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Algal bloom response and risk management: On-site response tools

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ABSTRACT

Harmful algal blooms caused by cyanobacteria can present a risk to the safety of drinking- and recreational waters and beachfronts through the production of toxins, particularly microcystin, which are highly resilient to degradation. These blooms are difficult to predict, vary in appearance and toxicity, and can show significant spatial heterogeneity: wind- and current-borne scums can produce an order of magnitude range in toxin levels along shorelines. The growing demand for reliable, cost-effective and rapid methods to detect toxins in bloom material and reduce the risk of public exposure cannot be met by most analytical lab turnaround times. Commercial microcystin test kits are now available, but few have been rigorously field-tested or incorporated into monitoring programmes. Working with a local health agency, we evaluated two kits with different operative ranges of detection, applied to samples covering a wide range of water quality, sample matrices, and bloom composition. We compared their performance against lab analyses using Enzyme-Linked Immunosorbent and Protein Phosphatase Inhibition assays. Both kits could resolve samples with high (<10 μg/L microcystin equivalents (MCequiv)) and low/no toxins, but failed to reliably detect toxin levels between 1 and 5 μg/L, at which threshold there were few false negatives (8%) but ~ one third of the samples (32%) yielded false positives. We conclude that these kits are potentially useful for screening and informed risk management decisions e.g. on beach closures, but should be followed up with more rigorous tests where needed. We describe how, based on these results, the kits have been successfully incorporated into the routine municipal beach monitoring and advisory programme by the Hamilton Public Health Services (Ontario).

1. Introduction

Reports of harmful algal blooms in drinking and recreational waters have increased significantly worldwide over the past decades, particularly blooms dominated by cyanobacteria (Murphy et al., 2003; Boyer, 2008; Paerl, 2008; Pelaez et al., 2010; Winter et al., 2011; Watson et al., 2015). There is a growing need for effective and rapid response programmes to minimize the risk of human exposure to these blooms, but their unpredictability, variable dynamics, and complexity make this a challenge. For example, a bloom can develop for several weeks unobserved in the offshore areas of a waterbody before it is transported shoreward by winds and currents and is manifested as thick scums along beaches and shorelines, escalating the risk of public exposure (Bartram and Rees, 2000). These situations can shift rapidly with changes in prevailing winds and currents or other factors, and are extremely difficult to anticipate and manage.

Some species of cyanobacteria produce one or more toxins, the most prevalent and stable being the hepatotoxic microcystins, of which over 120 variants (congeners) are now identified. In addition, cyanobacteria can produce other hepatotoxins, neurotoxins, skin irritants, and numerous other biologically active compounds (Carmichael, 1997; Chorus and Bartram, 1999; Chorus et al., 2000; Funari and Testai, 2008; Carmichael and Boyer, 2016). There are numerous documented cases of animal poisonings attributed to toxic blooms (e.g. Walker et al., 2008) but very few known human fatalities, in part because humans are more likely to avoid water that is aesthetically impaired. Nevertheless, non-lethal exposure may occur more frequently than thought, since it can produce symptoms similar to those caused by flu and other common illnesses. These include fever, chills, sore throat, headache, and gastrointestinal disorders (Carmichael and Boyer, 2016). Skin contact can produce itchiness, redness, hives, and rash. Chronic exposure to cyanobacteria toxins has been associated with liver damage

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and cancer (e.g. Falconer and Humpage, 1996), which is difficult to attribute specifically to the toxins in the presence of other environmental factors (e.g. Stewart et al., 2006; Burch, 2008).

As a result of their prevalence and stability, microcystins are the cyanobacteria toxin most commonly monitored by health agencies and source and drinking water management agencies. Microcystin-LR (MC-LR) is one of the most toxic congeners and more commonly reported as it was the first to be identified. As techniques improve, other congeners such as MC-LA and MC-RR are also recognized to be locally common (Zastepa et al., 2014). The congeners have different biological toxicity (MC-LA > MC-LR > MC-RR) and cross reactivity in antibody-based assays such as the test strips described here. For this reason, the integrated value measured in microcystin equivalents by the test strips and the specific concentrations of individual congeners measured using chemical analyses such as LC-MS/MS are often not equivalent. Current guidelines and regulations for drinking and recreational waters are generally based on maximum acceptable concentration of MC-LR or MC-LR equivalents (MCequiv) (e.g. Chorus, 2013). In Canada, for example, Health Canada (HC) guidelines are specifically based on MC-LR in (treated) drinking water and recreational water (1.5 μg/L and 20 μg/L respectively). In the United States, the US-EPA has adopted a similar standard for drinking water for adults but based on microcystin equivalents (1.6 μg/L MCequiv as a 10-day average, US-EPA, 2015) and has recommended a more stringent standard of 0.3 μg/L to protect children —up to 6 years of age.

While not all cyanobacteria blooms produce toxins, it is advisable to take precautionary risk management actions in response to an event, and there is a rising demand for reliable, cost-effective and rapid methods to detect toxins in bloom and post-bloom material. Toxin-producing cyanobacteria, and the toxins themselves, are difficult to diagnose and monitor (Paerl, 2008; Watson et al., 2015). Toxic and non-toxic cyanobacterial blooms cannot be distinguished by visual inspection. A given bloom can show a wide range of toxin levels, particularly along shorelines where wind and water movement can generate spatial heterogeneity in toxin levels that range over several orders of magnitude (e.g. Bartram and Rees, 2000). Microcystins in particular are highly stable and may persist in the dissolved form or in residual shoreline mats for up to several weeks after an active bloom has disappeared, depending on the conditions, demonstrating the need for post-bloom event follow-up and monitoring (Zastepa et al., 2014).

Bloom response guidance documents developed by regional, national and international organisations provide background and a general framework of procedures and responsibilities (e.g. Chorus and Bartram, 1999; Chorus et al., 2000; Burch et al., 2003; Stone and Bress, 2007; SWRCB/CDPH/OEHHA, 2010). However, most do not define standard monitoring, screening and analytical protocols that can be practically applied in a locally-based bloom risk management programme. An effective programme should include ongoing vigilance and rapid, event-based response, using on-site screening as the basis for follow-up with lab analysis, advisories/postings and other actions. Currently, however, few tools exist which enable a rapid and reliable first-line response and appropriate follow-up as well as discrimination between toxic and non-toxic blooms. This typically necessitates lab analyses and turn-around times of 1–3 days, particularly where blooms are sighted after lab hours. These operational difficulties often result in precautionary and at times, unnecessary lab analyses and postings and closures of beach and recreational waters.

The goal of this study was to evaluate the performance of semi-quantitative microcystin field screening kits in their application as a first line response that can be carried out on site by local personnel. A number of commercially available assays have been developed recently for this application, which include on-site fluorescence-based pigment (phycocyanin) probes and toxin test strips. Although the latter are designed to provide field and lab staff and operators a means of rapid screening for these toxins, few studies have evaluated the performance of these test strips (e.g. Humpage et al., 2012; Aranda-Rodriguez et al., 2015). Especially lacking are rigorous onsite field evaluations of their application, reliability and practicality. Here we compare the *in situ* data collected using two commercially available microcystin test strips with different operative ranges of detection against lab-based analyses of the same samples using Enzyme-Linked Immunosorbent Assays (ELISA) and Protein Phosphatase Inhibition Assays (PPIA), two commonly applied methods used to measure these toxins. Water and bloom material representing a range of water quality, sample matrices and bloom composition were collected in late summer-fall from shorelines, beaches and open waters in Lake Ontario (Canada) and two connected embayments (Hamilton Harbour, the Bay of Quinte). Most areas of the lake itself have good water quality and few or no blooms (Watson et al., 2008). In comparison, Hamilton Harbour and the Bay of Quinte are eutrophic embayments at the west and east end of the lake respectively (Fig. 1). They have a long history of algal blooms, which in the past were dominated by non-toxic, shade-tolerant cyanobacteria and eukaryotic algae. Following remediation and invasion by dreissenid mussels in the 1980–90s, Hamilton Harbour and the Bay of Quinte underwent dramatic shifts in water transparency and foodweb structure and have developed annual and sometimes severe blooms with high spatial, seasonal, and inter-annual variance in toxin levels and cyanobacterial taxa (Murphy et al., 2003; Watson et al., 2005, 2007). They are popular recreational areas, with public and private beaches, marinas, waterfront parks and shoreline access points where there is a high potential for exposure to blooms and toxins. Until recently, the Bay of Quinte and Hamilton Harbour bloom management has been largely reactive, with no formal bloom response management plan (BRMP) in place, but in response to increasing public and management concern, pilot programmes have been established for pathogen and offshore water quality monitoring. Here we describe how we evaluated strip tests for application in the now-established BRMP by local Hamilton Public Health Services (HPHS) agency staff.

2. Methods

2.1. Field sampling

Water samples and bloom material were collected at inshore and offshore sites in western Lake Ontario, Hamilton Harbour and the Bay of Quinte during the summer and fall of 2010 (Fig. 1). Sites were selected based on their level of contact with the public (beaches, waterfronts) and risk (i.e. low-to-high) of cyanobacterial impairment (offshore-inshore sites). Hamilton Harbour and Lake Ontario sites included a deep open water site (1001, Environment and Climate Change Canada long-term monitoring station) and five beach/recreational waterfront areas (Bayfront Park (BF), Pier 4 (P4), Beach Blvd (BBVD), Confederation Park (CP) and Van Wagner's Beach (VWB)). These stations were sampled on a weekly (Hamilton Harbour sites) or biweekly (Lake Ontario sites) basis from late July to the end of October, as part of the HPHS beach monitoring programme. In addition to routine monitoring, all sites were sampled in the event of a bloom report, together with other affected waterfronts in the area. The Bay of Quinte sampling design captured temporal and spatial variance in bloom composition and impairment. This included weekly monitoring at 10 sites (river mouths, shallow nearshore and offshore areas) from the end of July to the end of August and a three-day spatial survey in late September (21–23) at 18 of the sites shown in Fig. 1. As part of a larger monitoring programme, samples were collected at all sites for