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LakeLine

Volume 43, No. 2 • Summer 2023

Harmful Algal Blooms

Great Lakes, Local Solutions

43rd International Symposium of the North American Lake Management Society

October 22–26, 2023 • Erie, Pennsylvania

At the time when climate change, invasive species risks, and cultural pressures threaten the natural environment and biodiversity of our fragile ecosystem, the opportunity to highlight and mesh the State of Pennsylvania and its rich diversity of aquatic habitats is long overdue.

The Pennsylvania Lake Management Society is proud to welcome the 2023 North American Lake Management Society Conference to Lake Erie. As we endeavor to highlight our Great Lakes, Local Solutions agenda, Erie Pennsylvania provides the opportunity to explore Presque Isle State Park, a National Natural Landmark and The Tom Ridge Environmental Center, while indulging in the amenities of the Bayfront Convention Center and all that Erie has to offer.

Contact Information

General Conference, Registration, Exhibitor & Sponsorship Information: NALMS Office • nalms2023@nalms.org
NALMS Conference Coordinator: Sara Peel • speel@arionconsultants.com
Host Committee Chair: Kate Harms • info@palakes.org

Tentative Schedule

Sunday, October 22
- Exhibitor Set Up
- Welcome Event

Monday, October 23
- Opening Plenary Session
- Technical Sessions
- Exhibits Open
- NALMS Membership Meeting
- Exhibitors' Reception and Poster Session

Tuesday, October 24
- Clean Lakes Classic 5K
- Technical Sessions
- Exhibits Open
- NALMS Awards Reception

Wednesday, October 25
- Technical Sessions
- Exhibits Open

Thursday, October 26
- Workshops
- Field Trips

Workshops

We will be offering a full slate of full- and half-day workshops on Thursday, October 26. These workshops provide attendees the opportunity for in-depth focus on a topic of interest, and many will provide hands-on experience.

Visit the conference website, www.nalms.org/nalms2023, for full details on workshop offerings. Conference registration is not required to attend a workshop.

Photo: Todd Tietjen

Technical Program

Photo: Todd Tietjen

The NALMS 2023 Program Committee has organized an excellent array of presentations on diverse aspects of lakes, ponds, reservoirs, their watersheds, and their many users and inhabitants. Below is a sample of session topics, but please check the symposium website regularly for complete program information.

- Aquatic Invasive Species
- Aquatic Plant Management
- Climate Change
- Fracking
- Harmful Algal Blooms (HABs)
- Nutrients
- Oxygenation
- Paleolimnology
- Remote Sensing
- Reservoir Management

Field Trips

The NALMS 2023 host committee has organized a series of educational and fun field trips on Thursday, October 26. Visit the conference website for more details on the available field trips. Space is limited.

Clean Lakes Classic 5k Run/Walk

Photo: Lisa Borre

Need a little mid-symposium physical activity? Strap on your running/walking shoes for the 2023 Clean Lakes Classic 5K Run/Walk! Starting at 7:00 am on Tuesday, October 24, the 5-kilometer run or walk takes participants on a route along the shores of Lake Erie. You need not be a runner to participate!

Student members of NALMS who participate in the Clean Lakes Classic are automatically eligible to receive $500 for use toward their education thanks to the **Kenneth H. Reckhow Scholarship Fund**. Visit the conference website for full details.

Registration Fees

Regular registration rates available until October 13. Add a 2024 membership to your registration and receive 20% off the membership!

	Early Bird *by Sept 1*	Regular *by Oct 13*	On-site *after Oct 13*
NALMS Member	$535	$595	$685
Non-Member	$665	$735	$825
Student	$285	$375	$455
Single Day	**$255**	**$295**	**$365**
Guest	$270	$300	$350

Register online at nalms.org/nalms2023

LAKELINE

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On the cover:
"Objectionable art – cyanobacteria accumulate over invasive plants." Photo by Ken Wagner, submitted as an entry for the NALMS 2022 photo contest.

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P.O. Box 5443 • Madison, WI 53705
(All changes of address should go here.)

Address all editorial inquiries to:
Amy P. Smagula
29 Hazen Drive
Concord, NH 03301
Tel: 603/419-9325
LakeLine@nalms.org

Address all advertising inquiries to:
Alyssa Anderson
North American Lake Management Society
PO Box 5443 • Madison, WI 53705
aanderson@nalms.org

Payments:
PO Box 7276 • Boulder, CO 80306-7276
Tel: 608/233-2836

From Amy P. Smagula the Editor

Happy summer! I hope you can get out and enjoy your favorite lake(s) during this period of long daylight and warm (hot) days. During this time period, many of our lakes unfortunately become unusable because of problems that arise from warm water, excess nutrients, and all that summer sun. In particular, cyanobacteria blooms, also call cyanobacteria Harmful Algal Blooms (HABs), among other terms, are common during this summer season. Every other summer, we highlight current work and insights related to HABs, and so this issue of *LakeLine* brings together a range of articles focused on HABs.

Rebecca M. Gorney, **Jennifer L. Graham**, and **Jennifer C. Murphy** dive into the term "Harmful Algal Blooms" (HABs) and break down and evaluate the importance of each word in that term, with context about how to describe a harmful algal bloom. Because of the variety of terms used to describe blooms, and the differences in responses and action thresholds across regions and levels of government, this article is both timely and quite useful. Their insights will hopefully help all of us in framing our messaging related to HABs in a more strategic and deliberate manner.

Anne Wilkinson, **Dendy Lofton**, and **Katie Kemmit** identify and review some of the common blind spots in monitoring for harmful algal blooms, which can result in underestimating bloom occurrences or toxicity of blooms. They provide context for improving monitoring programs by identifying potential gaps.

LakeLine encourages letters to the editor. Do you have a lake-related question? Or, have you read something in *LakeLine* that stimulates your interest? We'd love to hear from you via e-mail, telephone, or postal letter.

Ron Zurawell and **Jennifer Graydon** provide an overview of cyanobacteria blooms across Canada, and the variability in monitoring and response frameworks among the Canadian provinces. They also include information about how citizen scientists are answering the call to assist with long-term bloom monitoring activities, which could be a useful model for others adopt.

Jennifer L. Jermalowicz-Jones and **Ryan Navarre** review cyanobacteria and their ability to adapt in and to various habitat conditions. They discuss the causes of blooms, and various means of mitigating the blooms.

In the Student Corner, **Benjamin Harris** discusses his work toward his M.Ed. in Environmental Education as a student at Bard College. Ben is working to evaluate the effectiveness of "Lake School" for lake residents and managers across the Poconos Mountains area of Pennsylvania. He evaluates the level of understanding among program participants before and after their participation in the curriculum, to gauge the effectiveness of educations programs for the citizen science community.

Our *Lakespert*, **Steve Lundt**, expertly weaves a summary of his summer reading on the "devil's element" (phosphorus) with some of the water woes that many of our lakes are facing, but beyond that he recognizes the implications of the global cycling of phosphorus and its impact on a larger scale.

We also hear from one of our NALMS interns, **Skye Embray**, who just completed her internship with the NALMS 314 Workgroup. Skye shares her background, and her upcoming transition to graduate school, as well as her future goals. She discusses her work for NALMS, the deliverables she crafted, to help restore funding for lake restoration and preservation activities.

NALMS president, **Kiyoko Yokota**, provides updates about NALMS, and some of her experiences with HABs.

It's also time to start thinking about attending the NALMS Annual Symposium. We include a preview of the program elements for the NALMS Symposium set for October 2023, in Erie, Pennsylvania. Thank you to NALMS Executive Director, **Philip Forsberg**, for compiling this information. Visit https://www.nalms.org/nalms2023/ for up-to-date conference information.

Happy reading and enjoy your summer season!

Amy P. Smagula is a limnologist with the New Hampshire Department of Environmental Services, where she coordinates the Exotic Species Program and special studies of the state's lakes and ponds.

We'd like to hear from you!

Tell us what you think of *LakeLine*.
We welcome your comments about specific articles and about the magazine in general.
What would you like to see in *LakeLine*?

Send comments by letter or e-mail to editor Amy Smagula (see page 3 for contact information).

From Kiyoko Yokota the President

Happy Lakes Appreciation Month, NALMS friends! This is the time of the year that we enjoy the lakes, reservoirs, and ponds the most.

Otsego Lake in NY (yes, there is another beautiful Otsego Lake in MI) is the headwater of the Susquehanna River and the northernmost end of the Chesapeake Bay watershed. It was considered meso-oligotrophic (moderate to low in productivity) in 2013 when I started teaching at the State University of New York at Oneonta. It was already invaded by several aquatic invasive species (AIS) including Eurasian watermilfoil, curly leaf pondweed, and zebra mussels (ZM). Some considered the increased water transparency (what I consider to be "fake oligotrophication" – increased filter feeding by ZM suppressing the standing phytoplankton biomass and therefore superficially increasing Secchi depth and decreasing chlorophyll-*a*) favorable, while others were concerned about the long-term effects of the invasion documented in the North American Great Lakes.

An ecological tipping point was reached on 27 July 2022 – Otsego Lake started to have recurrent toxigenic cyanobacterial blooms (aka, harmful algal blooms or HABs, although as a biology professor, I insist that cyanobacteria are prokaryotes and therefore not algae!). Otsego Lake blooms at times resulted in multiple independent reports of irritated eyes, nose, and throat by people working on or near the lake, even in the absence of the typical pea-soup green appearance. Now we must consider cyanobacterial blooms in planning lake work in addition to the weather and other constraints.

The Otsego Lake community was shaken. The lake that looked pristine in recent years due to the increased water transparency suddenly turned out to be "toxic." Many seasonal houses on the lake have been using lake water as their sole water source, often with an in-home treatment system designed to reduce pathogenic bacteria and protists but not cyanotoxins. New York State advises against using any surface water for drinking unless it is treated by a public water treatment plant, and people who use household systems to treat surface water for drinking are doing so at their own risk.

I was shocked during the oral presentation by Sarah Ryan (Environmental Director/Emergency Management Director of Big Valley Band of Pomo Indians) at the 13th National Water Quality Monitoring Conference in April 2023 to learn that the researchers found **whole filaments of cyanobacteria**, not just cyanotoxins, in the tap water of homes on Clear Lake that was drawn from the lake and filtered through in-home treatment systems. The results are now published as an original research article in a peer-reviewed journal (Stanton et al. 2023), and I thank the authors for conducting this important study that shed light on how HABs disproportionately affect drinking water safety for those who do not have access to public water lines or deep wells.

In early May I participated in the annual New York State Federation of Lake Associations (NYSFOLA, a NALMS affiliate) annual meeting at Lake George, NY (a large oligotrophic lake also affected by HAB), along with members of OLA and the nearby Canadarago Lake Improvement Association (CLIA). I was very happy to see the first-time participants finding the same "lake connectedness" throughout the meeting. Fred Lubnow and Chris Mikolajczyk (NALMS past president) introduced the NYSFOLA members to the CWA Section 314 advocacy work by the NALMS 314 Working Group. A few weeks later, I was invited as an instructor for the inaugural weekend Lake School by the Pocono Lake Ecological Observatory Network (PLEON) at Lacawac Sanctuary in Lake Ariel, PA. NALMS Region 3 Director Beth Norman put together an excellent program that combined field, classroom, and lab components that covered important concepts that I teach in an upper-level limnology course. NALMS Student Director Lauren Knose taught the highly anticipated HAB module on the last day, culminating with a skillful demonstration of cyanotoxin testing.

I have now joined many of you who are directly engaged in dealing with HABs in a nearby waterbody. I keep empty jars and rubber gloves in my car for opportunistic sampling, and I have invested in a portable microscope, which already helped decipher the identity of a suspected bloom at a popular swimming beach (Figures 1-3).

HABs are a serious global water resource challenge that affects both freshwater and marine systems but, I as a limnologist, am very much encouraged by many breakthrough research findings that are helping us better understand the bloom mechanisms every day, which lead to more targeted and effective management. I hope that this issue of *LakeLine* provides you updated knowledge and inspirations shared by many NALMS members who are working on the frontline of HAB management.

Figure 1. A Microcystis bloom on 12 September. Photo: Holly Waterfield (CLM).

Figure 2. A suspected bloom on 11 June 2023 led to a beach closure – it turned out to be accumulated pollen. Photo: Kiyoko Yokota.

Reference

Stanton, B., A. Little, L. Miller, G. Solomon, S. Ryan, S. Paulukonis and S. Cajina. 2023. Microcystins at the tap: A closer look at unregulated drinking water contaminants. AWWA Water Science. 5(3):e1337. doi:10.1002/aws2.1337.

Kiyoko Yokota, Ph.D., CLM is a limnologist at the State University of New York (SUNY) Oneonta, USA. She graduated from Saint Cloud State University in Minnesota with B.S. in biology with ecology emphasis (summa cum laude) and qualified as an associate professional engineer while working for a civil engineering consultancy in Tokyo, Japan. She was responsible for environmental assessment and water quality forecasting and management projects for new and existing reservoirs, lakes, and rivers. After earning a Ph.D. in ecology, evolution, and behavior at the University of Minnesota – Twin Cities, Kiyoko completed a short-term postdoctoral training at Netherland Institute for Ecology (NIOO-KNAW) before she started teaching full-time, starting at the University of Tampa in Florida. Kiyoko's service to NALMS includes Region 2 Director (2015-18), Student Programs member (2016-present), Government Affairs Committee member (2018-20), Membership ad-hoc Group member (2018), and Professional Certification Program Lead (2018-2022) and member (2018-present). Her research interests include phytoplankton (incl. cyanobacterial bloom) dynamics, microplastic-phytoplankton interaction, biogeochemical cycling, and the impact of climate change on lakes. Aside from her academic position as associate professor of biology at SUNY Oneonta, Kiyoko serves as the technical advisor for the Otsego Lake Association (Cooperstown, NY) and a member of the Water Resources Working Group of the New York State Climate Impact Assessment.

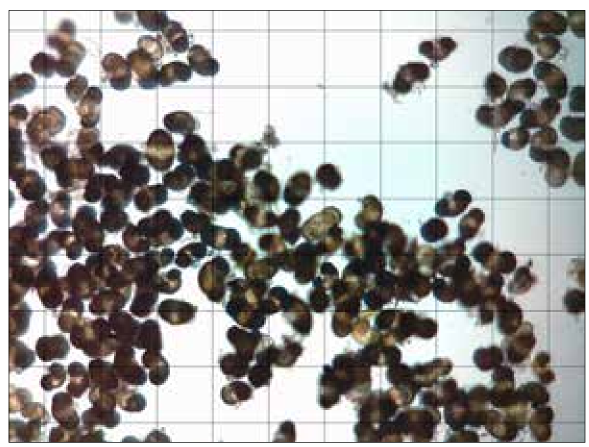


Photo 3. Pollen grains. Each grid in the photomicrograph is 100 µm x 100 µm. Photo: Kiyoko Yokota.

The "H," "A," and "B" of a HAB: A Definitional Framework

Rebecca M. Gorney, Jennifer L. Graham, and Jennifer C. Murphy

Introduction

The use of the phrase "harmful algal bloom" and the acronym "HAB" originated in the marine science world, and referred to blooms also known as red tides, which can kill fish and sea life. The organisms that make up marine HABs generally do not thrive in lakes. In freshwater, HABs are most often associated with blooms of toxin-producing cyanobacteria. The term HAB started to be used broadly in the early 2000s to encompass both marine and freshwater phenomena. Beyond just lakes, cyanobacterial blooms occur in reservoirs, impoundments, streams, rivers, estuaries, or brackish water all over the world (Meriluoto 2017). In addition to cyanobacteria, other freshwater algal groups can accumulate and lead to detrimental impacts on humans, animals, the environment, and the economy.

Usage of HAB has become embedded in the lexicon of many people in the water resource and public health communities. Despite widespread use, an unambiguous definition of the phrase remains elusive, in part because of the inability to define the individual terms scientifically, or even informally. Each user, researcher, or manager of a waterbody will have different concerns. Therefore, they will have different perceptions and definitions of what is harmful and what should be called a bloom. Given this broad use, a simultaneously universal and specific definition of HAB is not feasible.

Here, we seek to break down each term and suggest ways to rebuild with all three elements to foster a shared sense of meaning among individual contexts. When these words are used inconsistently or vaguely, everyone is at risk of miscommunication, and it impedes progress on development of solutions. Lack of understanding can create false expectations, lead to missed opportunities, poorly designed studies, or inefficient use of scarce funding resources. First, we cover the adjectives (algal and harmful) before tackling the noun (bloom). Since a clear, universal, and specific definition is lacking, in this article we aim to build a framework for how to improve the contextual definition and use of HAB moving forward.

Algal/Algae

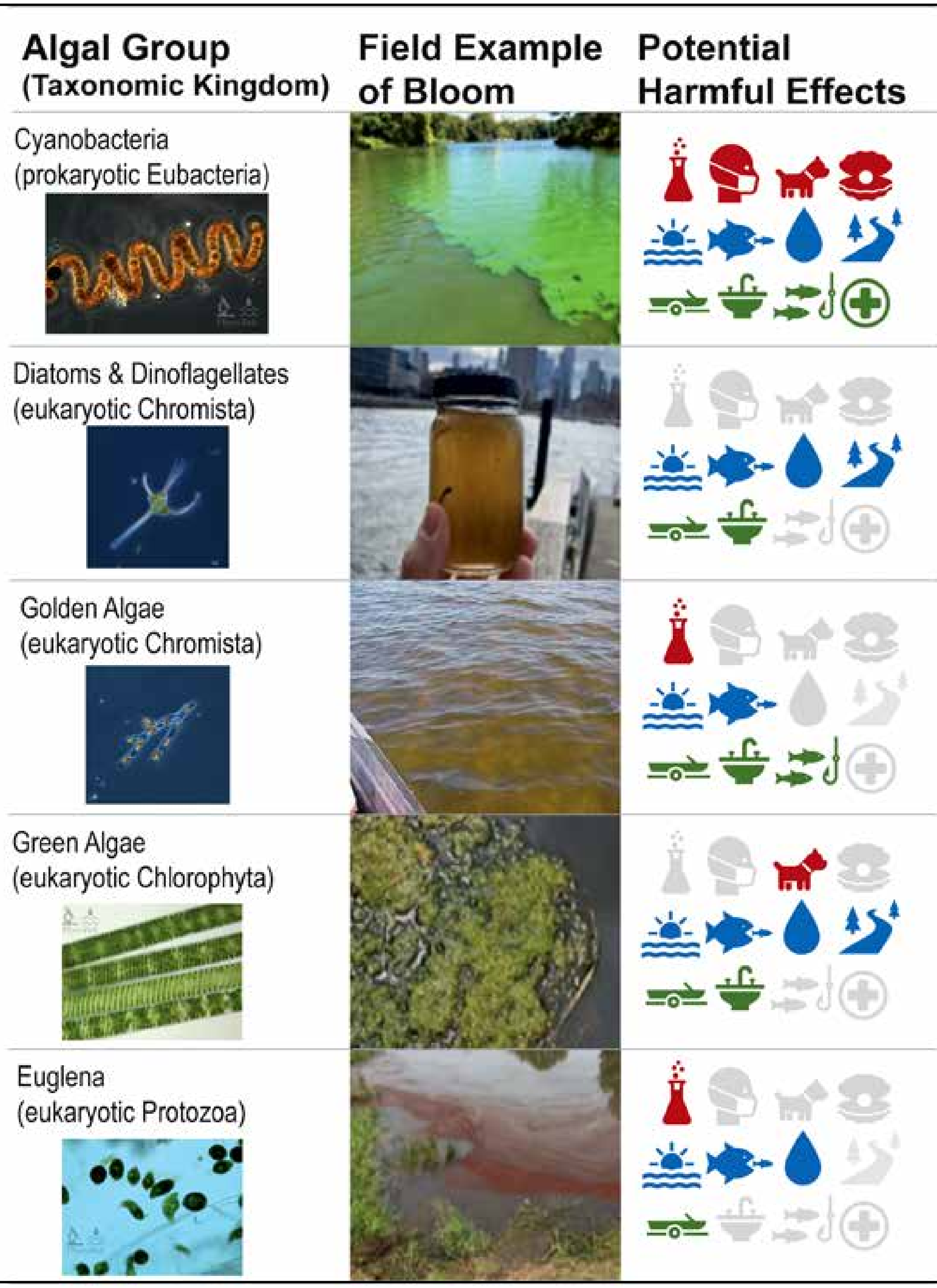
In this context, "algal" is used as an adjective to indicate that the bloom in question is made up of algae rather than flowers or your favorite fried onion dish. The term "algae" includes a diverse group of organisms with only distant genetic connections, across many taxonomic kingdoms (Figure 1). What they all have in common are a preference for living in water, a relatively simple structure (single-celled or colonies of cells) with no vascular system (unlike aquatic plants such as duckweed or pond weeds), and the ability to conduct photosynthesis using chlorophyll-*a*.

Before the advancement of modern-day genetics and microscopy, nearly all green things that grew in lakes were called algae. When it became evident that the group of organisms formerly known as blue-green algae were in fact bacteria, the name was changed to cyanobacteria, though they are still commonly referred to as algae by many people. Nearly all other aquatic algal-type organisms are eukaryotic and have a complex cell structure (cells that have a nucleus and organelles, occur as single or multi-cellular). Cyanobacteria are the only prokaryotic organisms (no nucleus or organelles, always single-celled) that contain chlorophyll-*a* and are capable of photosynthesis. Cyanobacteria have been on the planet for billions of years and evolved well before other algae, zooplankton, fish, or humans. However, the intensity and toxicity of blooms today seem higher than has been measured within the last couple of centuries (Chorus and Welker 2021).

As primary producers, algae serve as the foundation of all aquatic food webs. Algae can be planktonic (live up in the water column), benthic (located at the bottom of a lake or river) or occupy other habitats (such as attached to plants). Algal communities are often mixed assemblages of cyanobacteria, diatoms, green algae, and other algae. However, algal *blooms* are often dominated by one or a few types. The bloom appearance, as well as potential harms will depend on the dominant group (Figure 1). Several terms have already been used to identify cyanobacteria blooms (cHAB, CyanoHAB, or HCB-harmful cyanobacteria bloom), with no consensus appearing to take hold on the best of the bunch. Regardless of the specific acronym or term used, the inclusion of language that clarifies which type of algae is dominant, such as cyanoHAB or green algae bloom, more clearly defines exactly what is being described.

(Potentially) Harmful

When used as an adjective for an algal bloom, "harmful" is subjective, can be confusing, and will depend on the use of a waterbody and the algae present. Thus, the creation of a broad definition of harmful poses a challenge. Harm suggests that damage or injury has already happened, but when we call an algal bloom harmful, often what we really mean is *potentially* harmful. Whether or not a bloom has caused harm can be



LEGEND

Human & Animal	Toxin production
	Human illness via ingestion, skin contact, or inhalation
	Illness and/or mortality of pets, livestock, or wildlife
	Shellfish uptake of toxins
Ecological	Water discoloration/shading
	Reduced biodiversity; Food web alteration
	Hypoxia (low or depleted oxygen) may cause fish kills
	Benthic habitat alteration
Economic	Loss of recreation or tourism revenues; decline in property value
	Increased drinking-water treatment costs; Cleanup costs
	Loss of subsistence fisheries; other fisheries or aquaculture impacts
	Increased medical and veterinary care costs

Figure 1. Potential effects on human and animal, ecological and economic health associated with common freshwater bloom-forming algal groups. Photo credits: Microscopy Photos: (A. St. Amand, PhycoTech); Field Photo Credits: Cyanobacteria (New York State Department of Environmental Conservation), Diatoms (Hudson River Park), Golden (Texas Parks and Wildlife Department), Green (A. St. Amand, PhycoTech), Euglena (B. Rosen, Florida Gulf Coast University).

difficult to determine. Though, to a lake association member, perhaps as soon as a HAB is visible, harm has been done. To a drinking water plant operator, if testing shows finished drinking water meets health standards without added treatment steps, the harm has been minimal. By comparison, if all health standards are met but taste- and odor-causing compounds are causing aesthetic issues, the harm may be substantial. To a dog owner, knowing which type of algae is in bloom and the likelihood that toxins are present will help gauge potential risk to Fido's health and inform the decision whether to let them play in the lake today.

Potential risks to human, animal, ecologic, or economic health (Figure 1) are poorly understood and have not been well quantified, especially in freshwater (Chorus and Welker 2021). Several different types of algae can pose risks, but cyanobacteria blooms are of particular concern in freshwaters due to their potential to produce several types of toxins (Meriluoto 2017) and the wide variety of potential harms they may cause (Figure 1). Algal blooms are often called harmful as a protective measure by public health, resource management, and other decision-makers. This precautionary approach prevents exposure for some but can lead to unnecessary loss of access to drinking water, agricultural water uses, or recreational resources for others. Decisions are sometimes made quickly (for example altering a drinking-water treatment process or issuing a press release) with incomplete information because of a perceived, but poorly understood, health risk that leaves members of the public with more questions than answers.

Care is needed when we talk about harms caused by toxins because only a limited number of algal toxins are routinely measured and our understanding of how toxins affect human, animals, and ecosystems continues to develop. For example, bioaccumulation of algal toxins is an important issue. Shellfish, such as mussels and clams, that live in estuaries where freshwater and saltwater mix can accumulate the toxins in their tissues and may be negatively impacted (Chorus and Welker 2021). While toxins from cyanobacteria have received a lot of attention (and rightfully so), new toxins produced by other algal groups continue to be discovered and studied. Additionally, cyanobacteria blooms can also produce other harmful substances that are non-toxic but can lead to rashes or allergic-type reactions (ITRC 2020). Because our understanding continues to evolve, we do not yet have exposure thresholds for many human or animal health effects related to toxins or other harmful substances produced by algae (Meriluoto 2017).

In addition to humans, our pet dogs, or even livestock, there are potential harms to the entire ecosystem (Figure 1). Some of these potential harms are direct, like excessive algal biomass leading to a reduction in biodiversity or alterations of the food web. Others are indirect, such as oxygen depletion related to biodegradation of algae (Figure 1). Some potential harms are surprising due to a complex chain of effects. For example, *Cladophora* (a genus of green algae) doesn't produce toxins, but when it washes on shore and decomposes, it can act as a home for *Clostridium botulinum*, a bacterium that can lead to botulism outbreaks that kill birds (Chun 2013).

The potential harms to economic health are diverse (Figure 1). There can be loss of revenue for businesses that rely on an access to water, such as marinas. Municipalities may have substantial increases in the cost to treat drinking water for toxins, taste-and-odor causing compounds, and degradation byproducts associated with high amounts of organic carbon. There are also costs that are more difficult to quantify but are certainly detrimental, such as the loss of the use of water for irrigation, or loss of access to subsistence fisheries for Native American communities. When a bloom occurs, end users benefit from as much information as possible.

The combination of the variety of health effects and the scientific unknowns regarding several algal groups warrants the continued use of the word harm in the development of a definition of HAB. Managers might seek to achieve a balance of awareness and alarm among constituents by providing detail on the known impacts of the bloom, and how to reduce harm in the short term. The appropriate outreach will need to be context-dependent such as closing a beach (even on a busy holiday weekend) for swimmers, or in a lake with no swimming, a warning sign at a public boat launch. Many people (including the authors!) tend to use the term HAB and leave it up to the listener or reader to infer the potential harm an algal bloom may impose. Instead of relying on an implicit understanding of the word harm, strive to be explicit about the harms of concern. These potential harms will certainly vary by the waterbody, water user, or scientific study.

Blooms

The word "bloom" has many meanings and is usually associated with a flourishing condition. In the case of algal blooms in aquatic ecosystems, it can imply the potential for negative consequences. Algal blooms can be a completely natural phenomena or can be caused by environmental imbalances related to disturbance, anthropogenic influences, or other factors that promote rapid growth. Because algae are present in most waterbodies, the term "bloom," at the minimum, needs to express an excess in density as compared to background conditions.

Most types of blooms are associated with water discoloration and accumulations of algal material that forms thick scums or mats. Visible indications are, in essence, the simplest way to define a bloom (if you can see it, it's a bloom). But the hue of the water does not necessarily explain the type of algae present, the presence of toxins, or other potential harms. For example, algae, as well as cyanobacteria, may appear green, blue-green, red, brown, or yellow (Figure 1). At times, blooms are present even without the usual visual indicators. This is especially the case for benthic cyanobacteria, which usually don't have the trademark lime green coloration, and deep-water lake blooms that don't float at the surface (ITRC 2022).

Blooms are also notoriously difficult to sample, which makes the documentation of how much algae is growing a challenge. Algal blooms can be highly variable in time and space. Anyone who has seen a bloom in the morning only to find no trace a few hours later understands this issue. Furthermore, surface scums are more likely at the shoreline rather than the middle of a lake, but there could be variable amounts present along a shoreline, within a cove, or around a whole lake. Distribution can easily change with variable water depth, wave action, or daily wind patterns. So how can someone estimate how much of a lake is impacted by a specific bloom?

To further explore how confusing the term bloom can be, below are several indicators that may be used to define a cyanobacteria bloom (adapted from Chorus and Welker 2021 and Hardy et al. 2021):

- an increase in biomass over a relatively short period of time (such as daily, between a few days, or one to two weeks)
- a large algal population indicated by measurement of the algae (such as cell density or biovolume) or proxy measure of a pigment such as chlorophyll-*a* or phycocyanin
- an algal community dominated by a single group or species, such as cyanobacteria
- a visual accumulation of cyanobacteria at the water surface
- a reduction in water clarity
- an event associated with the presence of toxin(s)
- excess growth that extends over a defined area.

Each indicator may have temporal, qualitative, or quantitative thresholds that need to be met for a bloom to be declared present. But the thresholds themselves can vary among states, countries, and habitat types (Hardy et al. 2021). Sample analysis is needed for several of the indicators, which can be costly and time-consuming, but ultimately provides useful data and supports qualitative observations such as photos (Table 1). The parties who collect, analyze, and interpret sample results are often not one and the same. It is important that all people involved have a shared understanding of how a sample should be collected and how the results will be evaluated and shared. Using a spatial component when defining a bloom has tremendous value to making people aware of their exposure risk, as not all blooms affect an entire lake or river.

Communication is particularly important for benthic HABs because they are not always visible at the water surface (ITRC 2022). Cyanobacteria blooms perhaps get the most attention, but there is a wide range of harms associated with other algal blooms and many of the indicators mentioned above can be applied to those different groups.

The design of monitoring programs and setting of thresholds are often focused on public health protection rather than the ecological health. For example, if a bloom occurs in an area where there is limited public access, sampling may not occur, and the bloom is less likely to be documented. Another limitation of monitoring programs is timing, both within a week and throughout the year. A HAB that occurs on a weekend can leave response teams underprepared as staff are not on duty. Many recreational areas are only monitored regularly during the summer, but the waterbody may be used as a drinking-water supply year-round. A bloom that begins in November or occurs under ice could easily be missed or be under-reported.

Since there are so many ways to characterize a bloom, explicit definitions are necessary when communicating to assure all parties are on the same page (Table 1). It is important to describe which indicator measures they used,

Table 1. Several common indicators and examples of thresholds to be met to define a HAB (thresholds adapted from Chorus and Welker, 2021).

[<, less than; >, greater than; µg/L, micrograms per liter; mm^3/L, cubic millimeters per liter]

Indicator	Example Threshold	Benefit	Limitation	Relative Cost
Visual report	Meets visual appearance of a HAB	Rapid, highly protective	Potential for incorrect judgement, no quantification of risk	$
Waterbody Imagery or Micrographs	Meets visual appearance of a HAB and/or cyanobacteria present	Highly protective	Requires expertise for identification, limited quantification of risk	$
Water Clarity (Secchi Disk Depth)	<2 meters visibility	Rapid, highly protective	Potential for incorrect judgement	$
Chlorophyll-*a*	>12 µg/L chlorophyll-*a* with dominance of one algal group	Characterize risk for algal exposure	Time for sample collection & analysis; Not necessarily an indication of the presence of cyanobacteria	$$
Cyanotoxin (toxins specific to CyanoHABs)	>8 µg/L microcystin	Characterize risk for cyanotoxin exposure	Time for sample collection & analysis	$$-$$$
Microscopy	>0.3 mm^3/L biovolume of toxin-producing cyanobacteria	Characterize risk for cyanobacteria exposure	Time for sample collection & analysis	$$$

whether the measures were qualitative or quantitative, if thresholds were used and what they were, and which spatial or temporal characteristics were considered. All these aspects add context to the determination that a bloom was present, its temporal and spatial extent, and how it may lead to harm.

Definitional Framework:

To wrap up, those communicating about HABs benefit their audience by defining each of the three components of the acronym as described above. When interacting in a scientific or public context, strive to be as explicit as possible. Here are some suggestions:

Harmful: Whenever possible, provide information about the relevant potential risks to human, animal, ecological, or economic health associated with excessive algal growth (Figure 1). This information will be context-dependent (for example, recreation versus drinking water treatment) and in consideration of multiple users and potential impacts.

Algal: For communication purposes, cyanobacteria can remain under the umbrella words algae and algal. A clarifying term that specifies which type of algae is present in a bloom (if known) can be used to describe the conditions. If unknown, that is worth stating too.

Bloom: Be explicit about the qualitative or quantitative nature of bloom identification. If quantitative information is used, articulate the specific indicator(s) and threshold(s), along with the data used to derive these. If a spatial or temporal component is known, this provides even more information.

Bottom Line: Because of the current range in state, federal, and international guidelines, the diversity of water users, and the many scientific unknowns, it is not possible at this point to come to a consensus on a single definition of a HAB. To avoid confusion, we highlight the use of this definitional framework where each term is explicitly defined. This small, but concrete step improves communication by not simply using HAB by itself and assuming that the definition is known to the audience.

References

The following resources include extensive information on how to define cyanbacteria-dominated harmful algal blooms. We summarized to a great extent here and have included them as additional publicly available resources on the topic for any readers that want to learn more.

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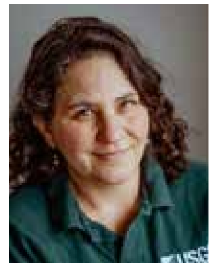
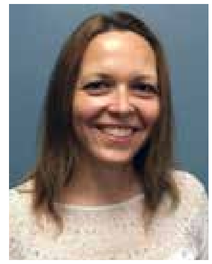


Rebecca Gorney is a physical scientist with the U.S. Geological Survey, New York Water Science Center in Troy, New York. She oversees several HAB research projects and is passionate about science communication. A full professional bio can be found here.



Jennifer Graham is the Chief of the Integrated Water Research Branch in the U.S. Geological Survey New York Water Science Center. She has studied harmful algal blooms in the United States for the past 24 years. Jennifer represents the U.S. Geological Survey on the Interagency Working Group for the Harmful Algal Bloom and Hypoxia Research and Control Act. A full professional bio can be found here.

Jennifer Murphy is a hydrologist with the U.S. Geological Survey, Central Midwest Water Science Center. Much of her work focuses on characterizing and understanding water-quality trends in the Nation's streams and rivers. Jenny also leads a team of scientists working to develop a proxy for harmful algal blooms in rivers. A full professional bio can be found here.

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Blind Spots in CyanoHAB Monitoring

Anne Wilkinson, Dendy Lofton, and Katie Kemmit

Introduction

Cyanobacterial harmful algal blooms (CyanoHABs) are made up of microscopic photosynthetic microorganisms and are most recognizable as bright green or blue-green masses on the water surface of lakes. Not only are these blooms unsightly and odorous, but they can also produce toxins that contaminate drinking water supplies, make pets and livestock sick, and in extreme cases, cause fatality. Currently, there is no universal trigger for CyanoHABs or cyanotoxin production. However, there are some known drivers of cyanobacteria accumulation, which may include excess nutrients and inorganic carbon, warm temperatures, and a stable thermal structure within the water column.

Cyanobacteria can gain competitive advantage over other phytoplankton by regulating their buoyancy, persisting in warm temperature, fixating nitrogen, and producing cyanotoxins. Studies indicate that cyanobacteria produce toxins, like microcystin, to compete with other aquatic microorganisms, e.g., phytoplankton and zooplankton, for dominance within the aquatic ecosystem.

Furthermore, microcystin may aid in regulation of intracellular inorganic carbon during periods of ambient low carbon conditions (Jahnichen et al. 2007), inhibit metabolic activities of other microorganisms, or maintain colony formation through promotion of extracellular polysaccharide production, which aids in buoyancy regulation and predation avoidance (Gan et al. 2012). Because of these competitive advantages, cyanobacteria outcompete other phytoplankton and grow to large densities; consequently, adequate methods to monitor their dynamics and impacts on water quality are of the upmost importance.

Cyanobacteria are ubiquitously found in lakes, reservoirs, rivers, and stormwater ponds. Accordingly, CyanoHABs are monitored by lake managers, water treatment plants, industrial dischargers, municipalities, lake associations, and citizen scientists. CyanoHABs can be monitored on different spatial and temporal time scales. Spatial monitoring can include whole-lake scales monitored via satellite imagery, to finer scales, such as monitoring beach sites designated for swimming. Temporally, CyanoHABs can be monitored on a response basis or near-continuous resolution. There are many types of technologies available for CyanoHAB monitoring, which can be biomass- or toxin-based. For biomass-based methods, the options include microscopy, in situ probes, and satellites. For toxin-based methods, the options range from simple test strips to complex lab analyses able to detect many different types of cyanotoxins. The wide variety of options can make CyanoHAB monitoring intimidating and overwhelming for water resource managers. This article outlines common blind spots in CyanoHAB monitoring and recommendations for overcoming CyanoHAB monitoring challenges.

Common Blind Spots

Equipment selection and procurement may be the largest challenge for many lake managers to overcome for CyanoHAB monitoring, depending on available resources. In addition to questions on the equipment selection, some of the other most common questions for CyanoHAB monitoring include:

- What parameters should be monitored?
- When and how should equipment be calibrated?
- What is the best spatial sampling strategy?
- What is the most appropriate temporal sampling frequency?

Chlorophyll vs phycocyanin

There is no known relationship between chlorophyll and phycocyanin pigment concentrations in lakes. Cyanobacteria (aka, blue-green algae) can contain several different photosynthetic compounds, including chlorophyll and phycocyanin. Chlorophyll-*a* is a common pigment found in all photosynthetic aquatic organisms which facilitates absorption of sunlight. Phycocyanin, on the other hand, is a pigment that is specific to cyanobacteria. In fact, it is the compound which gives blue green algae its name. Chlorophyll-*a* is often used as a proxy for phytoplankton biomass. It is often regulated in lakes and is typically already part of an existing monitoring plan. However, since chlorophyll-*a* is not specific to cyanobacteria, relying on chlorophyll-*a* data alone can lead to inaccurate assumptions of cyanobacteria biomass. For example, phytoplankton assemblages are usually comprised of diverse taxa of algae, all of which can produce chlorophyll-*a*. Conversely, some cyanobacteria only produce small concentrations of chlorophyll-*a* but will produce large concentrations of phycocyanin; therefore, low chlorophyll-*a* concentrations do not always indicate the absence of cyanobacteria. We have often observed cases where chlorophyll-*a* concentrations are relatively low, but concurrent taxonomic data revealed a high density of cyanobacteria. Consequently, it is important to be aware of this potential monitoring blind spot. Where resources allow, chlorophyll-*a* data should be corroborated with taxonomic measurements or phycocyanin measurements to more accurately assess CyanoHAB conditions.

Toxins vs biomass

The true risk to human health is the cyanotoxins and not the cyanobacteria cells themselves, and there is no universal correlation between cyanobacteria biomass and cyanotoxins. The World Health Organization (WHO) has developed advisories for cyanobacteria cell concentrations as a proxy for cyanotoxin likelihood; however, these recommendations have not been adopted by the United States Environmental Protection Agency (U.S. EPA). Cyanobacteria do not consistently produce toxins, and there is currently no way to accurately predict when cyanobacteria will produce toxins. Additionally, most algal blooms are made up of several genera of cyanobacteria that produce different toxins at varying rates. For example, *Microcystis sp.* is a cyanobacteria capable of producing high concentrations of microcystin. It does not, however, produce as many different types of cyanotoxins, as does *Aphanizomenon sp.,* which can produce cylindrospermopsin, anatoxin, and saxitoxins, among others. Thus, an advisory based on cell counts does not account for the species composition of the cyanobacteria and can therefore misrepresent the cyanotoxin risk.

Cyanobacteria biomass can be measured in several different ways: phycocyanin, microscopic identification, or dry weight. Cyanotoxins can be measured using qualitative test strips, enzyme-linked immunosorbent assay (ELISA), or more precise laboratory methods like liquid chromatography combined with mass spectrometry (LC MS). Though there have been correlations between biomass and cyanotoxins (Wilkinson 2020), they are lake- and assemblage-specific.

Some major disadvantages of cyanotoxin analysis includes the costs and turnaround time for results, which can be a week or more. Biomass methods, especially those with a calibrated probe can provide some level of risk assessment more quickly and at a lower cost, but it is important to communicate the level of uncertainty with using biomass-only results. So why measure biomass at all? It depends on the goal of the monitoring plan, but understanding the accumulation of cyanobacteria biomass, and ideally the taxonomic identification of cyanobacteria, can illuminate management strategies and risk management. Also, management strategy effectiveness can vary between different cyanobacteria species. For instance, artificial mixing management would not be as effective on low-buoyant/low-light dependent cyanobacteria like *Planktothrix sp.* because they are adapted to and thrive in well-mixed conditions. Understanding the cyanobacteria composition and characteristics of dominant species can inform management and monitoring strategies. Thus, as budgets allow, monitoring plans should include both cyanotoxin and cyanobacteria biomass measurements. While there is no universal correlation between cyanotoxins and cyanobacteria, documenting local trends can help with risk management on a lake-specific basis.

Phycocyanin probe calibration

As discussed above, phycocyanin is a photosynthetic pigment specific to cyanobacteria. There are several options for phycocyanin analysis, including bench scale laboratory analysis and phycocyanin probes for collecting in situ measurements. Phycocyanin probes are a great way to get quick qualitative cyanobacteria assessment and can sometimes be added to multiparameter sondes. Phycocyanin probe data should be used as a qualitative measurement to understand relative changes in cyanobacteria biomass spatially and temporally. Phycocyanin probe data can be affected by turbidity, color, and cyanobacterial community. The default unit for the phycocyanin probes is relative florescence units (RFU), and these data can often be calibrated with rhodium, extracted phycocyanin, or cyanobacteria enumeration to establish site-specific relationships. It is difficult to compare phycocyanin probe measurements between different lakes or even different years within the same lake because of the water column conditions stated above. Thus, it is recommended that if phycocyanin probes are used as a proxy for cyanobacteria biomass, they should be calibrated using cyanobacteria biomass enumeration from the lake each year to establish site-specific relationships for trend analysis. These lake and seasonal relationships adjust the phycocyanin data to compensate for geographic and seasonal water column conditions that can affect the phycocyanin probe measurements. After the data are adjusted, phycocyanin data can be compared amongst different lakes and different years.

So, what parameters should be used to calibrate the phycocyanin probe? Calibrants that are direct measurements of cyanobacteria concentrations are the most representative for CyanoHAB conditions (e.g., cell concentration, biovolume [BV], dry weight). Since cyanobacteria have different morphologies (Figure 1) and produce phycocyanin at different rates, using BV is the best calibrant (Wilkinson 2019). BV can be analyzed by microscopy and is a normalizing parameter amongst different cyanobacteria, as it is a measure of the cellular volume and captures the variable morphologies of the cyanobacteria genera.

Spatial heterogeneity

CyanoHAB presence and density can vary vertically and horizontally within the lake. Most cyanobacteria can regulate their buoyancy which allows them to move throughout the water column seeking favorable conditions like nutrients and light. It is important to understand the spatial variability within the lake, when designing monitoring plans so that CyanoHAB presence and risk is not underestimated. Horizontal variability can be assessed through different methods including satellites, drones, citizen scientists, historic accounts, shoreline inspections, in situ measurements, and wind analysis. Vertical variability is driven by mixing conditions and density gradients within the water column (Wilkinson 2019 and 2020). Overall water column stability acts as a scaffold for cyanobacteria accumulation, allowing us to predict if cyanobacteria are mixed throughout the water column or can accumulate in the epilimnion. The driving force for vertical heterogeneity of cyanobacteria within the epilimnion is wind-mixing and surface water temperature, which determines if

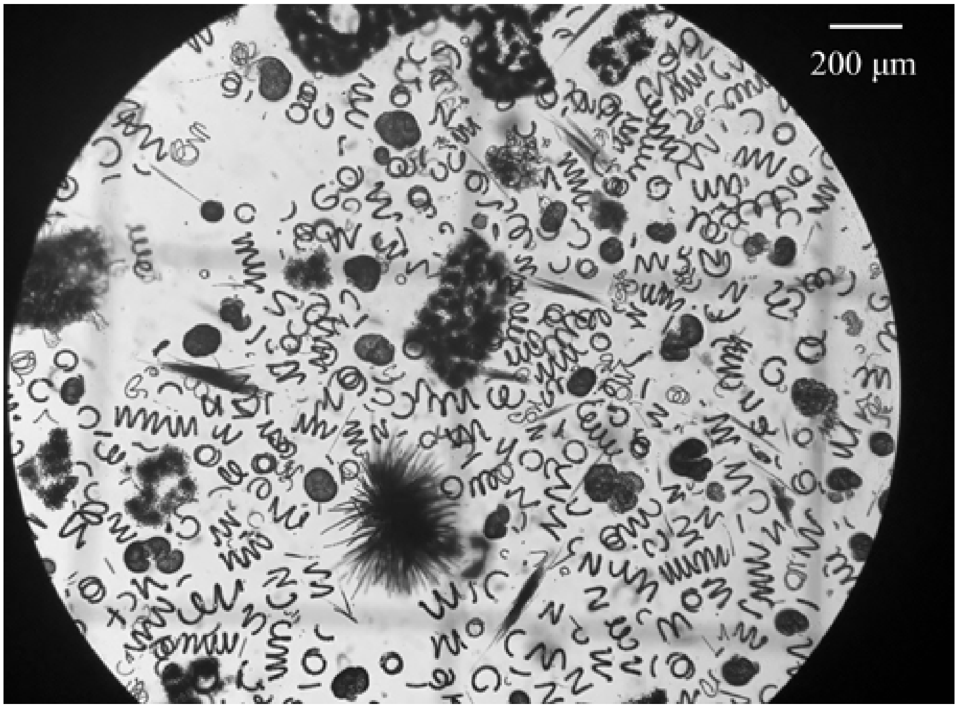

Figure 1. Micrograph of cyanobacteria assemblage.

cyanobacteria are uniformly mixed above the thermocline or whether they form distinct peaks throughout the epilimnion.

Understanding the stability of the water column and local mixing conditions dictates the monitoring depth(s) so that cyanobacteria concentration is not underrepresented. For instance, in the case of a thermally unstable water column, cyanobacteria are uniformly mixed throughout the entire water column (Figure 2a). Thus, cyanobacteria sample collected from anywhere within the water column will likely be representative. If the water column is stable but the wind is high, the cyanobacteria are expected to be well-mixed in the epilimnion (Figure 2b). Likewise, any monitoring depth within the epilimnion will be representative. However, if the water column is stable and the wind is low, cyanobacteria can form local maxima (Figure 2c). Multiple monitoring depths within the epilimnion are therefore necessary to capture the variation in community composition and density.

Depending on the goals of the monitoring plan, it is possible that only one location is appropriate for risk assessment, such as at water treatment intakes or swimming beaches. However, if predictive models based on observed data are being developed to achieve early warnings for CyanoHAB formation, it is imperative that representative samples are captured to accurately predict the risk (Figure 3).

Monitoring frequency

Cyanobacteria blooms are temporally transient because of their competitive advantages, aggressive accumulation potential, and susceptibility to mixing, as discussed above. High monitoring frequency is paramount to predictive modeling accuracy. Monitoring gaps can lead to missed or inaccurate conclusions. For example, cyanobacteria can reach exponential growth in five days, thus even weekly monitoring is potentially not frequent enough to capture bloom dynamics (Wilkinson 2016). Thus, high-frequency monitoring of CyanoHABs and toxins is really needed to accurately assess public health risk; however, lower frequency monitoring of CyanoHABs is often necessary due to resource limitations.

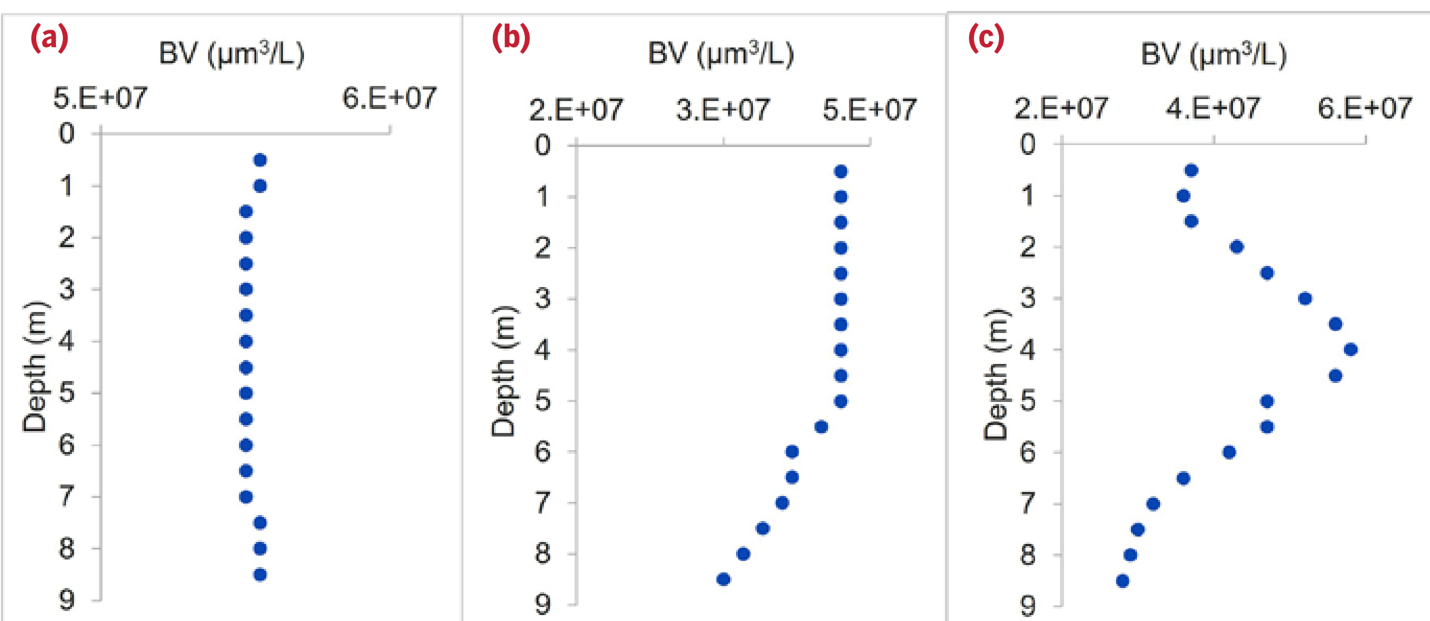

Figure 2. Examples of cyanobacteria vertical distribution under different stability and mixing conditions.

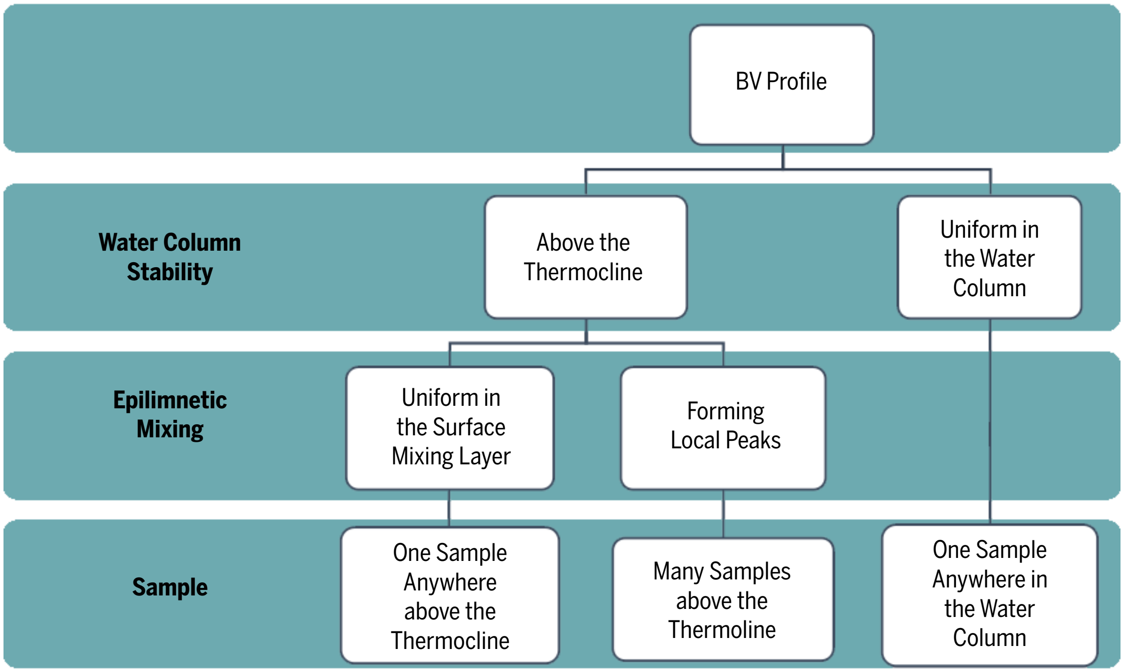

Figure 3. Monitoring depth decision tree.

Conclusion

The complexity and uncertainty of CyanoHABs can lead to blind spots in monitoring plans including monitoring parameters, equipment calibration, sampling location, and monitoring frequency. Additionally, the many options for CyanoHAB monitoring can be overwhelming for resource managers. However, understanding the potential blind spots and how to interpret monitoring results based on of those blind spots is key to achieve successful CyanoHAB management within your waterbody.

Consequences of blind spots

The consequences of monitoring blind spots include over or underestimating CyanoHAB or toxin risk, errors in assessing feasibility of in-lake management actions, and errors in prediction accuracy. Underestimating risk can lead to missed opportunities for effective management, misallocation of resources, and damage to the ecosystem or public health. Though these blind spots exist, any of the methods discussed above can still be used based on the goal of the monitoring plan and if the manager is aware of the blind spots in the interpretation of the data. For example, one monitoring location at the intake of a drinking water treatment plant can alert managers of conditions at the inlet, to help prepare for possible algal blooms within the source water. In large drinking water systems, additional monitoring locations and highly resolved data could aid in development of predictive models, which can be used to predict when a bloom might reach the water intake thereby giving water treatment managers more time to respond and implement HAB protection protocols (e.g., alter depth of water intake or utilize more expensive treatment options).

Recommended monitoring plan

Not everyone has the same resources or goals for their monitoring plans. Below are three options for monitoring plans, based on cost and staff effort (Table 1). The options range from tests for presence/absence of cyanobacteria only (Tier 1) to continuous, high-frequency monitoring, with quantitative cyanotoxins (Tier 3). Each tier has a varying degree of analysis outcomes and costs for implementation. Tier 1 is a low-cost, qualitative option for determining if cyanobacteria are present. Temporal variability of CyanoHABs can be recorded if Tier 1 is performed routinely. Samples collected can be preserved indefinitely and analyzed in the future if funds become available. Tier 2 includes qualitative cyanotoxin analysis, which can be performed in the field, and includes cyanobacteria identification. The cyanobacteria identification can inform the potential for other cyanotoxins that may be present and could guide the need to measure toxins. Where resources allow, Tier 3 analysis includes algae identification, phycocyanin profiles, quantitative laboratory cyanotoxin concentration, and cyanobacteria identification. Tier 3 analyses allow for high resolution of vertical variability of cyanobacteria distribution and can determine the exact concentrations of cyanotoxins to better inform the risk to the environment and public health.

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Table 1. Recommended Monitoring Plan Options.

Tier	Analysis	Equipment	Costs/Staff Commitment	Analysis Description	Data Analysis Outcomes
1	***Jar Test***	Bottles, preservative, eye dropper, test tubes	Staff time and equipment	***Jar Test:*** Presence/absence of cyanobacteria, does not inform level of toxicity/ toxins	***Answers:*** Presence of CyanoHAB and temporal variability (if test is performed routinely). Allows for preservation of sample for Tier 2 analysis in the future (if desired).
2	***Jar Test*** (Tier 1) ***Cyanobacteria identification*** ***Cyanotoxin Test Strip***	Bottles, preservative, eye dropper, test tubes, cyanotoxin test strips	Staff time and equipment $100-300/sample for Cyanobacteria Identification $10-$50/test strip	***Jar Test:*** See Tier 1 ***Cyanobacteria Identification:*** cyanobacteria concentrations and community composition ***Test Strips:*** qualitative toxin concentration	***Answers:*** See Tier 1 ***Answers:*** What is the cyanotoxin concentration range? ***Answers:*** What is the potential for other cyanotoxins? What triggers for CyanoHAB may be present in the lake which can help inform management?
3	***Cyanobacteria identification*** (Tier 2), ***Phycocyanin in-situ profiles,*** ***Laboratory Cyanotoxin test*** Note: no tier 1 necessary	Bottles, preservative, eye dropper, test tubes, Phycocyanin probe	$100-300 per sample for Cyanobacteria Identification $3,000-$15.000 for phycocyanin probe $200-600 sample for toxin analysis	***Cyanobacteria Identification:*** See Tier 2 ***In-situ profiles:*** vertical distribution of cyanobacteria ***Lab Test:*** specific concentration of the 3 most common cyanotoxins	***Answers:***: See Tier 2 ***Answers:*** Are the cyanobacteria accumulating at specific depths? ***Answers:*** What is the exact concentration of the cyanotoxins driving the HAB toxicity? This will better inform risk to animals and recreation and management efforts.

Anne Wilkinson, Ph.D., is a water resources engineer at Stantec in Minneapolis. She works on projects assessing in-lake and watershed nutrient management, harmful algal monitoring, and subwatershed water quality assessments. Anne Wilkinson received her Ph.D. from the University of Minnesota in civil engineering at St Anthony Falls Lab, investigating the effect of environmental conditions on the abundance and toxicity of harmful algal blooms. Her work focused on physical mechanisms in lakes that drive the distribution and fate of cyanobacteria and cyanotoxins. anne.wilkinson@stantec.com

Dendy Lofton, Ph.D., CLM, is a senior limnologist with Stantec based in Minneapolis, MN. Dendy has over 17 years of experience in water resource monitoring, assessment, and management with specialized expertise in biogeochemical nutrient cycling in lakes and eutrophication. She holds a Ph.D. from the University of North Carolina where she researched carbon and nutrient cycling in shallow Arctic Alaskan Lakes. Currently, Dendy leads Stantec's Minnesota-based lake restoration and management team and serves as Stantec's National Water Quality Technical Lead. dendy.lofton@stantec.com

Katie Kemmitt is a water resources scientist at Stantec in Plymouth, MN. She has six years of professional experience in planning, coordinating, collecting, analyzing, and communicating surface water and natural resources information. At Stantec, Katie serves as a technical advisor to the Shingle Creek and West Mississippi Watershed Management Commissions located in Hennepin County, MN. She leads the watersheds' monitoring programs, manages restoration projects, and provides technical expertise. Before coming to Stantec, Katie received a master's degree from Arizona State University studying biogeochemical cycles in arid streams. katie.kemmitt@stantec.com

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Cyanobacterial Blooms and Recreational Water Quality Monitoring in Canada

Ron Zurawell and Jennifer Graydon

History

For provincial and territorial governments and health agencies across Canada, the past decade has been a period of significant development and implementation of recreational water quality monitoring and surveillance programs. By area, Canada is the second largest country in the world at 9,984,670 Km^2 (3,855,100 mi^2) of which nearly ten (10) percent is covered by freshwaters. The more than two million Canadian lakes, reservoirs, and rivers span 20 ecozones, temperate, subarctic, and arctic climates, and represent a wide range in size, hydrology, water quality, and biological diversity. This great diversity in the quality and use of surface water resources along with massive differences in population density, creates significant challenges to protecting human health (Giddings et al. 2012).

Cyanobacterial blooms and toxic events are not new phenomena in Canada. Historically, they have been prominent across the prairie provinces of Alberta, Saskatchewan, and Manitoba whose ecozones are largely dominated by prairies in the south and boreal plains in the north (Figure 1a and 1b). Phosphorus-rich sedimentary bedrock predominates within these landscapes and in the transitional Parkland sub-region separating them and as a result, eutrophic lakes are common. These lakes often have shallow, polymictic basins that are highly susceptible to internal (sediment) phosphorus loading, which sustains significant growth of cyanobacteria (Figure 1b). In many cases, the nutrient-rich conditions are exacerbated by long water residence times exceeding 50 or even 100 years and for some, by anthropogenic land disturbance primarily relating to agricultural development and practices.

Figure 1. Cyanobacterial blooms western Canada: (a) Aphanizomenon bloom, Baptiste Lake, AB; (b) decaying bloom, Steele Lake, AB. Photo: R. Zurawell.

Early studies on cyanobacterial toxins began in Canada following investigations of animal poisonings on the prairies (ca. 1950s) and led to the discovery of both microcystin (originally called "fast-death factor") and another toxin originally coined "very fast-death factor" that was later named anatoxin-*a* (previously reviewed by Kotak and Zurawell, LRM 2007). By the late 1990s, growing concerns over the seasonal prevalence of microcystin in many of Canada's drinking water supplies led to the formation of The Federal-Provincial-Territorial (FPT) Committee on Drinking Water and resulted in the establishment of a national drinking water guideline (maximum acceptable concentration [MAC] of 1.5 μg/L) for microcystin-LR by Health Canada in 2002.

Increasing public awareness of cyanobacterial blooms and high-profile toxic bloom events emerging in other parts of Canada experiencing cultural eutrophication (including parts of the Great Lakes, Lake of the Woods, and impacted recreational lakes in Quebec), led to the formation of another FPT Working Group, this time focused on recreational water quality and risks to human health (Health Canada 2012, 2022). Following a review of approaches in use by other jurisdictions worldwide, the FTP concluded that recreational water quality guidelines for not only cyanobacterial toxins (i.e., microcystins), but cyanobacteria cells (i.e., cell count/density) were warranted. Guidelines were initially established (Health Canada 2012) for total microcystins (20 µg/L) and total cyanobacterial cell density (100,000 cells/mL). While the microcystin guideline provides a measure of protection against this family of toxins, the total cyanobacterial cell density guideline is intended to be used as a general indicator of the potential for bloom development; and as such, it is protective against exposure to both large amounts of cyanobacterial material and other toxins (besides microcystins) that may also be present.

Recently, the approach used to calculate the recreational guidelines was aligned with that used for drinking water. This resulted in the microcystin and cyanobacteria cell density guidelines being revised (lowered) to 10 µg/L and 50,000 cells/mL, respectively (Health Canada 2017). In addition, new guidelines for total cyanobacterial biovolume (4.5 mm^3/L) and total chlorophyll-*a* (33 µg/L) have been recently approved (Health Canada 2022). These two indicators were included to offer additional approaches to understanding potential bloom toxicity. While chlorophyll-*a* is relatively easy to measure (straightforward analytical methods and availability of hand-held meters), it is not unique to cyanobacteria, so it is most useful when used for early bloom detection along with additional methods of species identification (e.g., visual and microscopic assessment). Availability of multiple indicators of potential bloom toxicity and a microcystin-specific guideline provides flexibility to Canada's provincial/territorial authorities developing risk management plans appropriate to their respective jurisdictions.

Practical approaches for application of these guidelines as part of a recreational water quality risk management plan for cyanobacteria, including advice on sampling, analytical methods and risk communication have been recommended by Health Canada (2022). A generalized recreational health risk monitoring procedure for blooms in Canada (Figure 2, Health Canada 2022) involves: visual identification of a potential bloom (e.g., Step 1, Figure 2; by a recreational site operator, public health inspector or community representative); sample collection along recreational beach areas and assessment of measured indicator(s), and confirmation of bloom presence (e.g., Step 3, Figure 2); comparison of measured indicator values against Canadian Recreational Water Quality Guidelines (e.g., Step 4, Figure 2); continued monitoring (e.g., Step 5, Figure 2); issuance and updating of public health advisories, messaging and signage to alert users (e.g., Step 7, Figure 2; Figure 3a); and rescinding of alerts when water quality is deemed satisfactory once again (e.g., Step 6, Figure 2).

Monitoring of blooms in recreational waterbodies across Canada

While the federal guideline values and supporting guidance provide recommendations for managing recreational risks from cyanobacterial blooms and their toxins, it is the responsibility of individual jurisdictions (Provinces and Territories) across Canada to develop management strategies specific and appropriate to their own unique context as waterbody characteristics (e.g., degree of eutrophication, bloom and toxin prevalence) and use (e.g., seasonality, primary vs. secondary contact activities), and other factors will determine the extent of bloom monitoring and management programs. As a result, there is no consensus on a single approach (Table 1).

Across the western prairie provinces of Alberta (AB), Saskatchewan (SK), and Manitoba (MB) and the east-central Province of Quebec (QC), proactive, routine monitoring (i.e., at selected sites on a recurring interval) is conducted for blooms at public beaches. Additionally, AB and SK have implemented the use of risk assessment-based tools that include historical bloom information and indicator datasets, beach usage and waterbody trophic status, to inform site selection before each annual monitoring season. MB mostly monitors the same sites each year with some sites being added and removed as necessary, while other Provinces have not implemented proactive monitoring (Gasman 2021). However, most provinces, including AB, SK MB, Ontario (ON), New Brunswick (NB), and Newfoundland/Labrador (NL), conduct monitoring at public beaches in response to complaints about blooms (Table 1). Nova Scotia (NS) and QC do not conduct response monitoring, while Prince Edward Island (PEI), who have yet to receive complaints of blooms, will respond should an event occur. Most provinces issue cyanobacterial bloom advisories or alerts in response to presence of blooms in recreational waters. However, both QC and NL do not issue public notices based on environmental monitoring, but rather share results with affected municipal jurisdictions or complainants (Table 1).

Visual monitoring for blooms is the most employed guideline/indicator because of the accessibility and simplicity of this approach and is used by all jurisdictions with the exception of PEI. In British Columbia, initial screening for suspected blooms includes visual checks for bloom formation and water testing to determine levels of nutrients (e.g., total nitrogen and total phosphorus) and/or low N:P ratios (< 23), which can be indicative of conditions conducive to bloom formation. Portable field kits are then used to test for microcystins near recreational beaches and if concentrations exceed the guideline, additional sampling and confirmatory laboratory testing is performed (BC 2018). Specific testing for microcystins also occurs in AB, SK, MB, ON, and NL and is supported using various analytical methods including liquid chromatography linked mass spectrometry (LC-MS/MS; ON), enzyme-linked immunosorbent assay (ELISA; SK and ON) and the protein phosphatase inhibition assay (PPIA; AB) (Table 2). Cyanobacterial cell counts and/or species determination are used in AB, MB, ON and NL. However, no jurisdictions have adopted the newly recommended cyanobacterial cell biovolume guideline to date, while only NL has implemented the new chlorophyll-*a* guideline (Table 2).

Currently, no jurisdictions conduct routine monitoring for other cyanobacterial toxins. However, AB will measure anatoxins and cylindrospermopsin in a unified analytical suite to support investigations of animal deaths/illnesses suspected from cyanotoxin poisoning using liquid chromatography-high resolution mass spectrometry (LC-HRMS). Other

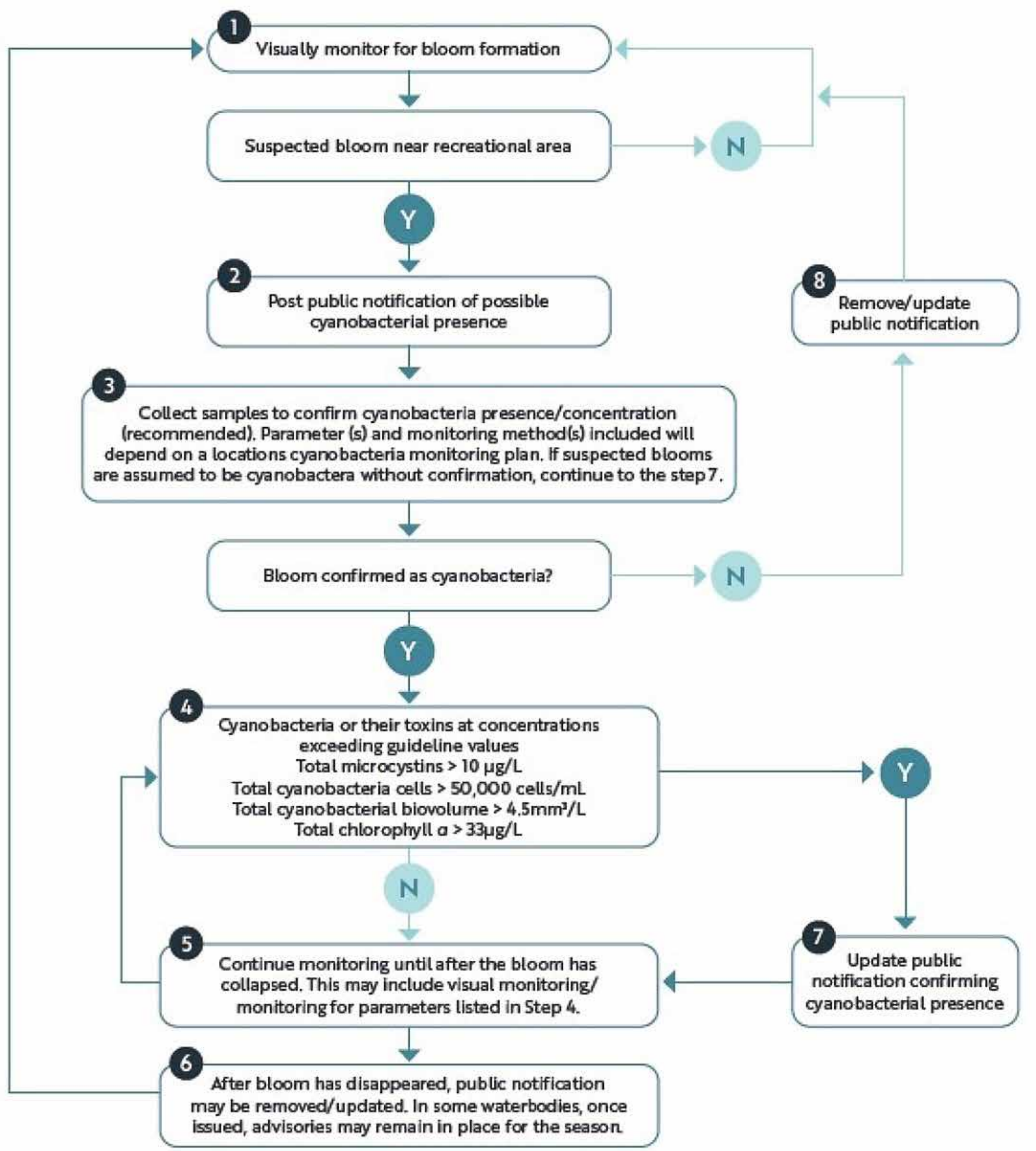

Figure 2. Flow chart for monitoring planktonic cyanobacterial and their toxins (Health Canada 2022).

approaches to bloom monitoring are also being developed and used in some provinces. For example, AB has been developing a cell-based toxicity (cytotoxicity) test for saxitoxin (Table 2) and is investigating the use of satellite remote sensing for chlorophyll-*a* and other pigments to forecast blooms (Figure 3b), while NL is using drone surveillance and measurements of the cyanobacteria-specific pigment, phycocyanin.

A unique approach to recreational water monitoring

In Alberta, recreational water monitoring is carried out to assess the exposure risk of lake users to cyanobacterial blooms and fecal contamination according to guidance

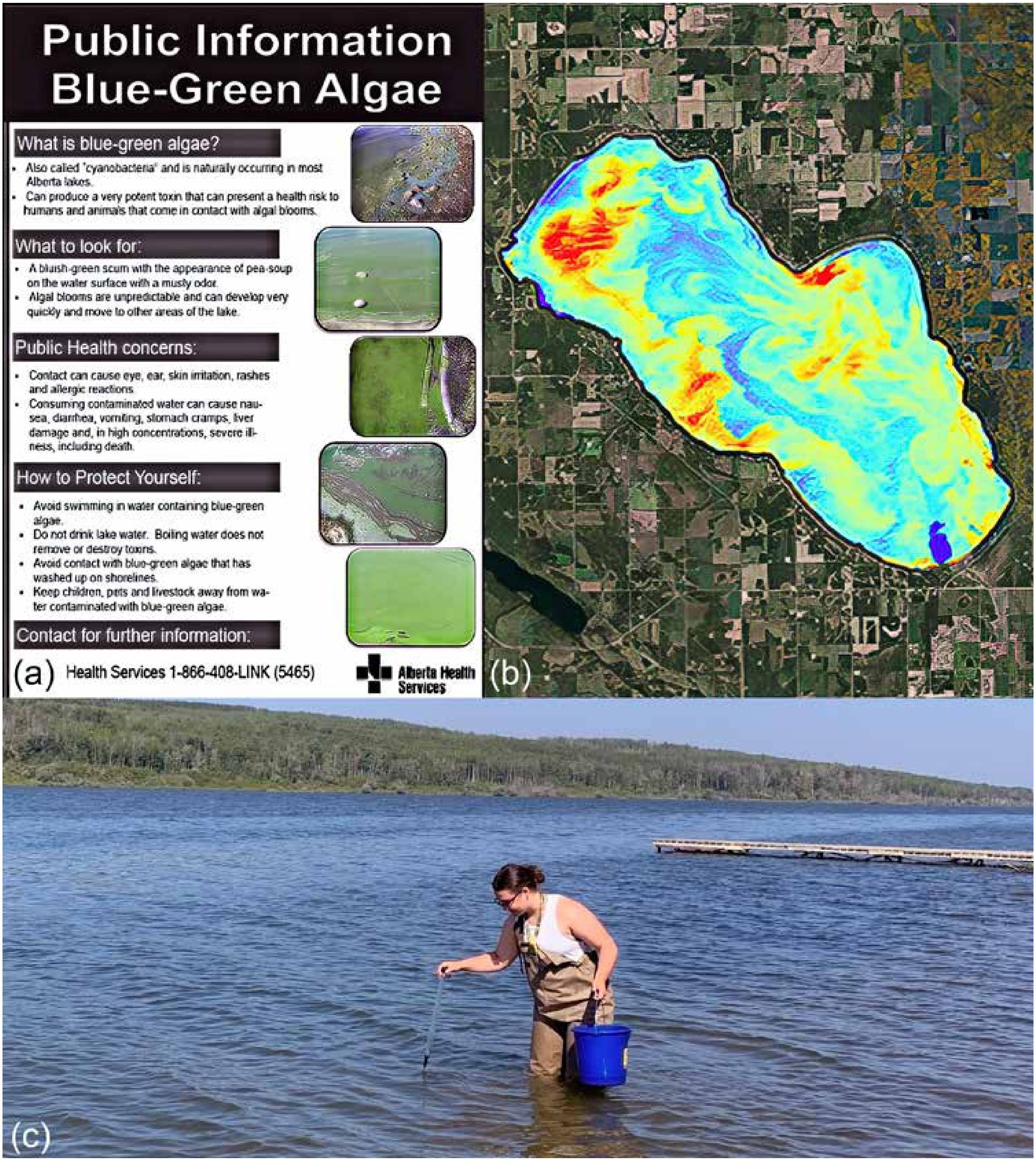

*Figure 3. (a) Public health risk information signage in Alberta (Alberta Health Services); (b) satellite-based remote sensing for chlorophyll-*a *pigment to track and forecast blooms in Pigeon Lake, AB (R. Vinebrooke, University of Alberta); (c) ALMS Recreational Water Technician, Sarah Klimchuk, performing bloom indicator sampling.* Photo: ALMS.

Table 1. Implementation of Provincial Cyanobacteria Recreational Water Monitoring.									
	AB	SK	MB	ON	QC	NB	NS	PEI	NL
Proactive routine monitoring (e.g., selected sites on a reoccurring interval) at public beaches	Yes: ~40 sites, weekly, May-Aug	Yes: microcystin at select areas; freq. depends on risk factors[a]	Yes: 60 sites	No	Yes[b]	No	No	No	No
Response monitoring in response to bloom complaints	Yes	Yes	Yes	Yes	No[c]	Yes	No	No[e]	Yes
Issuance of public advisories	Yes	Yes: microcystin >10 µg/L	Yes	Yes	Yes/No[d]	Yes: based on confirmed presence of cyanobacteria (no toxin analysis)	Yes	Yes	No[f]

[a] Ministry of Health monitors designated public swimming areas only.

[b] No provincial monitoring program, only regular visual inspections by bathing site managers (prohibit bathing in areas of beaches affected by blooms corresponding to more than 100,000 cells.

[c] There is no response monitoring program except in lakes with designated criteria, including: Canada/U.S. transboundary lakes (ex. Memphrémagog and Missisquoi); some municipal drinking water sources; in situations requested by health agencies (ex. swimming competition); and in lakes experiencing extreme blooms.

[d] No post-monitoring public notifications – cell count results are transmitted to concerned territories (ex. Municipalities) and directly to individuals filing the complaint.

[e] There have never been bloom complaints to date.

[f] Newfoundland and Labrador Environment and Climate Change Water Resources Management Division will test sites and provide results to municipal governments who then issue notices to the public.

Information on approaches to recreational bloom monitoring presented in Tables 1 and 2 was obtained by direct polling from representatives from AB, SK, QC, NB, PEI, and NL. Information for BC, MB, ON, and NS was obtained from publicly available information online (BC 2018) and from a recently published pan-Canadian comparison of cyanobacterial bloom management policies, programs, and practices (Gasman 2021).

Table 2. Implementation of Provincial Cyanobacteria Recreational Water Guidelines/Indicators.									
	AB	SK	MB	ON	QC	NB	NS	PEI	NL
Visual	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Microcystin	Yes: PPIA	Yes: ELISA[b]	Yes	Yes: ELISA, LC-(ESI) MS/MS	No	No	No	No	Yes[c]
Cell count/species	Yes	No	Yes	Yes	No	No	No	No	Yes
Cell biovolume	No	No	No	No	No	No	No	No	No
Chlorophyll-*a*	No	No	No	No	No	No	No	No	Yes
Other Toxins	Yes[a]	No	No	No	No	No	No	No	No
Other metric/indicator	Satellite, cytotoxicity-based test for saxitoxin	No	No	No	No	Taxon ID	No	No	Phycocyanin drone surveillance

[a] Anatoxin-*a*, homo-anatoxin-*a*, dihydro-anatoxin-*a*, cylindrospermopsin (LC-HRMS).

[b] Provincial Lab.

[c] Testing occurs at York-Durham Regional Environmental Laboratory.

Information on approaches to recreational bloom monitoring presented in Tables 1 and 2 was obtained by direct polling from representatives from AB, SK, QC, NB, PEI, and NL. Information for BC, MB, ON, and NS was obtained from publicly available information online (BC 2018) and from a recently published pan-Canadian comparison of cyanobacterial bloom management policies, programs, and practices (Gasman 2021).

provided in the Alberta Safe Beach Protocol (https://open.alberta.ca/publications/9781460145395). Monitoring at priority beach locations across Alberta is coordinated by Alberta Health (AH, Provincial Ministry of Health) and Alberta Health Services (AHS, Provincial Agency with responsibility for operational aspects of provincial health care and public health) and occurs annually from late May to early September. While recreational site (beach) owner/operators are the primary target groups, logistical and resource limitations sometimes preclude their routine participation in the annual monitoring program. To fill these gaps, AH funds the Alberta Lake Management Society (ALMS), to hire seasonal Recreational Water Technicians that coordinate a network of lake stewards (including Watershed Stewardship Groups, Watershed Planning and Advisory Councils and individual volunteers) to sample priority beaches throughout the province for public health targets (Figure 3c).

With their extensive history of fieldwork on lakes throughout Alberta, ALMS is uniquely qualified to support the establishment of a long-term, sustainable provincial monitoring network. For example, throughout the 2020, 2021, and 2022 recreational water seasons, ALMS coordinated the collection of 127, 80 and 137 samples for analysis of cyanobacterial bloom indicators from 52, 30, and 45 recreational beach locations, respectively. ALMS participates in steering committee and seasonal work planning activities with AH, AHS, and program partner analytical laboratories for the implementation of the Alberta Safe Beach Protocol. The Society helps establish processes/protocols for communication with beach monitors and educates beach owners/operators and other sample collectors through hands-on and webinar training sessions. In addition, ALMS supports completion of site assessments for the evaluation of public health hazards at recreational beaches, provides technical support for bloom complaint investigations by AHS Public Health Inspectors, conducts follow-up sampling at locations with active public health advisories and collaborates with Academic and Government researchers on scientific studies related to recreational water management and public health.

Recent activities include processing pelagic and beach water samples using Quantitative Polymerase Chain Reaction (qPCR) technology to support development of novel DNA-based public health targets (indicators) and validation of satellite imagery methods for detecting harmful cyanobacterial blooms.

Future trends and challenges in protecting Canada's recreational water quality

It is clear Canada's landscapes and water resources are not immune to impacts of a changing climate that are being documented globally including rising temperatures and atmospheric CO_2 levels, altered hydrologic patterns and eutrophication (reviewed by Visser et al. 2016). On the prairies, recent warmer-than-average winters and lower annual snowfall has seen a rise in the occurrence of toxic *Planktothrix* blooms both during the fall freeze-up period and under ice in late winter (Figure 4). Low spring seasonal precipitation combined with warmer-than average temperatures is causing earlier onset of cyanobacterial blooms, greater bloom intensity and a protracted growing/bloom season in eutrophic lakes – and increasing the occurrence of wildfires, which could exacerbate nutrient loading to surface waters (Carignan et al. 2000). These

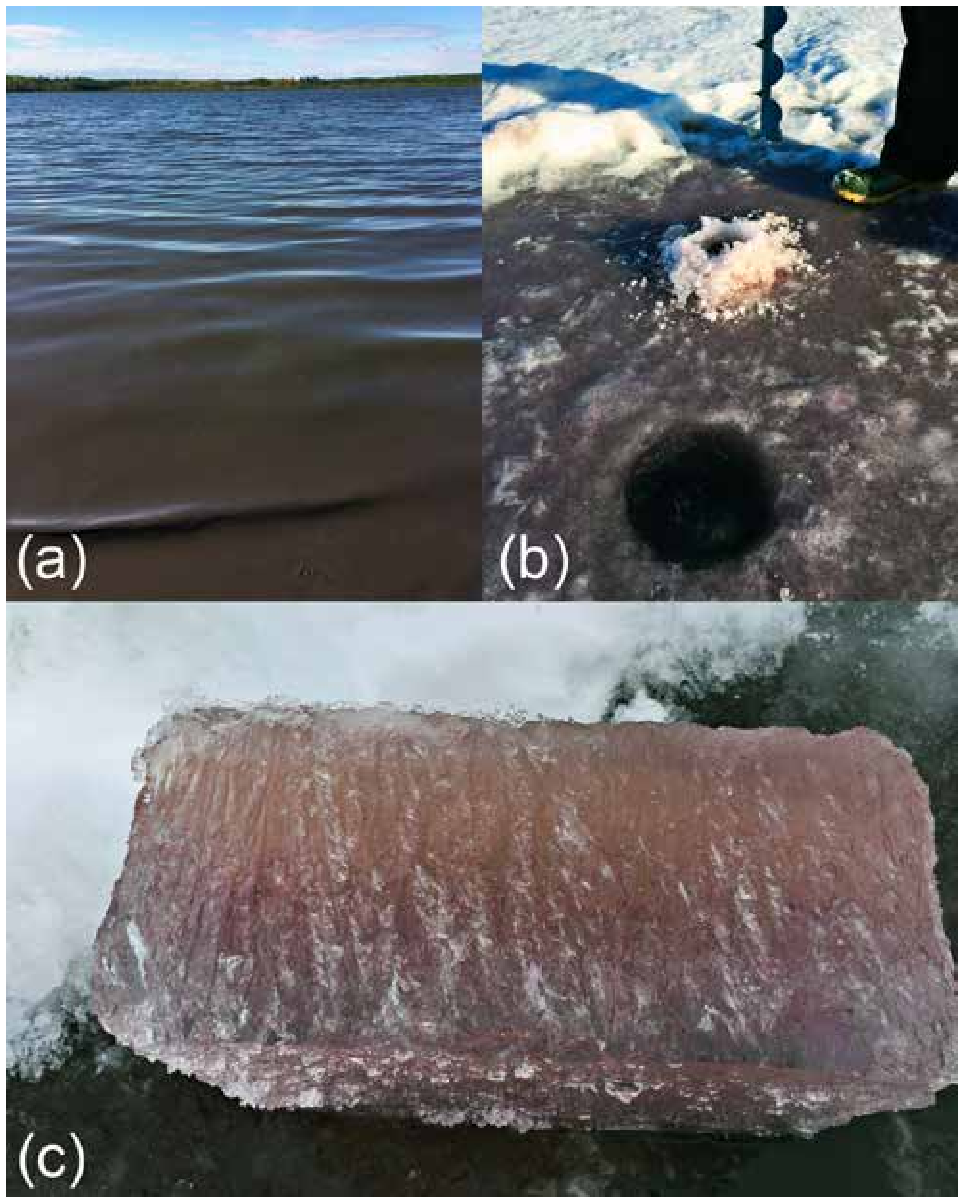

Figure 4. Planktothrix bloom, Matchayaw Lake, AB: (a) Bloom onset, September (photo: J. Fearnehough); (b&c) bloom captured in ice during fall freeze, November. Photo: D. Gullion.

conditions are also impacting mesotrophic waters across the country with blooms periodically occurring in lakes and now evidence suggesting that low, clear river water conditions are leading to blooms of potentially toxic benthic cyanobacteria in oligotrophic foothill streams in the west, to large rivers in eastern Canada that are being linked to pet mortalities and human illness (McCarron et al. 2023).

These events send a clear signal that more research is required to understand what future impacts can be expected and how best to counter them. Responsible authorities need to continue adapting monitoring strategies to protect recreational users of Canada's surface waters. Another FPT committee, led by the Canadian Council of Ministers of the Environment (CCME), is currently developing guidance for managing harmful cyanobacterial algal blooms and benthic mats in inland waters, in a changing climate. Additional monitoring and research will likely not be enough as the active management of lakes in Canada – that includes in-lake treatment options to control nutrients and harmful algal blooms – is largely in its infancy as our environmental laws largely preclude modification of natural aquatic ecosystems.

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Ron Zurawell is an aquatic scientist with the government of Alberta (Alberta Environment and Protected Areas), where he manages provincial lentic monitoring and research and leads aquatic invasive species monitoring. He has a 30-year history researching and monitoring cyanobacterial blooms and was integral in the design and implementation of the Province's Recreational (Beach) Monitoring Program. Ron is a strong advocate of community-based monitoring and citizen science programs and is a past board member with the Alberta Lake Management Society and NALMS. He can be reached at: ron.zurawell@gov.ab.ca.

Jennifer Graydon is an environmental public health scientist with the government of Alberta (Alberta Health). She has 11 years of experience working on Alberta's recreational water quality monitoring program. Jennifer supports scientific research on cyanobacterial blooms including methods for detection using satellite imagery and molecular and cytotoxicity approaches. She has been involved with development and implementation of novel indicators of fecal contamination and Alberta's operational policies related to recreational water (Alberta Safe Beach Protocol). Jennifer can be reached at: jennifer.graydon@gov.ab.ca.

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Cyanobacteria Blooms and Mitigation: **Adaptation, Causes, and Mitigation**

Jennifer L. Jermalowicz-Jones and Ryan Navarre

Introduction

Cyanobacteria, also known as "blue-green algae" were once the dominant life forms over 1.5 billion years ago and have thus had substantial time to adapt and evolve. They were responsible for the production of oxygen on Earth but today have become problematic in eutrophic and hyper-eutrophic aquatic systems. Their morphologies differ among and even within taxa and include growth forms such as single-celled, colonial, and branched and unbranched filaments (Figure 1). Additionally, they may produce reproductive cells such as akinetes, exospores, endospores or heterocysts, with the latter capable of nitrogen fixation. Taxa may also differ in the presence or absence of mucilage sheaths.

Although most cyanobacteria are autotrophs and produce their own food through nitrogen fixation, some from the genus *Nostoc*, among others, can be heterotrophic. This process is energetically costly, but many cyanobacteria have adequate nitrogen stores in eutrophic systems where this process is not necessary. Cyanobacteria also possess gas vacuoles that assist them with buoyancy on the water surface to better harvest sunlight for enhanced growth. When the sunlight is excessive, the algae can break down and release toxins and lower the dissolved oxygen in the water column. Not all cyanobacteria do produce toxins, but many taxa present in freshwater systems have the capability. The cyanobacteria *Microcystis* has also been shown to overwinter in lake sediments (Fallon et al. 1981). In addition, it may thrive in a mucilage layer with sediment bacteria that can release phosphorus under anaerobic conditions (Brünberg 1995).

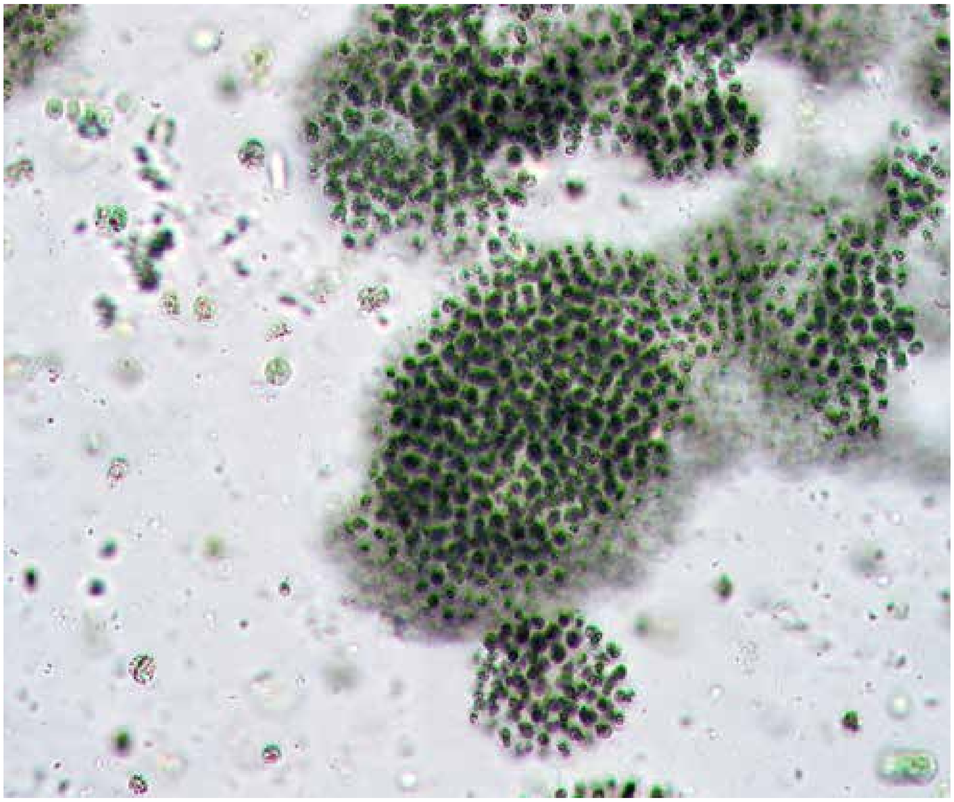

Figure 1. A colony of single-celled Microcystis sp.

Cyanobacteria assume a high volume in the water column compared to diatoms and other single-celled green algae. In general, calm surface conditions will facilitate enhanced growth of this type of algae since downward transport is reduced. Some cyanobacteria such as *Microcystis* may also be toxic to zooplankton such as *Daphnia* which are common in most lakes (Nizan et al. 1986). Without adequate grazers to reduce algae, especially blue-greens, the blue-green population will continue to increase and create negative impacts to water bodies. Fortunately, there are mitigation strategies available to reduce these algae with the benefits and limitations of each briefly discussed below, following a discussion of the causes of these cyanobacteria blooms.

Causes of cyanobacteria blooms

Harmful algal blooms (HABs) and hypoxia (low oxygen conditions) have been a major source of concern in freshwater systems. They have had negative socioeconomic, public health, and environmental impacts, costing lake communities millions of dollars annually. Hypoxia is defined as a condition in which dissolved oxygen in the water decreases to levels below 2 mg/L. Most macrofauna cannot survive at this level of oxygen. Hypoxia is a natural condition caused by physical, chemical, or biological processes, and can be exacerbated by natural or human induced environmental changes. In aquatic systems, hypoxia occurs when warm surface water coincides with calm weather, promoting stratification of the water column and limiting mixing, leading to oxygen depleted bottom waters. HABs are algal blooms that grow out of control and cause harm or nuisance to organisms in the ecosystem or pose infrastructure or health risks to humans.

There are two types of HABs impacting the Great Lakes region: toxic cyanobacteria, and non-toxic nuisance algae. Toxic cyanobacteria produce cyanobacterial toxins (cyanotoxins) that have the potential to kill fish as well as pose health risks to humans if enough toxins are ingested through contaminated drinking water, eating contaminated food, accidental ingestion during recreational activities, or even breathing contaminated air. Cyanotoxins can also kill and sicken pets, livestock, and wildlife. Dominant species of cyanobacteria that may become harmful include: *Microcystis*, *Dolichospermum*, *Aphanizomenon*, *Planktothrix*, and *Lyngbya* spp. With bloom formations of the cyanobacteria, light attenuation to bottom dwelling plants is reduced leading to decreased submersed aquatic vegetation and higher turbidity. Excessive growth and decay cycles of cyanobacteria can lead to decreased dissolved oxygen concentrations that can further exacerbate anoxic conditions, which in turn may lead to release of phosphorus with a strong feedback loop effect.

Mitigation of cyanobacteria blooms

While predictive modeling and monitoring of HABs are good for protecting human health, the best strategy to protect both humans and the environment is prevention. The introduction of nutrients (most notably phosphorus and nitrogen) is a major driver of HABs. Reducing the introduction of these nutrients into aquatic systems will greatly reduce the frequency and extent of HAB events. These nutrients predominantly come from nonpoint agricultural sources and urban stormwater runoff. Monitoring at multiple scales allows the immediate effect of conservation practices at the field scale as well as the cumulative effect on the watershed to be evaluated. Many freshwater systems are impaired beyond the point of prevention and thus restorative approaches are often needed to improve the overall water quality to reduce the frequency and severity of HABs over time (Figure 2).

Algaecides and peroxides

Algaecides have been used for decades on nuisance algal growth of all types, including filamentous, planktonic, and colonial green algae and more recently in the treatment of cyanobacteria. Baird et al. (2021) determined that chelated copper algaecides were associated with reduced release of microcystin toxin relative to others such as peroxides and endothall but did not reduce the toxins. Cyanobacteria possess a biological mechanism called programmed cell death, which is where the cells respond to a stressor such as ultraviolet radiation or an algaecide and leak toxins into the surrounding waters. Villada et al. (2004) caution that some cyanobacteria are able to mutate to adapt to increased concentrations of copper. Thus, repeated applications of copper may lead to reduced efficacy and potential accumulation in lake sediments. Peroxides such as sodium carbonate peroxyhydrate

Figure 2. Dense cyanobacteria blooms on an inland lake.

may be effective on cyanobacterial blooms but have limitations relative to the presence of sensitive fish species (Sinha et al. 2020) and thus caution is necessary prior to any large-scale treatments. Ample knowledge of the aquatic biota in the lake is important to avoid any potential negative effects of sensitive organisms from application of peroxides or copper products. Many cyanobacteria blooms aggregate in areas adjacent to wetlands where there may be rare aquatic plants and other sensitive biota (Figure 3).

Nutrient inactivation

There are a few products available that aim to reduce phosphorus in the water column and the release of phosphorus from a lake bottom. Such products are usually applied as a slurry by a special dose-metered vessel to the water column or just above the lake bottom. Most of these formulas can be applied in aerobic (oxygenated) or anaerobic (oxygen-deficient) conditions. In lakes that lack ample dissolved oxygen at depth, this product may help prevent phosphorus release from the sediments. A few disadvantages include cost, inability to bind high concentrations of phosphorus especially in lakes that receive high external loads of phosphorus such as those with a large catchment or watershed, and the addition of an aluminum floc to the lake sediments which may impact benthic macroinvertebrate diversity and relative abundance (Pilgrim and Brezonik 2005). Some formulas utilize a clay base with the P-inactivating lanthanum which may reduce sediment toxicity of alum. If these products are applied, it is important that external phosphorus loads be significantly reduced since these inputs would compromise phosphorus-inactivation formulas (Nürnberg, 2017). However, some recent case studies (Brattebo et al. 2017) are demonstrating favorable results with alum application in hypereutrophic waters that are also experiencing high external nutrient loads.

Aeration/oxygenation

Aeration has been used extensively in the past few decades to improve drinking water in reservoirs through the reduction of cyanobacteria and associated odors and health risks. There are many different forms of aeration ranging from localized fountain systems to lake-wide systems that completely destratify lakes. Some systems are capable of delivering oxygen to the hypolimnion without destratification of the upper layers of the water column. These systems require an oxygen source onshore whereas laminar flow aeration requires onshore compressors to supply air through a network of rubber hoses. A primary goal of aeration is to reduce the hypoxic condition that enhances the release of phosphorus and the presence of cyanobacteria blooms. Much research still needs to be conducted to determine whether the main mechanism for reduction of cyanobacteria is related to nutrient limitations or entrainment of the colonies to reduce ability to harvest sunlight and form surface blooms. Systems that are poorly designed, especially in deeper lakes, may result in the transfer of nutrients from the lake bottom to the surface. This could exacerbate cyanobacteria blooms over time. Recent research on an impoundment in Walkerton, IN, USA, has demonstrated that aeration

Figure 3. Cyanobacteria blooms near a wetland habitat on an inland lake.

has resulted in a reduction of measured algal toxins of all types of microcystin (Jermalowicz-Jones 2022, unpublished data) and much more data is needed to evaluate continued use of the system for cyanobacteria reduction. Similar to nutrient inactivation methods, the reduction of incoming nutrients from the immediate watershed is critical for aeration to process nutrients within the lake basin and to continue to reduce the presence of cyanobacteria blooms. This is especially important for lakes where rivers enter and exit the lake or where multiple drains enter the lake.

Concluding remarks

Reduction of nutrients to lake systems is the preferred method for reducing cyanobacterial blooms but some systems have an irreversible eutrophic state. Methods that bind nutrients or prevent their release may be needed to reduce the presence of unfavorable algae. Each method discussed has benefits and disadvantages and should be weighed based on socioeconomic factors as well as scientifically sound ecological data.

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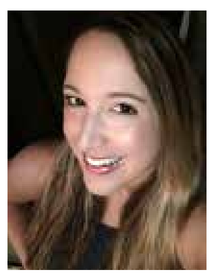
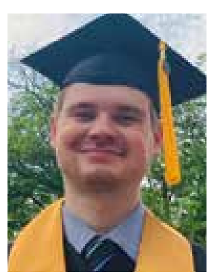


Dr. Jennifer Jermalowicz-Jones, CLP is the principal limnologist at Restorative Lake Sciences based in Spring Lake, MI. She currently manages and restores numerous lakes in the Midwest and has a special interest in comprehensive lake restoration.



Ryan Navarre, BS, is a current aquatic science intern at Restorative Lake Sciences and a recent graduate of Purdue University. Ryan is attending Michigan Technological University in the fall of 2023 to study GIS and remote sensing.

Benjamin Harris

Student Corner

Outcomes of a "Lake School" education program for residents and association members of lakes in Pennsylvania

Lakes are changing across the globe. Whether they are turning over at lower rates from warmer air temperatures, salinizing from intense road salt usage, or getting browner from inflows of dissolved organic matter, each lake faces its own unique assemblage of natural and anthropogenic stressors.

Since you are reading this article, you might have received an education in lake science, or you have access to materials or contacts that help you make management decisions for your lake. There are a multitude of people who live on any of the thousands of lakes across North America who are tasked with managing lakes with little to no training in lake science or access to informative materials, and they need support.

This is where my studies come in. As a current M.Ed. in Environmental Education student at Bard College, I am interested in furthering our understanding of how communities are responding to changing lakes, and how lake science educational programming can improve management decisions for lake residents and association members.

In this article, I will describe my research on one such program: a "Lake School" weekend educational intensive developed for lake residents and managers across the Pocono Mountains region of Pennsylvania. I will also discuss the broader context of this type of programming, as well as how you may be able to get involved in your community.

The Lake School, developed by the Pocono Lake Ecological Observatory Network (PLEON), and funded by the PA Department of Environmental Protection Environmental Education Grant program, was initiated to improve access to lake science information in the Poconos for a generally lay audience. The school, which took place in May of 2023, was headed by Dr. Beth Norman, Director of Science and Research at Lacawac Sanctuary Field Station and Environmental Education Center, with funding for my associated research coming from the National Science Foundation (DEB #1754271). The school was developed by lake scientists and professors across the Northeast and Great Lakes regions.

This educational program combined classroom, laboratory, and field-based modules covering a wide swath of lake science topics, from water quality to algae blooms, trophic cascades, field-based monitoring, and beyond. Its goal was to improve participants' understanding of lake science topics, their ability to interpret typical lake monitoring data, and to empower lake communities to begin a monitoring program.

Before they arrived at the Lake School, attendees answered a survey that asked them general information about their lakes (size, watershed characteristics, etc.), as well as questions to gauge their current monitoring efforts, their perception of changes in their lakes (eutrophication, salinization, climate change impacts, algae blooms, etc.), and their current efforts to engage community members in monitoring and management. I will utilize the data from this survey in my master's thesis to paint a broad picture of the state of PA lakes, with a focus on attendees' perceptions of change and community engagement efforts.

I am particularly interested in theorizing the level to which perceived lake changes match actual changes. While I will not be quantifying in my thesis the actual state of each lake represented in these surveys, the comparison of actual to perceived changes is an important discussion.

Perceived changes may be less than actual changes if the observer is not educated in lake science. On the other hand, perceived changes may be greater than actual changes if the observer is experiencing *ecophobia*, or a fear of the environment. Ecophobia can result from frightening lake changes like toxic algae blooms, bioaccumulation of pollution in fish, or the impacts of climate change. One way to potentially lessen ecophobia is by improving science literacy in lake communities through programming like the PLEON Lake School.

Immediately before the Lake School began, I asked attendees to participate in a second survey – this one quizzed them on their pre-Lake School knowledge of lake science topics and their ability to interpret lake monitoring data. Following the school, participants completed the same survey. This pre-/post-survey format is a typical approach in the education field, and the results will allow me to assess the knowledge and skills participants gained from attending the school.

My preliminary analysis of the pre-/post-survey (Figure 1) indicates that participants answered more questions correctly after attending Lake School. Interestingly, they also answered more questions incorrectly, perhaps because they actually attempted more questions in the post-survey than in the pre-survey – there was a far lower proportion of "I don't know" answers in the post-survey. These preliminary findings point to the effectiveness of the PLEON Lake School curriculum.

In the early fall of 2023, I plan to send out one final survey to the Lake School participants, which I will use to gauge how well they have retained the content and skills they learned after a roughly six-month hiatus from the school. I will also ask a

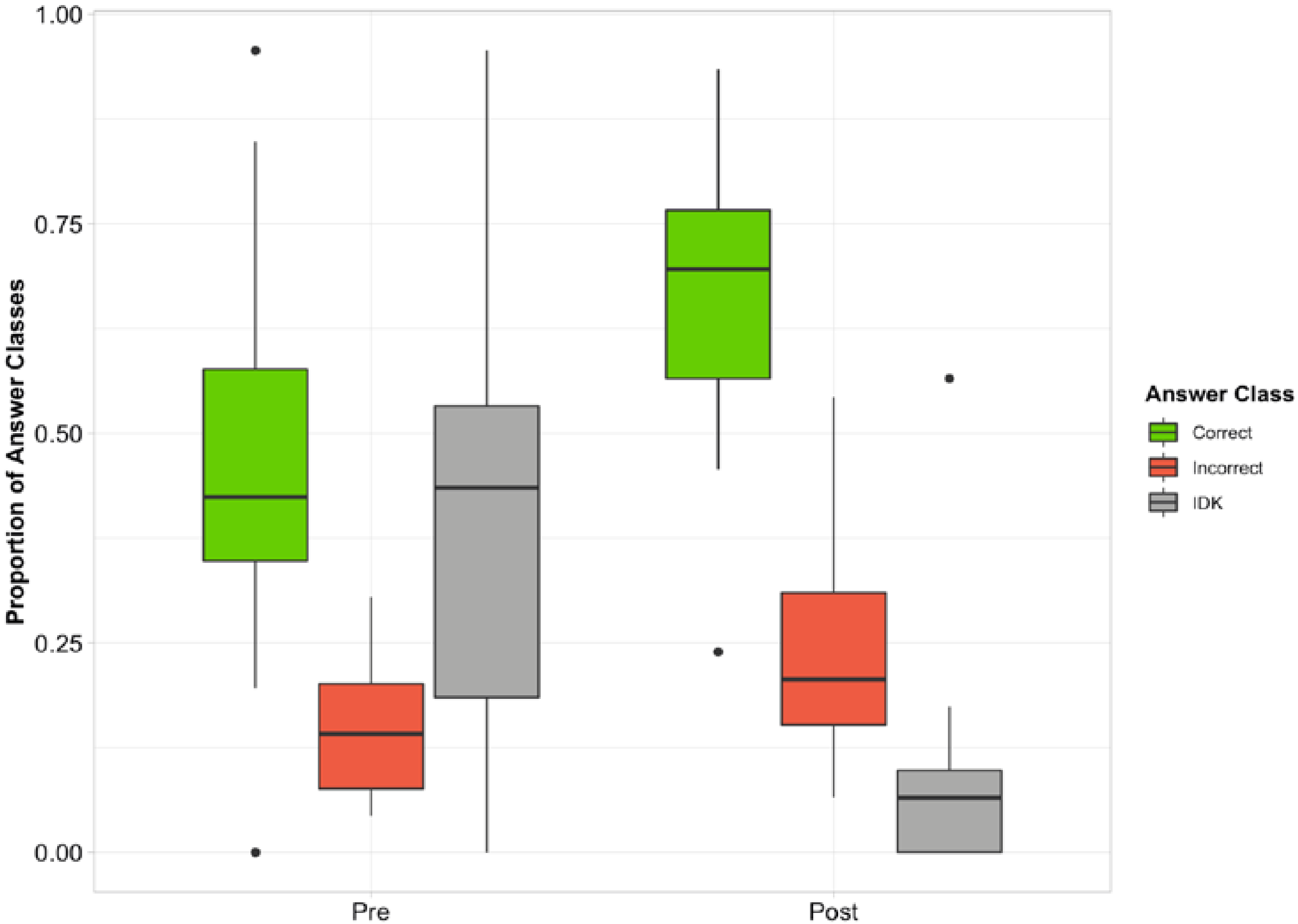


Figure 1. Proportion of correct, incorrect, and "I don't know'"(IDK) responses from participants to the pre- and post-Lake School surveys. Boxplot (in the style of Tukey) made in RStudio (Version 1.2.5033) using ggplot2 (Version 3.3.5).

series of questions related to the participants' implementation of their Lake School learning back at their home lakes, including:

- What is one concept from Lake School that has informed you of an issue affecting your lake?
- What concepts from Lake School have you shared with your community members and how did the community react?
- Did you implement a monitoring program following Lake School, or are you planning to implement a program next year?
- Have you used the information you learned at Lake School to attain funding for monitoring or management of your lake?
- Have you used information you learned at Lake School to advocate for land and/or water management policy changes around your community?

I am excited to see the level to which attendees have put the concepts they learned in Lake School into practice. Often, we assume that our educational efforts are impactful without putting in the work to actually document outcomes and impact.

It is also important, however, to consider equity and access when planning lake science programs like the Lake School. Many communities, especially those at smaller lakes without endowed associations, are on their own when it comes to lake monitoring and management. While the Lake School served several participants with no experience in lake science and very little funding at their lake groups (or no lake group whatsoever), it did cost money and target a region that has historically seen its fair share of privilege.

So, when we evaluate the scale and impact of these lake science programs for lake residents and associations, we must consider access for low-income communities.

If you have the knowledge and resources, one way that you can create change in your community is by holding a lake education program. Even a presentation about a topic you are passionate about or study at a local lake – like eutrophication for a visibly greening lake or road salt impacts in a heavily urbanized watershed – can start an important community conversation. You could also consider holding a community lake science day, where community members or a local school come together to learn about your research or monitoring data at a local lake.

The important aspect is that communities are involved – that their questions and concerns are raised (even if there is not a direct solution in the moment), and their voices are heard.

We, the lake science community of North America, must work together to lessen gatekeeping in science. Communicating research and translating it into approachable language is action. The only way we can begin solving the environmental issues that lakes are facing is by creating informed and active communities. And we can do this through communication, education, and facilitating conservation.

Benjamin Harris is currently finishing his M.Ed. in environmental education at the Center for Environmental Policy of Bard College and is also an educator with the Hudson River Sloop Clearwater. His current research explores the impacts of adult educational programming on lake monitoring and management. His previous research has covered water quality and algae studies in lakes of NY, PA, and IA, as well as fish population and migration studies within the Hudson River Estuary of NY.

UPCOMING IN *LAKELINE*

FALL 2023: Shoreline Stabilization – The fall issue will focus on topics related to shoreline stabilization. Topics related to impacts of shoreline erosion on water quality and aquatic life, methods for shoreline restoration and stabilization, case studies on restoration projects, and other topics related to shoreline stabilization are welcome.
Articles for fall 2023 are due by September 15, 2023.
The issue will be published in October 2023.

Winter 2023/2024: Declining Lake Volumes – Whether a reservoir for water supply or recreation, or a lakes across a region that are multi-use, declining lake volume is a concern that is widespread as we face changing weather patterns and prolonged periods of drought. Case studies, impacts of declining volume (water quality/supply), or long-term models of lake volume change, remote sensing, as well as other topics related to this issue are welcome.
Draft articles for winter are due by December 15, 2023.
The issue will be published in January 2024.

Please contact Amy Smagula, *LakeLine* Editor, with any questions, or to propose an article for one of the above-listed themes. Do you have a topic that doesn't match a theme? That's okay, we can include the article in any of these issues, or use it to build a themed issue. Amy can be reached at lakeline@nalms.org.

NALMS 314 Workgroup Intern

Skye Embray

I am Skye Embray, and I recently completed a policy internship with the North American Lake Management Society (NALMS). I graduated from Trinity College in May and received my bachelor of science in environmental science and public policy and law. I am currently pursuing a master of public administration degree in environmental science and policy at Columbia University. My educational background in environmental science and policy has provided me with an in-depth understanding of the ecological foundations that support the policies I hope to push and has allowed me to study policy development mechanisms.

During my undergraduate studies, I researched harmful algal blooms and how they affect drinking water quality. This experience sparked my interest in remediating freshwater ecosystems to protect the environment and public health. Therefore, I was interested in working with NALMS in this role because of the internship's focus on the value of lakes to the American economy and using this frame to vie for their protection. My career goal is to engage with the science that matters to policy and ensure equity in implementing and enforcing environmental laws and regulations. I am interested in bridging the gap between science research and policy and addressing the on-the-ground problems faced by communities disproportionately impacted by environmental racism and lack of access to clean drinking water. I aim to pursue an environmental protection specialist career within a U.S. federal agency to accomplish this.

For the past year, I have been working with the 314 NALMS working group to create informational materials for the campaign to bring awareness and new funding to Section 314 of the Clean Water Act, Clean Lakes Program. The goal is to explain to different audiences and through various formats the importance of the Clean Lakes Program, what it did, and its success, and ultimately convince others why we need the program re-established and adequately funded.

With the help of the working group, I have created a series of fact sheets for both public and legislator audiences, informational PowerPoint presentations accompanied by recorded narration, a template letter for constituents to contact their representatives, and a survey for state agencies to communicate their needs for funding and how to best implement funding if re-appropriated for the Clean Lakes Program. Additionally, I began work on a dashboard that will demonstrate just how few lake success stories there have been under the CWA Section 319 Non-Point Source Program, which the Environmental Protection Agency currently uses as the source of funding to address lake issues instead of the Clean Lakes Program. Within the dashboard maps, we can comprehend that more than resources apportioned from the Non-Point Source Program are needed to protect and remediate our nation's lakes comprehensively. The variety of resources created during my internship with the working group will be available on the NALMS website this summer.

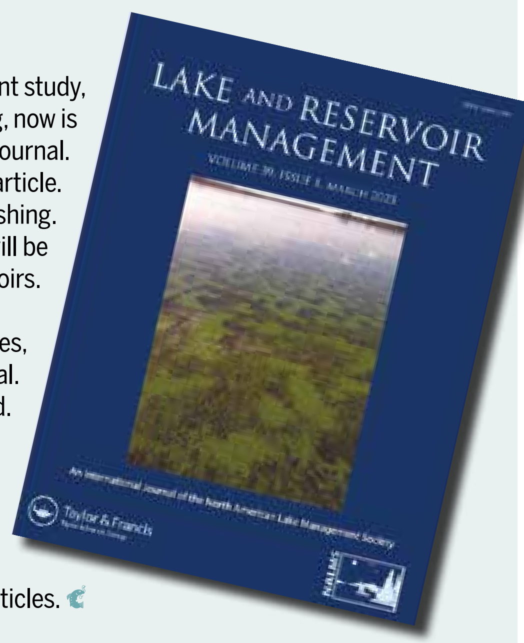
My professional role with the working group has taught me the importance of framing an issue to elicit a specific response from legislators and how scientific research directly affects how to present a policy issue to policymakers. This October, I hope to attend the NALMS annual conference in Erie, Pennsylvania, to show my work with NALMS and how this campaign intends to not only elicit new funding for an enhanced Clean Lakes Program but also how the communication of the science behind lake issues to various audiences is an essential aspect of pushing policy development.

The Clean Lakes Program is critical to protecting our nation's freshwater resources. It provides funding for research, monitoring, and restoration projects that improve water quality and promote lake ecosystems' health. However, the program's budget has been severely cut in recent years, jeopardizing its ability to carry out its critical mission.

By creating a range of materials to explain the importance of the Clean Lakes Program, we hope to educate legislators and the public on the need for enhanced funding for this vital program.

LAKE AND RESERVOIR MANAGEMENT

A scientific publication of NALMS published up to four times per year solicits articles of a scientific nature, including case studies.

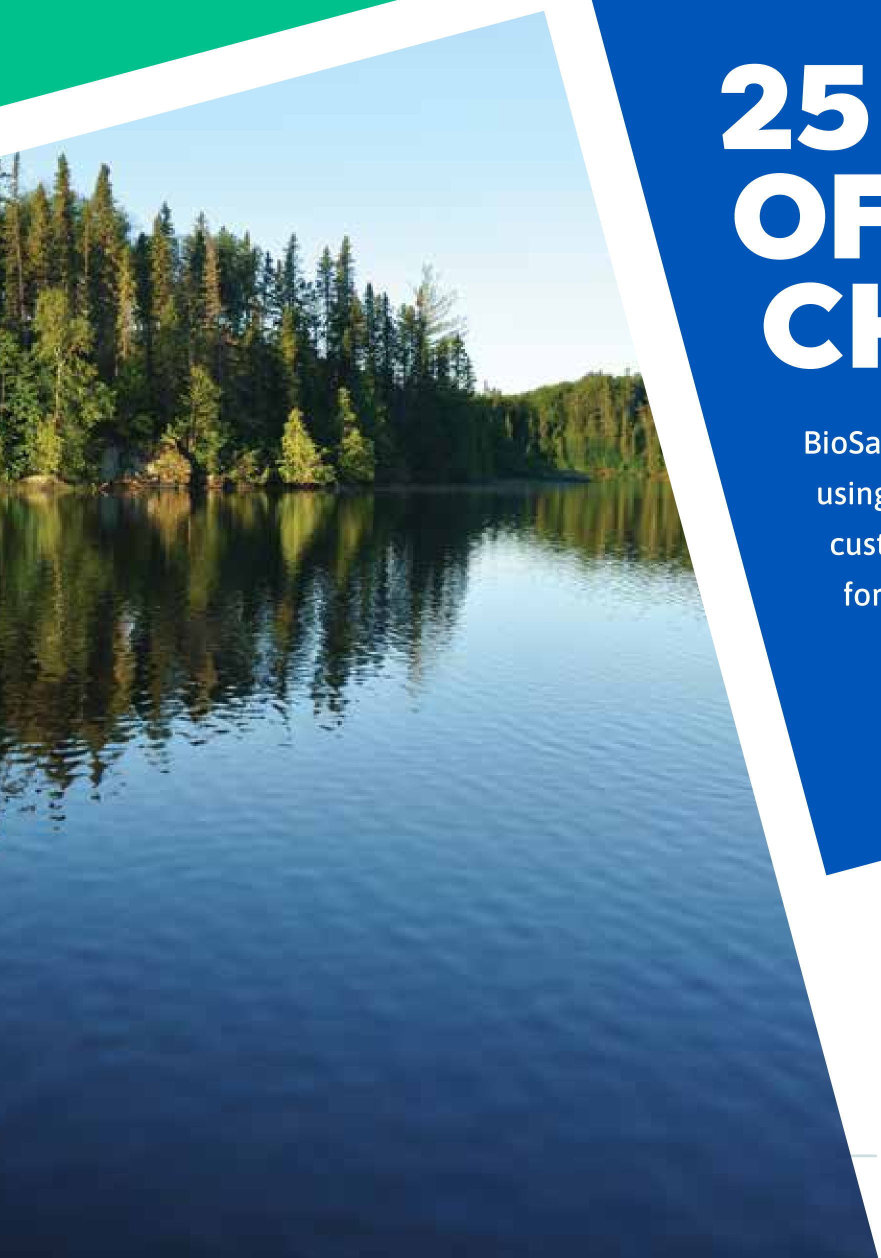


If you have been thinking about publishing the results of a recent study, or you have been hanging on to an old manuscript that just needs a little more polishing, now is the time to get those articles into your journal.
There is room for your article in the next volume. Don't delay sending your draft article.
Let the editorial staff work with you to get your article ready for publishing.
You will have a great feeling of achievement, and you will be contributing to the science of managing our precious lakes and reservoirs.

Anyone who has made or plans to make presentations at any of the NALMS conferences, consider writing your talk and submitting it to the journal.
It is much easier to do when it is fresh in your mind.

Send those articles or, if you have any questions at all, contact: Andrew Paterson and Andrea Smith, Co-Editors, *Lake and Reservoir Management*; lrmeditor@nalms.org.

If there is anyone who would like to read articles for scientific content, please contact the co-editors. The journal can use your help in helping the editorial staff in editing articles.



"Lakespert" – The Devil's Element

Steve Lundt, CLM

Did you know phosphorus has been called the devil's element? I had no clue until I started my summer read. Most people enjoy an easy, soppy beach novel, but not this lakespert. I have settled nicely into a historical summary of how phosphorus has impacted the world – from world wars to harmful algal blooms. The book is titled *The Devil's Element*, by Dan Egan.

I've read most of this book from the comforts of my front porch during an unusually wet June here in Denver. Phosphorus has been on my mind since my early years in grad school. I now find myself enjoying a good read about phosphorus, learning new details about this DNA builder that was first discovered by a seventeenth-century alchemist. Did you know that human bones and then Peruvian guano-encrusted islands were used as important phosphorus sources for growing food during the industrial revolution? I certainly have a more worldly view and appreciation of that phosphorus-laden runoff heading down my street toward the storm drain.

Every summer we are reminded that our lakes (even rivers and ocean bays) struggle to support human uses thanks to mismanagement of this life-creating element. On one hand, it seems like we are losing the battle on a global scale with these ever-larger algal blooms. On the other hand, I have seen local improvements in water quality thanks to better stormwater and wastewater treatment. At best, I feel optimistically worried about the future of our lakes and planet. From my summer read, I know we are smart enough to understand the causes of troublesome algal blooms. Yet, humans refuse to make good choices and do the right thing. *The Devil's Element* has shown me that it is even bigger than water quality. Food production and military unrest around phosphorus reserves will ultimately control just how many lives we are talking about when it comes to how deadly phosphorus can be.

My aquatic focus on phosphorus and the triggering reaction that it causes in lakes is just one small part of the overall problem with this biological accelerant. The devil's element is a finite resource. Humans have done a great job of wasting it away and sending it straight to the ocean via our rivers. My realization is that NALMS and the lake management community need to think beyond their lakeshore and watershed boundaries and work more on a global scale. This includes food production (we don't need 1.4 billion pounds of cheese stored in the U.S.), eating habits (eat less meat), geopolitical issues (Morocco and the 'blood phosphate" issues), mining practices (up to 50 percent of what is mined gets wasted), and private businesses (Tide used to be 50 percent phosphorus by weight and Biz was 74 percent). Maybe we should change it up – think locally, act globally.

Phosphorus recovery dropping into a bin at a wastewater treatment plant that serves 2.2 million people. This phosphorus will be repurposed instead of sent down river.

David Schindler changed the detergent world 50 years ago while raising a family in a tent next to Lake 227. We need something similar for the agricultural and wastewater world. Phosphorus recovery, whether on the farm or in the city, can protect our waters, avoid conflicts, and help feed the world.

On that note, enjoy your summer reading and may your bloom season be short.

Steve Lundt, Certified Lake Manager, has monitored and worked to improve water quality at Barr Lake (Denver, Colorado) for the past 19 years. Steve is active with the Colorado Lake & Reservoir Management Association and is a past Region 8 director for NALMS and an active member since 1998.