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Field and laboratory methods to monitor lake aerosols for cyanobacteria and microcystins

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Abstract This study tested field and laboratory methods for the collection of cyanobacteria and microcystins emitted from lake water. These methods feature a highly portable, on-lake system for collecting aerosols directly from the lake, as well as a laboratory system for measurement of aerosols from freshly collected water samples under controlled conditions. Membrane air filters (0.45 μm) collected small particles such as picoplankton (0.2–2.0 μm) from aerosolized lake water. Picocyanobacteria were distinguished from other photosynthetic cells with epifluorescence microscopy using excitation filters for chlorophyll *a* (435 nm) and for phycobilin pigments (572 nm), characteristic of cyanobacteria. Aerosolization of picocyanobacteria ranged from 8872 to 167,297 cells m^{-3} in the field and 23,764 to 365,011 cells m^{-3} in the laboratory. Microcystin levels from field air filters ranged (below detectable limits) <13–384 pg MC m^{-3} of air. The described methods could be used for monitoring aerosolized cyanobacteria for public health purposes.

Keywords Aerosols · Cyanobacteria · Microcystins · Monitoring

1 Introduction

Public interest and awareness of cyanobacteria blooms, as well as the risk posed by cyanotoxins has been rapidly increasing. Exposure of humans and wildlife to cyanotoxins is often related to surface blooms that result in dense scums of toxigenic cyanobacteria along lake shores (Hudnell 2008; Chorus 2001; Carmichael 1992; Domingos et al. 1999). Hepatotoxic microcystins are the most widespread and well studied of the toxins produced by cyanobacteria (Hudnell 2008; Chorus and Bartram 1999; Chorus 2001; Haney and Ikawa 2000). Microcystins have been detected in animal tissues (Galey et al. 1987; Anderson et al. 1993; Gaete et al. 1994; Hathaway 2001; Murby 2009; Ibelings et al. 2005; Smith and Haney 2006; Trubetskova and Haney 2006; Zimba et al. 2001), food stuffs (Galey et al. 1987; Anderson et al. 1993; Crush et al. 2008), plants (Mitrovic et al. 2005; Crush et al. 2008), and aerosols (Cheng et al. 2007; Backer et al. 2010; Edwards and Lawton 2010; Wood and Dietrich 2011; Gambaro et al. 2012).

There is much evidence suggesting cyanotoxins adversely affect the health of humans and wildlife (Domingos et al. 1999; Jochimsen et al. 1998; Levesque et al. 2013; Li et al. 2010; Hudnell 2008; Chorus 2001; Falconer and Humpage 1996; Caller

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et al. 2009). Few studies have examined risks to wildlife and humans from exposure to airborne cyanotoxins (Genitsaris et al. 2011). However, recent research has indicated that cells may be transported as aerosols from lakes with high concentrations of cyanobacteria and microcystins (Wood and Dietrich 2011; Backer et al. 2008, 2010; Cheng et al. 2007; Brodie et al. 2007). Since aerosols may be a more direct route of exposure to public health for those recreating or living by a contaminated body of water (Stommel et al. 2012; Fleming et al. 2005), we set out to design a method that could address the aerosolization of cyanobacteria released from lake water. We describe here simple, unique laboratory and field methods for the measurement of cyanobacteria and microcystins released from lake surface water.

2 Materials and methods

2.1 Air kit

All aerosols were collected using light-weight personal air monitoring vacuum pumps (Sensidyne, Gilian BDX-II) adjusted to a flow rate of 2 L min^{-1} (LPM) of air collection. Air samples were collected for 4 h in the laboratory and 2–4 h in the field. The field aerosol collector consisted of the personal air sampling pumps affixed to PVC pipes supported by a 1-m iron rod anchored in the lake sediment in the littoral zone of the lake (Fig. 1). Tygon tubing (2-mm-diameter) was connected from the vacuum pump to a Swinnex filter holder (25-mm-diameter) and collection funnel (20-cm-diameter). Filters were pre-rinsed with distilled water and autoclaved at 120 °C before placed in the Swinnex filter holder (25-mm-diameter, 0.45-µm Millipore HATF triton free, mixed cellulose ester filter, bioinert, cellulose acetate, cellulose nitrate, made by Millipore for fluorescence methods). Funnels were affixed over the lake water, approximately 20–30 cm above the surface. Mesh screening was wrapped around the diameter of the funnel to reduce horizontal wind and water disturbances from the collection area (Fig. 1). Membrane filters were used in both the field and laboratory studies for cell counts. Filters from the field were frozen (−40 °C) until processed for microcystins by ELISA (Enzyme-linked Immunosorbent Assay, Envirologix Inc., QuantiPlate Kit for Microcystins and Nodularins, Portland, ME).

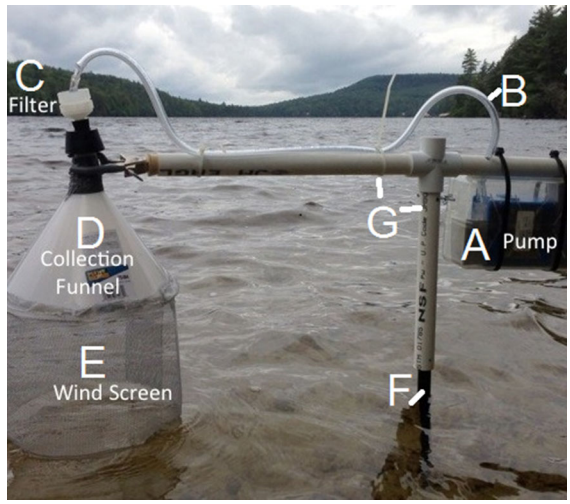

Fig. 1 Portable device for aerosol collections near lake shores. Materials for field air kits: *A* Sensidyne Gilian BDX-II air sampling pumps (with protective case), *B* Pyrex tubing (2-mm-diameter insert for Swinnex connection and 3-mm-diameter connection to pump), *C* Swinnex (25-mm-diameter) and filters (25-mm-diameter, 0.45-µm Millipore HATF membrane filters), *D* 20-cm-diameter funnels, *E* mesh netting (1-mm mesh), *F* metal rod (~2-cm-diameter), *G* ~1 m PVC pipe (2.54-cm-diameter)

Surface lake water was collected in 20-L carboys and kept at room temperature (~20 °C) before tested in the laboratory. All laboratory aerosol experiments were conducted with ambient light (photon flux 30–50 µmol m^{-2} s^{-1}) at 20 °C. A subsample of well-mixed water (500 mL) was transferred to 1-L glass bottles connected to a Swinnex filter holder and the vacuum pump with tubing (2-mm-diameter) in the same arrangement as used in the field aerosol collector (Fig. 2).

2.2 Epifluorescence microscopy

Aerosolized photosynthetic particles were analyzed using an epifluorescence microscope (Olympus BX41 and Olympus DP72 camera). Microscope illumination was provided by a 120-watt high-pressure metal (mercury), halide arc lamp with Intelli-Lamp technology (X-cite 120 lamp; Lumen Dynamics, Mississauga, Ontario, Canada). Autofluorescence and imaging of cells on the filters were visualized with Cell sense Standard software. The epifluorescence microscope had two filter units, each with a dichroic mirror, barrier filter, and excitation filter (Idexcorp, Semrock, Inc.).

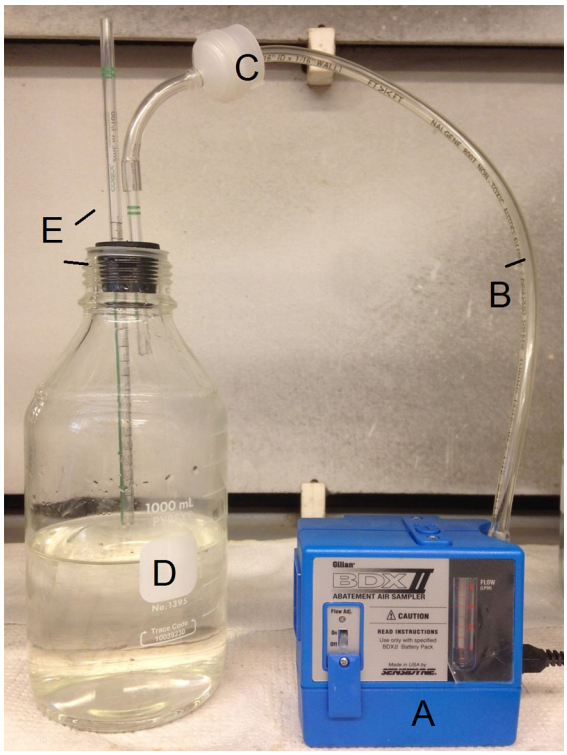

Fig. 2 Laboratory aerosol collection system using fresh surface waters. Materials for laboratory air kits: *A* Sensidyne Gilian BDX-II air sampling pumps (with protective case), *B* Pyrex tubing (2-mm-diameter insert for Swinnex connection and 3-mm-diameter connection to pump), *C* Swinnex (25-mm-diameter) and filters (25-mm-diameter; 0.45-µm Millipore HATF membrane filters), *D* 1-L flasks with 500-mL lake water, *E* rubber stoppers (no. 6/sized to the bottle opening) with 2-mm-diameter exhaust hole

Cell identification and count comparisons were analyzed from images taken from observations using green excitation of the "phycobilin cube" (572/28 nm EM, 605 nm D) and blue excitation of the "chlorophyll cube" (QDLP-A-OMF, QDOT ex: 435, EM) with excitations of 572 and 435 nm, respectively.

2.3 Picoplankton enumeration

After sample collections, filters were placed upright onto glass microscope slides. A drop of distilled water was first placed in the center of the slide to flatten and adhere the filter on top of the slide for viewing. Filters were scanned under epifluorescence microscopy (40× objective and 10× ocular) and photographed with approximately 30 images per filter, primarily using the cube for observing phycobilin pigments to achieve a cell count of at least 50–300 picocyanobacteria cells. The combination of the two filter units was used to best describe cells containing the phycobilin pigments such as phycocyanin and phycoerythrin, primarily associated with cyanobacteria.

Aerosolization of cyanobacteria and total estimated cells per filter were enumerated from the area of the objective field-view image and extrapolated to the effective filter area (21 mm) of the 25-mm-diameter filter. A factor of 3800 was determined from the filter area to the image area (346/0.091 mm) for estimating cells per filter. Average cell counts from approximately 30 replicate images were calculated to determine aerosolization of cyanobacteria from the total air filtered over time. Following microscopic evaluation, filters were frozen until processed for the detection of microcystins.

2.4 Microcystin–cyanotoxicity

Filters from the field were tested for microcystins to determine aerosolization of microcystins emitted directly from lake surface water. Aerosol filters were placed in 2-mL round-bottomed vials with 1 mL of distilled water. Vials were frozen and thawed in triplicate with 1-min sonication and 30-s vortexing in between cycles. Toxin extractions were concentrated 5× by lyophilizing to provide more sensitive detections of microcystins from the filters. Samples were centrifuged at 1200 rpm for 5 min before subsampled for enzyme-linked immunosorbent assay (ELISA) (Envirologix Inc., QuantiPlate Kit for microcystins and nodularins, Portland, ME, standard detection range of 50–2500 pg MC mL^{-1}).

3 Results

The aerosolized cells that were emitted from the lakes were primarily small and unicellular (0.5–2 µm) and were identified as picocyanobacteria based on fluorescence of phycobilin pigments. Aerosolized picocyanobacteria from the five lakes used in the field and laboratory comparisons ranged from 51,964 to 135,612 cells m^{-3} of air in the field and 23,764 to 147,335 cells m^{-3} of air in the laboratory (Fig. 3; Table 1). A wider range of cell concentrations were observed overall when all lakes in the study were included with the field ranging from 8872 to

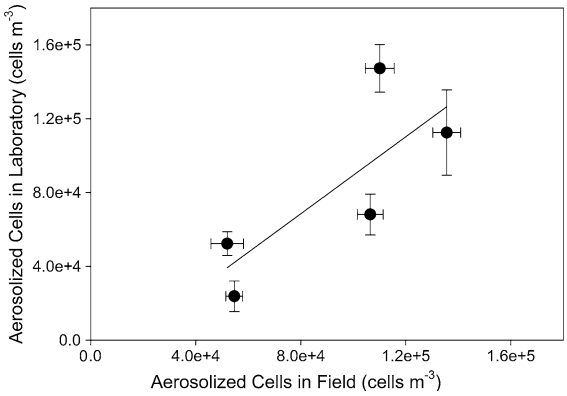

Fig. 3 Linear regression for estimates of cells m^{-3} aerosolized from lake water in the field and laboratory ($y = 1.04 \times -15164.93$, Adj. $R^2 = 0.49$, p value $= 0.12$)

167,297 cells m^{-3} and the laboratory ranging 23,764–147,335 cells m^{-3} for freshwater bodies and an upper limit of 365,011 cells m^{-3} aerosolized from water collected from South Freeport Bay, Maine (Table 1).

Distributions of cells across the filters were highly variable as the coefficient of variation (%CV) for the picocyanobacteria counts per image ranged from 42.89 to 140.52 % in the field and 19.61 to 83.08 % in the laboratory (Table 1). The highest variability from the total data set was from field-collected aerosols of Goose Pond and Mascoma Lake of Enfield, NH, lakes with intermediate aerosol picocyanobacteria concentrations. The %CV for water bodies that were both tested in the field and later tested in the laboratory ranged from 42.89 to 71.89 % and 19.61 to 78.17 %, respectively. Standard error and coefficient of variations support that the cells were not evenly distributed across the filter, with some areas having patches or more cells than other areas (Table 1).

Microcystins were extracted from filters in the field to determine in situ toxicity directly above the surface water. Microcystin concentrations in the lake aerosols ranged from below detectable limits (<13 pg MC m^{-3}) to 384 pg MC m^{-3}. Aerosolized microcystins were not significantly correlated with cell count or total cells estimated per filter.

Table 1 Aerosolization data for laboratory and field collections trials in 2013

Lake	LAT	Long	Date	Cells $image^{-1}$	Coeff. Var. (%)	Cells m^{-3}	Standard error
Laboratory							
Lake Attitash, MA	42.849571	−70.977894	8/14/2013	18.6	19.61	147335	12919
Lake Christine, NH	44.630412	−71.406127	7/24/2013	6.6	27.52	52280	6435
South Freeport, ME	43.823453	−70.106274	10/4/2013	28.8	83.08	365011	27643
Kezar Lake, NH	43.362073	−71.947557	7/24/2013	14.2	46.02	112482	23148
Province Lake, NH	43.691950	−70.995251	7/19/2013	5.4	87.45	42775	16729
Stevens Pond, MA	42.693424	−71.111168	7/18/2013	5.6	27.08	44359	5372
Lake Sunapee, NH	43.380601	−72.052635	7/19/2013	8.6	36.40	68123	11090
York Pond, NH	44.502922	−71.337408	7/24/2013	3.0	78.17	23764	8308
Field							
Lake Attitash, MA	42.849571	−70.977894	8/14/2013	13.9	71.89	110105	5472
Lake Christine, NH	44.630412	−71.406127	7/24/2013	4.1	65.29	51963	6181
Goose Pond, NH	43.697079	−72.092648	7/19/2013	0.8	140.52	8872	2299
Goose Pond, NH	43.697079	−72.092648	7/25/2013	13.2	95.03	167297	28954
Goose Pond, NH	43.697079	−72.092648	7/31/2013	1.3	76.59	15842	2215
Kezar Lake, NH	43.362073	−71.947557	7/24/2013	10.7	42.89	135612	5310
Mascoma Lake, NH	43.628088	−72.147806	7/23/2013	3.4	78.73	47880	6940
Mascoma Lake, NH	43.628088	−72.147806	7/30/2013	4.3	120.62	54498	12001
Mascoma Lake, NH	43.628088	−72.147806	8/8/2013	5.8	90.33	73509	12193
Lake Sunapee, NH	43.380601	−72.052635	7/19/2013	8.4	50.76	106462	4927
York Pond, NH	44.502922	−71.337408	7/24/2013	6.9	64.33	54657	3220

4 Discussion

Photosynthetic cells are often overlooked in the monitoring of airborne particles, although a wide range of living organisms have been identified in aerosols in the atmosphere (Sahu and Tangutur 2014; Dueker et al. 2012; Morris et al. 2011; Chrisostomou et al. 2009; Brodie et al. 2007; Despres et al. 2007; Brown et al. 1964). For example, Charles Darwin noted that the dust collected on the ship of one of his voyages may carry the largest biodiversity of species, settling, dispersing, and propagating in new areas (Darwin 1846). Species composition of airborne algae, varying in size and structure, includes unicellular and multicellular specimens of nearly all major algal taxa. Algae and cyanobacteria have also been found in areas other than aquatic habitats such as in deserts and caves, on surfaces of rocks and leaves, at high elevations, and even in human bones (Sahu and Tangutur 2014).

Chlorophyceae, bacillariophyceae, chrysophyceae, and cyanophyceae are commonly collected airborne algae. Gregory et al. (1955) observed up to 800 individuals of *Gloeocapsa* m^{-3}, while Brown et al. (1964) estimated up to 3000 algal cells m^{-3} of air comprised of 38 genera of chlorophyceae, 17 genera of cyanophyceae, and seven genera of chrysophyceae. Airborne collections from the highest elevations in Tuscon, AZ, USA, were reported to have 16 species from algae (chlorophyceae and bacillariophyceae) and cyanobacteria (Luty and Hoshaw 1967). The presence of diatoms in dust has suggested even these relatively heavy phytoplankton can become aerosolized (Polymenakou et al. 2008; Melia 1984). Schlichting repeatedly detected airborne algae in the atmosphere by culturing cells from air collected by airplanes at altitude (Schlichting 1969, 1974; Schlichting et al. 1973). Most of the studies examined relatively large phytoplankton that could be seen by simple light microscopy after culturing the airborne cells.

Picoplankton including picocyanobacteria are among the most numerous photosynthetic organisms in the world and typically dominate in oligotrophic systems including oceans and deep freshwater bodies (Callieri 2008, 2010; Callieri and Stockner 2002). In this study, we primarily observed picocyanobacteria cells directly from the filters. By using epifluorescence with excitation wavelengths that distinguished between cells with chlorophyll a and cyanobacteria cells with phycobilin pigments, we were able to quantify the abundance of cyanobacteria cells in the picoplankton size range of 0.2–2.0 μm. The methods used in this experiment allowed for collection and enumeration of picoplankton, with focus on the picocyanobacteria.

Replicate scanning and images were necessary for finding the cells on the 21-mm-diameter filter area due to patchiness of cells collected on the filters and to resolve differences between the sample lakes. We selected 0.45-μm HATF membrane filters because of their porosity, smooth surface, and ease of use with epifluorescence microscopy. Our pilot studies indicate filter types such as GFF ($\sim$0.3–0.6 μm after combustion) could also be used for epifluorescence and microcystin detections, as the pore size allows capturing of the picoplankton size categories and glass fiber filters have been used for collection of aerosolized microcystins in other studies (Cheng et al. 2007; Backer et al. 2008, 2010). Glass fiber filters can allow for high-volume sampling, but the thickness and "haystack" configuration of glass fibers may not allow for easy visualization of cells in a small focal plane (unpublished data). Criteria for filter selection will vary according to the intended use and should include porosity and filter thickness for counting small, single aerosolized cells. Filters to be used for toxin collection should be chemically inert and should have both small pore size and high sample volume to allow for detection of toxins present in low concentrations.

For the five-lake comparison, estimates of picocyanobacteria densities ranged from 51,964 to 135,612 cells m^{-3} of air in the field and 23,764–147,335 cells m^{-3} of air in the laboratory (Fig. 3; Table 1). However, when additional lakes were investigated, an even wider range of aerosolized cells can be reported (Table 1). Picocyanobacteria cells were approximately 10–100$\times$ more numerous in our findings than cells enumerated in previous studies. This may be due to our ability to enumerate single cells of picocyanobacteria in aerosols by epifluorescence. For example, the location, filter size, and high-volume sampler used by Wood and Dietrich (2011) in the New Zealand study may explain why there were only between 130 and 9500 cells estimated per filter as compared to the $\sim$3000–110,000 estimated cells per filter used in our study. Though there are several factors that could contribute to such variations, this should be tested further. Additionally, the higher

concentrations of aerosolized picocyanobacteria we have found correspond to concentrations of picocyanobacteria in lake water that generally numerically exceed other larger phytoplankton by several orders of magnitude (Callieri 2008; Callieri and Stockner 2002; Burns and Stockner 1991).

Field and laboratory techniques were designed to estimate the emission of cyanobacteria and microcystins aerosol production directly above the lake surface water. Field air collectors were set in close proximity to the surface water (~ 20–30 cm above the lake water) to allow air movement, but minimize horizontal air flow as well as aerosolization from waves and water turbulence. Aerosolized cells and toxins were likely a result of evaporative processes, small-scale water turbulence, and close proximity of potentially aerosolized cells to the lake surface. Aerosol production in the laboratory was not enhanced by any mechanical agitations or moving other than the exchange of air through the pumping process, and collections were set at 2 LPM (liters per min) in an enclosed fume hood. The cells that were collected were pumped from the air, 2 cm above the subsample of water (500 ml of lake water) in each flask (Fig. 2). Thus, laboratory aerosols were not created by water sprays that may occur under some conditions in lakes, such as high winds and near impoundment outflows. Lack of water sprays or turbulence in our study may have also reduced the likelihood of collecting larger and denser phytoplankton. Although smaller particles have a greater potential to be aerosolized and carried into the air by wind and atmospheric influences (Sahu and Tangutur 2014; Polymenakou et al. 2008), little is known about the mechanisms for aerosolization of phytoplankton and the conditions that promote release of small cells such as picocyanobacteria from lake water.

There has been extensive research indicating the potential toxicity of bloom-forming colonial cyanobacteria, but only few studies have measured cyanotoxins from picocyanobacteria (Domingos et al. 1999). Cyanotoxins are produced by a variety of cyanobacteria with a range of different compounds that affect humans and wildlife in detrimental ways (Hudnell 2008). For example, microcystin is well known to be a liver toxin, inhibiting protein phosphatase activity (Chorus 2001), while BMAA is a highly controversial, non-protein-bound amino acid that has been found to replace serine in the structures of brains (Dunlop et al. 2013). However, microcystins are the most common and well studied of the toxins. There is evidence for microcystin production in many types of cyanobacteria and for its accumulation in animal and plant tissues. Microcystins may affect people by direct consumption of water or indirectly through food. However, little is known on its route to people by breathing or inhalation (Edwards and Lawton 2010). Additionally, little to nothing is known on the route of other potent cyanotoxins such as BMAA to people (Stommel et al. 2012). The recent focus on cyanobacteria as possible contributors to human diseases such as amyotrophic lateral sclerosis and other neurological disorders has raised questions about possible transfer of toxic cyanobacteria through aerosols (Stommel et al. 2012; Banack et al. 2015). This preliminary study reports the potential exposure to picocyanobacteria (or single cells of cyanobacteria from colonies) and the potential contact with the various toxins produced by cyanobacteria through aerosolization directly from lake surface water.

Microcystins were detected in field aerosol trials in New Zealand ranging between 0.2–1.8 and up to 16.2 pg m^{-3} of nodularins from high-volume air samplers set 20 and 30 m above or away from the lake (Wood and Dietrich 2011). Studies near the Midwestern US lakes detected 80 pg MC m^{-3} from people wearing air pumps for 134 min and 34 pg MC m^{-3} after 8 h of pumping air from boats on the water (Cheng et al. 2007; Backer et al. 2008). In our current study, we detected similar concentrations of aerosolized microcystins from five lakes in New Hampshire and Massachusetts (USA) ranging from 13 to 384 pg MC m^{-3} of air. The higher microcystin concentrations in our study lakes may be the result of collecting aerosols directly over surface water, whereas the above-mentioned studies had air collections at greater distances from the surface water of the lakes. The variations in detectable microcystins may also be due to the types of cells aerosolized, as not all cyanobacteria produce similar concentrations of cyanotoxins. Although picocyanobacteria were detected on the filters in our study, the lack of a correlation between cell concentrations and microcystin levels suggests at least some of the microcystins could have been dissolved toxins in the air or single cells from colonial toxic cyanobacteria. It is not surprising that the microcystin concentrations were not significantly correlated with the abundance of cells collected as it

could reflect varying toxicity of the picocyanobacteria cells and/or differences in the abundance of (free) dissolved microcystins potentially present in the aerosols.

There are several hypotheses as to why microcystins specifically did not correlate with cells. (1) We focused on pigments indicative of cyanobacteria to establish the relationship of cyanobacteria cells with microcystins on these filters. However, it is well known that not all cyanobacteria cells produce microcystins. Even strains known to be toxic might have variations in which cells of a single colony are producing these toxins. (2) It is generally assumed that more cells may correlate well with toxins; however, microcystins are only one of many potential toxins produced by the cyanobacteria and it is unknown what the species of cells were. (3) Another unknown is whether the toxins detected were from dissolved free toxins, possibly exhausted from the lake without being transported in a cell. (4) The cells observed were mostly comprised of picocyanobacteria and single cells from colonies. The range and quantities of toxins produced by picocyanobacteria in nature are not well known. Genetic variation of these small cells could aid in understanding the toxicity of these tiny cells. These preliminary tests are the first to explore these as toxic airborne picocyanobacteria. Further studies, possibly using these collection methods, may be done in order to collect small cells that could also be genetically identified to know which cells are producing the toxins.

The methods we propose here are simple, relatively low-cost ways of collecting and classifying cells that are aerosolized directly from lake surface water. Since both the laboratory and field collection methods do not involve enhanced turbulence, bubbling, or sprays of surface water, these concentrations likely represent the emission of cells from surface water. It is also possible that enhancement of aerosolization by sprays may increase the cell concentrations released from lake water and should be further investigated. However, the laboratory aerosol collection method described here may be useful for lake monitoring as it allows for the measurement of aerosolization under controlled conditions and minimizes time spent in the field. The concentration of aerosolized picocyanobacteria corrected for air volume over time was generally higher in the field than in the laboratory when comparing waters collected from the same five lakes (Fig. 3). Conditions in the field, such as horizontal and vertical water movements, may renew the supply of aerosolizable particles, whereas in the laboratory the small volume of water may be exhausted more quickly. Furthermore, samples were aerosolized in the laboratory within a few hours (and not exceeding 24 h) after collection from the field to minimize time-related errors, but it is possible that some changes in water could occur that might alter the aerosolization of cells and toxins in the lake water, such as cell degradation, removal of cells by zooplankton grazing or release of toxins by cell death or sloppy feeding by zooplankton (Lampert 1978).

These methods could be employed under controlled settings as a way to monitor aerosol production from lakes with known harmful cyanobacteria bloom (HCB) problems or clusters of illness. In addition to the potential toxicity of airborne picocyanobacteria, there is also concern of the allergenic effects that some algae and cyanobacteria may have on people (Sharmaa and Rai 2008; Annadotter et al. 2005; Gregory et al. 1955). It is possible that such airborne particles may have higher implications for allergic reactions than pollen alone because they are capable of carrying heavy metals and other pollutants (Sharmaa and Rai 2008; Schlichting 1974; Polymenakou et al. 2008; Gregory et al. 1955). The location of the field air collectors described here could represent the approximate location of a person's head while swimming above water. Therefore, these aerosolization concentrations collected in this manner could be used to estimate recreational exposure by swimming or other activity with close exposure to lake surface water. Since our measurements of aerosols were taken within 2–3 m of the shore, it is not known whether such estimates over- or underestimate the production for the entire lake without a more synoptic survey of aerosols from other regions of each lake. Field aerosol collectors could be placed at varying distances from the lake to allow for estimates of exposure risk to cells and toxins related to location and distance from lake. The comparisons of the field and laboratory methods are especially useful as they suggest that these methods may be employed interchangeably depending on the need of the monitors, weather events, or uses of the lake. There are limitless factors and dynamics that may be tested as monitoring of lake water for cyanobacteria becomes a larger public health issue. Water quality and cyanobacteria monitoring programs may also need to consider the potential public health exposure to toxic cyanobacteria by air.

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