogeneous to combine both years. Maumee Bay is located in the western basin of Lake Erie, east of Toledo, Ohio. For the purpose of this article, Maumee Bay is considered a discrete entity, although it is part of Lake Erie. During May–November, 2013–14, 24 samples were collected at the Maumee Bay State Park (MBSP) Lake Erie beach (41N41′11″, 83W22′32″).

Morphometric, land-use, chemical, physical, and cyanobacterial community composition characteristics of the three study lakes are shown in Table 1. Buckeye Lake and Maumee Bay are both shallow (mean depth <3 m) and Maumee Bay has the largest area among the three lakes. The study lakes are predominantly located in agricultural watersheds (>60% agriculture), with small percentages of impervious surfaces ($<4\%$). Among the physical measurements, pH and average phycocyanin measurements were highest at Buckeye Onion Island and average chlorophyll and turbidity measurements were highest at MBSP Lake Erie. Microcystin concentrations consistently were elevated at Buckeye Onion Island, were lowest at Harsha Main, and ranged most widely at MBSP Lake Erie. At Buckeye Onion Island, cyanobacterial concentrations by qPCR and microscopy were highest (9.1 log copies.100 mL^{-1} and 6.3 log $\mu\mathrm{m}^3\,\mathrm{mL}^{-1}$) among the three sites and *Planktothrix* dominated. Harsha was characterized by a mixed cyanobacterial assemblage and *Dolichospermum*, *Microcystis* and *Planktothrix* *mcyE* DNA were present in significant quantities. *Microcystis* dominated the cyanobacterial community at MBSP Lake Erie.

2.2. Sample collection and field measurements

At each site, three 1-L subsamples were collected within the designated swimming area from the same depths at Harsha Main and MBSP Lake Erie (1-m depths) or the same locations at Buckeye Onion Island (1–1.5-m depths) throughout the season and composited into a 5-L bottle (Graham et al., 2008). The 1-L bottle was lowered approximately 0.3 m below the water's surface, the lid was removed, and the bottle was filled while bringing it up to the water's surface. Water temperature, pH, dissolved oxygen, specific conductance, chlorophyll, and phycocyanin were measured at each subsample location using a hand-held sensor calibrated and operated by use of standard USGS methods (Wilde, variously dated) or per the manufacturer's instructions (YSI Incorporated,