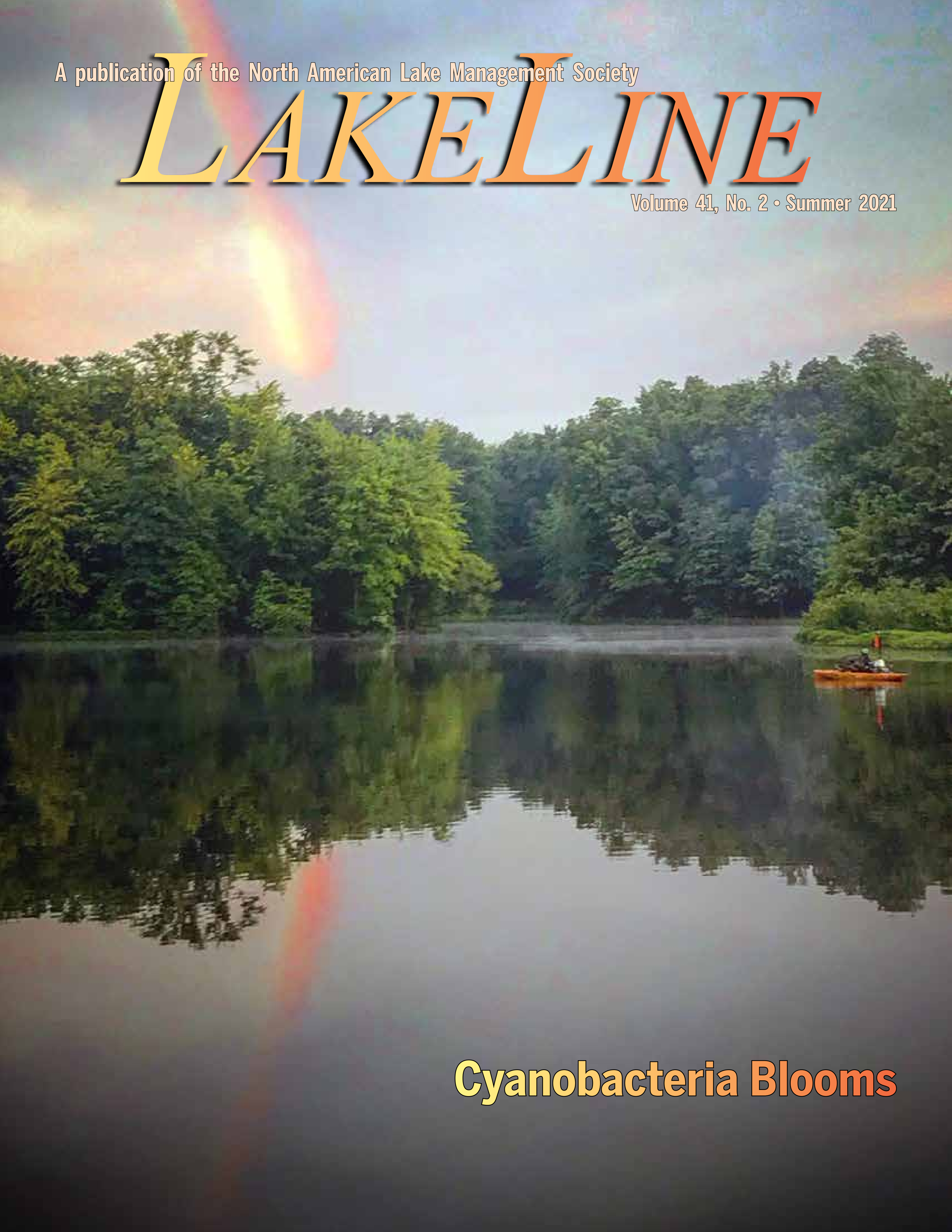
A publication of the North American Lake Management Society
LakeLine
Volume 41, No. 2 • Summer 2021
Cyanobacteria Blooms

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41st International Symposium of the
North American Lake Management Society

Hosted by the Oklahoma Clean Lakes
and Watersheds Association

nalms 2021 oklahoma city

Valuing Water

Economics, Ecology, & Culture

November 15–18, 2021

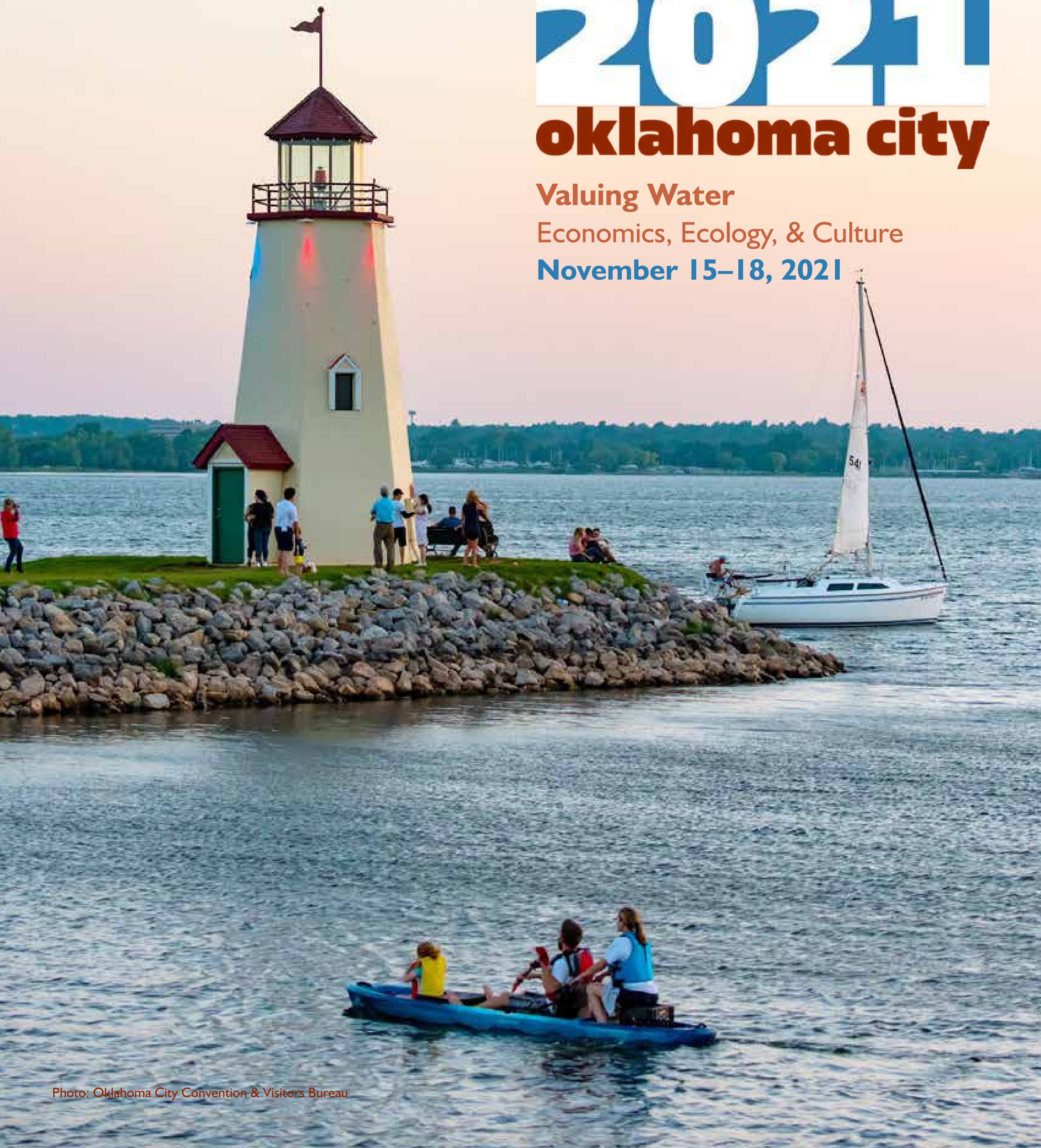

Photo: Oklahoma City Convention & Visitors Bureau

Valuing Water: Economics, Ecology, & Culture

The Oklahoma Clean Lakes and Watersheds Association welcomes you back to Oklahoma City for the NALMS 41st International Symposium. Downtown Oklahoma City is a beautiful place to be in the fall with amazing weather! Explore The Modern Frontier! From our parks, museums, and entertainment districts as well as a fantastic selection of restaurants, there's something for everyone to enjoy during your stay in OKC.

Don't miss the opportunity to network with some of the most knowledgeable leaders in lake and watershed information and technology. The symposium will consist of multiple panels and discussions focused on the value of water for economics, ecology, and culture.


Photo: Oklahoma City Convention & Visitors Bureau

Tentative Schedule

Monday
November 15

- Workshops
- Welcome to Oklahoma City Events

Tuesday
November 16

- Opening Plenary Session
- Technical Sessions
- Exhibits Open
- NALMS Membership Meeting
- Exhibitors' Reception


Photo: Todd Tietjen

Wednesday
November 17

- Clean Lakes Classic
- Technical Sessions
- Exhibits Open
- NALMS Awards

Breaking away from the traditional concurrent session format, Wednesday afternoon's program will offer virtual session opportunities for all registrants as well as field trips, workshops, and vendor demonstrations for those attending in person.

Thursday
November 18

- Technical Sessions
- Exhibits Open

Technical Program

The NALMS 2021 Program Committee is organizing 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 potential session topics, but please check the symposium website regularly for up-to-date program information.


Photo: Todd Tietjen

- Bioindicators in Reservoirs
- Climate Change Impacts
- Drilling Impacts to Water Quality
- Drinking Water
- Harmful Algal Blooms
- Invasive Species
- Lake Management & Restoration
- Measuring the Value of Water
- Nutrients & Internal Loading Dynamics
- Soil Health
- Water Planning
- Water Quality Standards
- Water Reuse
- Watershed Planning
- Western State Water Issues
- Wetlands

Workshops

We will be offering a variety of full- and half-day workshops during the symposium. These workshops provide attendees the opportunity for a more in-depth focus on a topic of interest, and many will provide hands-on experience. Below is a list of proposed workshops, but please check the symposium website for up-to-date program information and pricing.


Photo: Todd Tietjen

- Collecting and Analysing Water Quality Data With Sensors
- Collection, Identification, Ecology and Control of Freshwater Algae
- Ecology of Cyanobacteria
- Educating the Next Generation in As Little as 20 Minutes!
- Get Your Communications As Crystal Clear as Your Lake!
- Stormwater Management for Lake Managers
- The Role of Aeration/Oxygenation in Lake Management

Opportunities for Students

The NALMS Student Programs is planning opportunities specifically for students before and during the symposium. Visit the symposium website for updates, additions, and more detailed information.

Student and Early Career Virtual Panel
This panel discussion, tentatively scheduled for September 2021, offers students and early career professionals the opportunity to meet and ask professionals about jobs in a wide range of sectors including private consulting, government science, and academia.

Student Resume Builder/Mock Interview Workshop
This workshop will focus on building your resume and practicing your interviewing skills.

Student Mixer
Get to know fellow student symposium attendees at this Monday night mixer.

Student Luncheon
Join fellow students and members of the NALMS Board to learn more about NALMS and what the organization has to offer student members.

Student Programs Trivia Night

Special Events

The host committee is working on several special events during the symposium week. Visit the symposium website for updates, additions, and more detailed information.

Welcome to Oklahoma City
NALMS and the host committee are planning several meet and greet opportunities on the first night of the symposium including mixers specifically for first time symposium attendees and students.

Exhibitor Reception
Take time following the first day of technical sessions to visit with exhibitors and fellow attendees.

Clean Lakes Classic 5k Run/Walk
The Clean Lakes Classic offers a mid-week break from technical sessions. You need not be a runner to participate! All pre-registered participants receive a t-shirt as part of the sign-up fee. New this year, graduate student participants in the Clean Lakes Classic will be eligible for a drawing to receive $500 toward educational expenses through the newly established Kenneth H. Reckhow Scholarship Fund.


Photo: Todd Tietjen

NALMS Awards
The NALMS Awards is the culmination of the Society's year. Awards are presented for Leadership and Service, Advancements in Lake Management Technologies, and Lake Management Success Stories, along with our special recognition awards: Friends of NALMS, the Jim LaBounty Best Paper Award, Jim Flynn Award (outstanding corporation) and the Secchi Disk Award. Our most prestigious award, the Secchi Disk Award, honors the NALMS member who has made the most significant contributions to the goals and objectives of the Society.


Photo: Todd Tietjen

Important Deadlines

September 10, 2021
Early bird and presenter registration deadline.

October 22, 2021
Last day symposium hotel rate available.

November 5, 2021
Regular registration deadline.

Registration for in-person attendance is open now. Registration for virtual attendance will open in October with more details to follow as the program is finalized.

Hotel Information

Omni Oklahoma City Hotel
100 West Oklahoma City Blvd
Oklahoma City Oklahoma

Photo: Oklahoma City Convention & Visitors Bureau

- Room rates are $169/night for single or double occupancy (plus taxes)
- Government rate rooms are available at the federal per diem rate for single occupancy (King) rooms.
- The sales and lodging tax rate is 14.12%.
- Symposium rates are available for November 10–21, 2021.
- Wi-Fi Internet service – complimentary for Select Guest® members
- Omni Oklahoma City offers overnight valet parking at $28/day plus tax, hourly valet parking starts at $10 plus tax from arrival up to four (4) hours and $20 plus tax from four (4) hours up to ten (10) hours.
- Hotel check in is 4:00 pm and check out is 11:00 am.
- Any guaranteed reservation not cancelled 72 hours prior to the arrival date will be subject to a one night room and tax cancellation fee.
- An early checkout fee of one night's room and tax charges will apply unless guests inform the Omni of any change in planned stay prior to or during check-in.
- **The symposium rate is available until October 22, 2021.**

Visit the symposium website to reserve your room at the discounted symposium rate.

Visit nalms.org/nalms2021 to register!

Transportation

The Will Rogers World Airport is located approximately 10 miles from the Omni Oklahoma City Hotel and is served by major airlines including Alaska Airlines, Allegiant Air, American Airlines, Delta, Frontier Airlines, Southwest, and United Airlines.

Airline	Markets Served Non-Stop
Alaska Airlines	Seattle (SEA)
Allegiant Air	Destin – Ft. Walton (VPS, Seasonal), Las Vegas (LAS), Los Angeles (LAX), Orlando – Sanford (SFB, Seasonal)
American Airlines	Charlotte (CLT), Chicago O'Hare (ORD), Dallas – Ft Worth (DFW), Los Angeles (LAX), Miami International (MIA), New York LaGuardia (LGA), Phoenix (PHX), Washington National (DCA)
Delta	Atlanta (ATL), Minneapolis (MSP), Salt Lake City (SLC)
Frontier Airlines	Denver (DEN), Orlando (MCO)
Southwest	Chicago Midway (MDW), Denver (DEN), Houston Hobby (HOU), Las Vegas (LAS), Nashville (BNA), Orlando (MCO), Phoenix (PHX), St. Louis (STL), Washington National (DCA)
United	Chicago O'Hare (ORD), Denver (DEN), Houston Intercontinental (IAH)

The Omni Oklahoma City Hotel does not offer airport shuttle service.

Contact Information

General Symposium, Exhibitor & Sponsorship Information
NALMS Office | 608-233-2836 | nalms2021@nalms.org

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We look forward to seeing you in Oklahoma City!

LAKELINE

Contents

Volume 41, No. 2 / Summer 2021

On the covers:
"Hidden Lake", submitted by Alex Boskovic to the NALMS 2020 photo contest.

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From Amy Smagula the Editor

Harmful Algal Blooms (HABs), cyanobacteria harmful algal blooms (cyanoHABs), harmful cyanobacteria blooms (HCBs), these are all terms you will read about in this issue of *LakeLine*. No matter what you prefer to call them, these blooms appear to be increasing in frequency and occurrence in many areas, and in some places, so too is the duration of blooms. For this reason, every other year the summer issue of *LakeLine* is dedicated to sharing a cross-section of new and emerging topics related to cyanobacteria research.

Special thanks to **Angela Shambaugh**, who co-chairs the NALMS Inland HABs Program. She sought out authors from an array of affiliations and backgrounds to round out the topics covered by articles in this issue of *LakeLine*. Angela has also been actively involved in the Interstate Technology and Regulatory Council (ITRC). For more information about the work of the ITRC, please see the update from Angela later in this issue (page 20), including information about the newly released guidance document on cyanobacteria – *Strategies for Preventing and Managing Harmful Cyanobacteria Blooms (HCBs)*.

In our first article of this issue, **Jennifer Graham**, a research hydrologist with the United States Geological Survey (USGS) provides an overview of the evolution of the understanding of cyanobacterial blooms both from her personal studies and work experience, and prior. She reviews some of the key concepts related to cyanobacteria from first studies to where we are today, still wrestling with some of the key concepts related to blooms and toxins.

With time there has been an expansion and diversification in the tools and the methods used to analyze cyanobacteria blooms and toxins. **Guy Foster**, with USGS, discusses a holistic approach for understanding HABs into the future. In his article he reviews a number of monitoring techniques and tools that are and will be useful in collecting data on waterbodies to help piece together the picture of blooms as they manifest.

In their article, **Hebah S. Mejbel**, **William Dodsworth**, and **Frances R. Pick** discuss the use of sediment DNA analysis to determine cyanobacteria abundance and species composition in waterbodies across a geologic timeframe. Their article discusses the benefits and gaps in sedDNA analysis as a tool.

As we strive to control nutrients in a system to reduce blooms, there is a need to catalogue all of the possible sources of nutrients to a system, and in some cases those come from unexpected inputs. When the numbers in a phosphorus budget for a New Jersey lake just weren't adding up, **Steve Souza** and **Alan Fedeli** investigated further and determined an unusual source of phosphorus to a lake – drinking water. Read their article to learn more about this occurrence, and the rationale behind it.

Efforts to track and report HABs are becoming increasingly more important these days, some offering "on the go" capabilities to report blooms and check in on the status of the waterbody you live on or plan to visit. **Brad Autrey**, **Jana Compton**, **Mike Galvin**, **John M. Johnston**, **Michelle Latham**, and **Blake Schaeffer** discuss a ready-to-use app for Android devices to map and find harmful cyanobacteria blooms easily and on the go.

The more we learn about HABs, the more information we need to continue to convey to all who value our lakes. Differences exist in approaches relative to outreach efforts for HABs. To better understand these differences, a survey was conducted to gauge the levels of effort by states to implement outreach and education programs as they relate to HABs. The results of the survey are summarized here by **Ellen P. Preece** and **F. Joan Hardy**, and they also discuss their future work with a follow-up survey to further explore regional preferences in how people prefer to receive information.

David Matthews, **Monica Matt**, **Nancy Mueller**, and **Stephanie June** next discuss the expansion of HABs education thanks to citizen science efforts in New York State. Regular monitoring on 168 lakes across New York led to a data set that elucidates a number of interesting trends in cyanoHAB blooms and highly toxic blooms, and at the same time helped to train and educate citizen scientists on bloom formation and what to look out for while they are out on the water.

In our last article of this issue, **Emily Kinzinger** and **Rebecca North** (both with the University of Missouri) share information about the Reservoir Observer Student Scientists (ROSS) program that teaches water quality monitoring to high school students. The program includes hands on sampling methods and data analysis. High school students in the program have the opportunity to learn more about local waterbodies by sampling a number of parameters on the water and in the classroom laboratory. The University of Missouri provides the equipment, and is looking to expand this program across the country, so please do reach out to them if you are interested in bringing this program to your own local area.

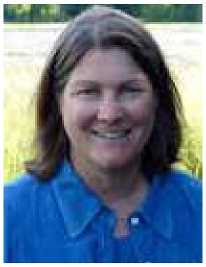
Our "Lakespert" (**Steve Lundt**) shares his idea for an algal rating system, complete with an idea for a sign to post by a lake. This creative idea can both help

(From the Editor, continued on p. 7 . . .)

From Lisa Borre

the President

Greetings from Northern Michigan where summer has arrived but the nights remain refreshingly chilly. My husband David and I are spending the summer near family on Beaver Island, a Great Lakes island community that I first visited on a summer vacation with my family 51 years ago. We are lucky to live on one of the island's seven inland lakes where we are enjoying regular sightings of loons, sandhill cranes, eagles, and migrating songbirds, and can watch snapping turtles lay their eggs near the sandy shore or a nearby gravel road.



Now fully vaccinated, I traveled across state lines for the first time again in May. I quickly discovered that we were not the only ones reorganizing our lives to be closer to family or spend time in a special place. Witnessing the changes first-hand has made me wonder about the implications for lake protection and shoreline management. The hot real estate market means that properties in desirable locations like lake communities are selling as soon as they hit the market. Little-used and seasonal cabins are being torn down or converted to much larger seasonal and year-round homes. Many companies are making the permanent transition to remote work arrangements or at least becoming more flexible about it, which is allowing people to rethink where they call home. This shift is transforming rural communities and putting unprecedented development pressure on lakes and their watersheds. I anticipate that this will be a major issue facing lake communities in the months and years ahead. Please contact me or your regional representative on the board with ideas for how NALMS can help our members and partners navigate the rapid changes underway.

With vaccinations becoming more widespread, it gives me optimism that many of us will be able return to an in-person annual symposium later this year. The host committee for NALMS 2021 is looking forward to welcoming as many of you as possible in Oklahoma City in November. In recognition of ongoing travel and budget restrictions and also based on the positive feedback from our virtual conference in 2020, we will be experimenting with our traditional conference format again this year, this time to offer limited virtual meeting options along with the in-person meeting. Registration is opening soon, so look for more details in this issue of *LakeLine* and on the NALMS website.

With the arrival of summer, we are also turning our attention to addressing issues like harmful algal blooms (HABs) on the lakes where we live, work and play. Once again, our capable editor and members of the NALMS Inland HABs program have organized a series of informative articles on this important topic. NALMS has also partnered with the U.S. Army Corps of Engineers Invasive Species Leadership Team, Aquatic Plant Management Society and American Water Works Association to offer a Summer Seminar Series on Comprehensive Strategies to Protect Drinking Water from Harmful Algal Blooms.

Last week, I dipped a Secchi disk in a lake for the first time since the pandemic began. I'm looking forward to joining with many of you to continue the Secchi Dip-In tradition again this year or to contribute to volunteer lake monitoring program. The newly upgraded Secchi Dip-In database developed by AWQMS is ready to receive data submissions, or if you're like me and prefer a mobile app, the Lake Observer app can also be used to submit Dip-In data. Check out the Lakes Appreciation Month website if you're looking for new ways to celebrate lakes this summer, including a LakeBlitz organized by our friends at Living Lakes Canada or Libraries Love Lakes organized by Global Lake Ecological Observatory Network members.

I hope all of you are able to reconnect with family, friends, and a lake you love this summer!

Lisa Borre has worked for more than 30 years to conserve and manage lakes and wetlands around the world. In her early career she worked in state government as coordinator of the Lake Champlain Basin Program. She went on to co-found LakeNet, a world lakes network that was active for ten years. She is currently a senior research specialist at the Cary Institute of Ecosystem Studies where she coordinates the Global Lake Ecological Observatory Network (GLEON). Lisa has a B.A. from the University of Vermont and an M.E.S. from Yale School of the Environment. She lives in Annapolis, MD.

(. . . From the Editor, continued from p. 6)

raise awareness of HABs, and also inform the lake user about risks of using the water during a HAB event.

Lisa Borre, NALMS President, shares some updates about lakes in the post-pandemic period, as well as other NALMS-related activities and updates.

We hope that you find this issue of *LakeLine* to be informative. Enjoy!

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.

Cyanotoxin Occurrence in the US:
A 20-Year Retrospective

Jennifer Graham

Cyanobacterial blooms, and associated cyanotoxin occurrence, are a concern because of the potential harm posed to humans, wildlife, and aquatic ecosystem health. Evidence suggests the magnitude, frequency, and duration of cyanobacterial blooms are increasing, and these events represent a significant challenge for freshwaters and, increasingly, marine waters, worldwide. Cyanobacterial blooms routinely receive local and national attention because of occurrences in new locations, recreational closures, drinking-water impacts, animal illnesses and deaths, scientific advances, and novel management and mitigation strategies. Due to public information campaigns at local, state, and federal levels, the public is generally aware of what cyanobacterial blooms look like and potential risks posed to human and animal health. It is difficult now to imagine a time when cyanobacterial blooms were considered an occasional nuisance in lakes and reservoirs, well-known only by limnologists. When I began my career over 20 years ago, however, that was the status. Cyanobacteria were just beginning to capture attention, and they certainly captured mine.

I took advantage of an opportunity to study cyanobacteria and cyanotoxins with Dr. Jack Jones at the University of Missouri. During August 1999, when I collected my first samples, it was understood that cyanobacteria produced cyanotoxins, but relatively little was known about occurrence. Our goal was to simply see if we could detect microcystin, the most commonly occurring cyanotoxin worldwide, in Missouri and Iowa lakes and reservoirs. I had a plankton net and a pickup truck and set out to sample cyanobacterial blooms. The challenge – I had no idea how to identify a cyanobacterial bloom. Jack told me I would "know it when you see it." I was skeptical but he was right, you cannot miss the vibrant colors and thick paint-like accumulations characteristic of cyanobacteria blooms (Figure 1).

Figure 1. Cyanobacterial bloom in Washington Park Lake, New York illustrates the vibrant blue-green colors and surface accumulations that are often characteristic of cyanobacterial blooms. Photo credit J.L. Graham, U.S. Geological Survey

Cyanobacteria as a growing concern

Cyanotoxin production by cyanobacteria has been recognized for well over a century. The first report of cyanotoxin-related animal deaths occurred in Australia in 1878 (Francis 1878). Cyanotoxin-related animal poisonings and deaths were reported in Minnesota a few years later (Figure 2), and into the 1990s incidents were reported in the United States every so often (Yoo and others 1995). Reports of cyanotoxin-related incidents increased in the late 1990s, a pattern that seems to continue through the present. Today, most states in the United States have documented human illnesses or wildlife, livestock, and/or pet poisonings associated with cyanobacterial toxins. Many states have educational and/or monitoring programs focused on public health protection. For example, in August 2020, 322 sites located across 26 states had reported cyanobacterial blooms, beach closures, and health advisories (written communication from L. D'Anglada, U.S. Environmental Protection Agency, 2021).

The first cyanobacterial blooms I encountered were in natural lakes of northwestern Iowa. A substantial amount of research had already been conducted in these Iowa lakes, following a series of cyanotoxin-related incidents in the 1940s and 1950s (Rose 1953). Animal mortalities associated with these incidents numbered in the thousands and included a range of bird and mammal species. Potential human health concerns resulted in the first recreational beach monitoring programs in the United States, as well as some of the first lake management efforts to control blooms. What was known about cyanobacterial blooms and cyanotoxins at that time included recognition that:

- Cyanobacterial blooms are a nuisance issue that are sometimes, but not always, toxic;
- Cyanobacterial blooms are usually, but not always, a summer phenomenon;
- High nutrient concentrations play a key role in cyanobacterial bloom development but are not the only controlling factor;
- Cyanobacteria, including *Anabaena* (now called *Dolichospermum*), *Aphanizomenon*, and *Microcystis* produce cyanotoxins; and
- There is more than one type of cyanotoxin.

Cyanotoxins, however, were considered complex substances that were almost impossible to identify or quantify. Major advances in understanding did not occur until the 1970s and 1980s, when analytical methods that allowed identification and quantification of cyanotoxins were developed. Today, the tools available for cyanotoxin measurement range from simple test strips to advanced analytical methods, including liquid chromatography and mass spectrometry.

These early studies on cyanotoxins in Iowa lakes are fascinating, and every time I revisit them I am impressed by how much was known, given that cyanotoxins could not be measured. Many of the unique challenges to the study of cyanobacteria and associated cyanotoxins faced by scientists conducting those initial studies are ones we continue to struggle with today, including: (1) complex mixtures of cyanotoxins are common in mixed-assemblage cyanobacterial blooms, (2) spatial and temporal variability is characteristic of blooms, and occurrence of cyanobacteria and cyanotoxins may vary substantially within relatively short distances and periods of time, and (3) relations between spatial and temporal dynamics and environmental conditions are unique to individual systems as a result of complex interactions between biological, physicochemical, and hydrologic factors. Over the last 20 years, advances in analytical chemistry, remote sensing, genetic techniques, and *in situ* sensors have greatly enhanced our ability to study cyanotoxin occurrence and deepen our understanding of causal factors across a range of aquatic ecosystems. Many of these topics are delved into more deeply in the other articles featured in this *LakeLine* issue devoted to cyanobacteria.

The cyanotoxins

The cyanotoxins are diverse and include many different types and variants (Table 1), with frequent new discoveries. For example, when I went out in search of my first cyanobacterial bloom in 1999, there were about 60 known variants of the cyanotoxin microcystin and there are now over 250 known variants (Chorus and Welker 2021). Focused study of cyanotoxins other than microcystin lags behind. Within the last decade, however, the anatoxins, cylindrospermopsins, saxitoxins, and more recently discovered cyanotoxins such as anabaenapetins and cyanopeptolins, have received more attention. Studies that have included multiple cyanotoxins indicate that complex mixtures are relatively common. Defining the ecological and public health risks associated with these complex mixtures remains an ongoing challenge and an active area of research.

Not all cyanobacteria have the ability to produce cyanotoxins, and even among those taxa that do, cyanotoxin production does not occur all the time. The early Iowa studies identified some of the most commonly occurring cyanobacterial taxa that may produce cyanotoxins (Table 1). As with the cyanotoxins, the list of cyanobacterial taxa with the potential to produce cyanotoxins continues to grow. The diversity of cyanobacteria with the potential to sometimes, but not always, produce cyanotoxins adds a layer of complexity to studies focused on understanding the conditions that promote cyanotoxin production. The advancement of genetic techniques has greatly enhanced our ability to develop testable hypotheses about the physical, chemical, and biological factors associated with cyanotoxin production. In addition, genetic tools provide a novel monitoring technique focused on the genes responsible for cyanotoxin production,

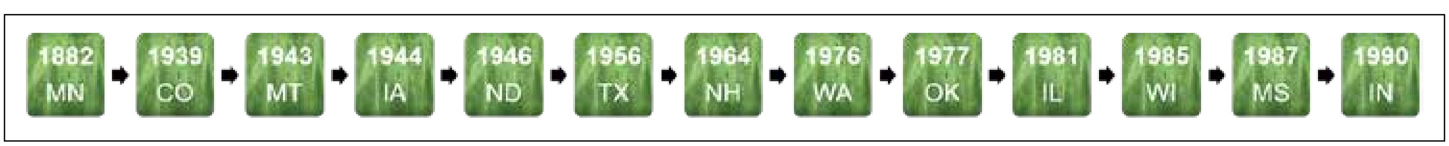


Figure 2. First reports of cyanotoxins in the United States from 1882 to 1990 (data from Yoo and others 1995).

Table 1. Three of the Most Commonly Occurring Cyanobacterial Taxa and the Cyanotoxins they May Produce.*

		Hepatotoxins		Neurotoxins		Dermatoxins
	Cyanobacteria	**Cylindrospermopsins**	**Microcystins**	**Anatoxins**	**Saxitoxins**	
	*Anabaena/ Dolichospermum*	X	X	X	X	X
	*Aphanizomenon*	X	?	X	X	X
	*Microcystis*		X			X

**Hepatotoxins are a group of cyanotoxins that affect the liver, neurotoxins are a group of toxins that affect the nervous system, and dermatoxins are a group of cyanotoxins that affect the skin and mucous membranes.* Photo credits: A. St. Amand, PhycoTech, Inc.

which may be used as an indicator of the potential for cyanotoxin production within a cyanobacterial community. Genetic approaches may ultimately be the key to answering some of the most frequently asked questions about cyanotoxins that we still cannot answer – *why do cyanobacteria produce these compounds and what function do they serve?*

The last two decades have seen substantive advances in our understanding of where cyanotoxins may occur. Until recently, the study of cyanotoxins focused largely on locations where cyanobacterial blooms were noted – often in lakes and reservoirs. We now know that cyanotoxins may be associated with cyanobacteria located in all types of habitats and aquatic ecosystems ranging from attached algae in small streams to estuaries. We still know relatively little about the downstream fate and transport of cyanobacteria and cyanotoxins from upstream areas, but now know that they can be transported considerable distances. Transport may affect downstream drinking-water utilities, recreational areas, and aquatic life. Cyanobacteria and cyanotoxins originating in freshwater environments may also be transported to coastal and marine environments. For example, sea otter deaths in Monterey Bay in 2007 were linked to microcystins derived from freshwater sources (Miller and others 2010). The persistence and effects of freshwater-derived cyanotoxins at the land-sea interface is a relatively new area of study.

Shifting paradigms

Physical, chemical, and biological factors are all important in cyanobacterial bloom dynamics, and nutrients and water temperature are key. The past two decades have elucidated many of the processes associated with cyanobacterial bloom development and highlighted that the factors driving cyanobacterial bloom development are not necessarily those that are controlling cyanotoxin production. Long-held paradigms, however, are also shifting, thereby confounding our mechanistic understanding of occurrence. For example, nutrients are important, but timing and magnitude of nutrient delivery is changing; cyanobacterial blooms with relatively high cyanotoxin concentrations are occurring in nutrient poor systems that I would have confidently told you were not at risk 20 years ago; shifts in thermal regimes are altering the onset, strength, and duration of thermal stratification; and cyanobacteria and/or cyanotoxins are being transported long distances from source areas, emphasizing the need to focus on hydrologic connectivity and environmental processes at the landscape level. Despite the many advances in recent decades, many unanswered questions remain in part due to a changing climate and paradigm shifts in the way we think about key influences and driving factors on cyanobacterial blooms and cyanotoxin occurrence.

Cyanobacterial blooms and cyanotoxin production are multifaceted. There are many interacting factors that influence cyanotoxin occurrence and potential consequences of exposure on human and aquatic ecosystems (Figure 3). Over the last 20 years, cyanobacterial blooms and cyanotoxin incidents have shifted from an occasional phenomenon to one of the most prevalent water quality challenges of our time. Cyanotoxin occurrence in the United States has gone from being relatively unknown, to a critical component of professional and citizen science monitoring programs and a major focus of private, academic, and federal research. Substantial emphasis is being placed on early warning systems and mitigation and management strategies. Thoughtful collaborations and integrated studies across a range of disciplines are essential to further our understanding and mitigation of this challenge.

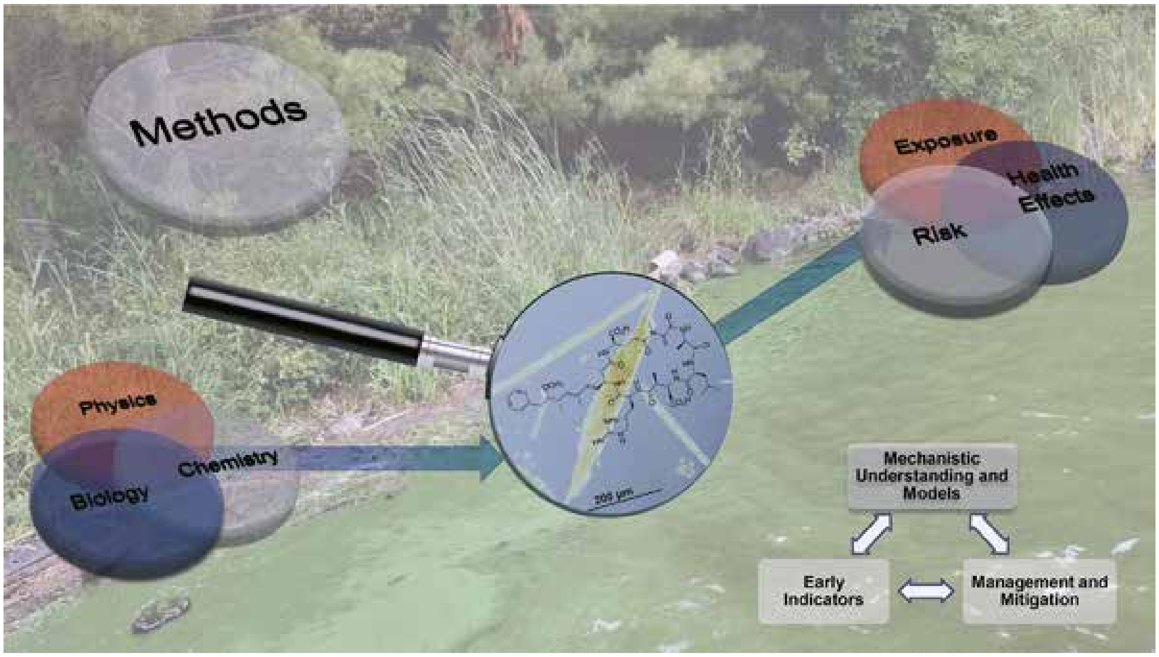


Figure 3. Cyanobacterial blooms and cyanotoxin production is multifaceted. There are many interacting factors that influence occurrence. Interdisciplinary study is needed to elucidate the complex factors that influence cyanotoxin occurrence, consequences of exposure on human and aquatic ecosystem health, and ultimately develop robust management and mitigation strategies. Photo Credit: J. LeDuc, NPS. Concept Credits: J. Graham, G. Foster, V. Christensen and L. Fogarty, USGS.

Selected references

Chorus, I. and M.Welker (Eds.), 2021. Toxic cyanobacteria in water 2nd edition. London: World Health Organization, 858 p.

Francis, G. 1878. Poisonous Australian lake. *Nature*, 18: 11-12.

Miller, M.A., R.M. Kudela, A/ Mekebri, D. Crane, S.C. Oates, M.T. Tinker, M. Staedler, W.A. Miller, S. Toy-Choutka, C. Dominik, D. Hardin, G. Langlois, M. Murray, K. Ward and D.A. Jessup. 2010. Evidence for a novel marine harmful algal bloom: cyanotoxin (microcystin) transfer from land to sea others. *PLoSONE*, 5: e12576.

Rose, E.T. 1953. Toxic algae in Iowa lakes. *Proceedings of the Iowa Academy of Science*, 60: 738-745.

Yoo, R.S., W.W. Carmichael, R.C. Hoehn and S.E. Hrudey. 1995. *Cyanobacterial (blue-green algal) toxins – a resource guide*. American Water Works Association, 229 p.

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Understanding Harmful Algal Blooms
Into the Future: A Holistic Approach

Guy M. Foster

There has been increased focus on harmful algal blooms (HABs) by both the public and the scientific community over the past decade, which has allowed for the confluence of isolated communities and water-resource managers researching HABs. HABs are driven by microscopic organisms and can occur at scales that can be observed by both visualization on the ground, as well as satellites in orbit. HABs occur in locations frequented by the public and can have direct impacts not just on water quality but they can also have serious economic impacts on local communities. These factors have resulted in an increasingly engaged public, as well as a broad swath of scientific researchers of various disciplines, who document and study HABs.

Advances in technology

Over the same period, technological advances in digital data storage and access, computer processing power, miniaturization of electronic components, high-speed data networks and the normalization of access to the internet has tremendously driven HAB science forward. These advances have placed technology and information that historically would have been cost prohibitive to attain into the hands of almost anyone investigating and researching the science of HABs. The ability to collect, store, and disseminate high-quality data is now easy, cheap, and widely available to anyone with the interest to do so.

Another benefit of these technological advances is the ability to collect high frequency data without human intervention. Data collection is no longer limited to physically collecting water samples for laboratory analysis. While perhaps taken for granted today, the ability to deploy water-quality sensors reliably, over long periods of time, is relatively new compared to centuries of manually collecting water samples. There is currently not a universal "HAB-sensor" (akin to a Star Trek tricorder) to provide measurements of all the water-quality conditions necessary to answer questions about the development, duration, extent, and decline of HABs. However, the tools available to the public and scientific researchers are much more advanced than those available decades ago.

Currently, there are many tools available on the market that, while not designed for HABs data collection, can help to understand the factors associated with HAB development, duration, extent, and decline. For instance, it is nowadays rare for someone to *not* to be carrying a smartphone – and therefore a fairly high-quality digital camera, as well as the ability to instantly upload pictures (along with the time, date, latitude and longitude) to databases or directly to researchers. There are even kits available to those citizen scientists with a heightened interest in HABs that will turn smartphones into microscopes, allowing for the evaluation of algal species present, be it directly by the user or indirectly by sending pictures to be analyzed by taxonomists.

On the more research-focused front, water-quality sensors have become more reliable and accurate over time in measuring ancillary factors that drive HAB development, evolution, and toxicity. Because of the ability to integrate these sensors with a Global Positioning System (GPS) to precisely mark locations, data collection can be done over large areas (and water depths) and are not limited to a single location; the mapping of HABs in space and time has given critical insights into the driving factors behind HAB movement (Figure 1).

The collection of dissolved oxygen and pH data at relatively coarse scales (weekly to annually), through discrete data collection, has laid the foundation of limnological and hydrologic research. Continuous measurements of dissolved oxygen and pH using multiparameter water-quality sensors have given rise to new ways of looking at that data. However, diurnal variations of these parameters are only now starting to be explored with respect to their meaning to HAB development. Large variations in the dissolved oxygen diurnal signal, for example, are in some systems very likely the first sign of excessive algal biomass. Similarly, a pH signal that is slowly rising into a range not typically seen in the waterbody being measured is also a potential indicator of biological processes associated with HAB development.

One of the most promising sensor technologies available for HAB studies are field fluorometers, which measure the fluorescence response (wavelengths) in the color pigments present for algae at the time of the bloom. While these measurements are indirect proxies for pigments like chlorophyll and phycocyanin (an accessory pigment present in cyanobacteria), the real value in these data are in the relative patterns over time. When a network of these sensors is operated in a consistent manner, site comparisons become not only possible but are a powerful tool for research. However, fluorescence sensors are more complex in that they can be affected by numerous interferences and many times users may misunderstand their quantitative capabilities.

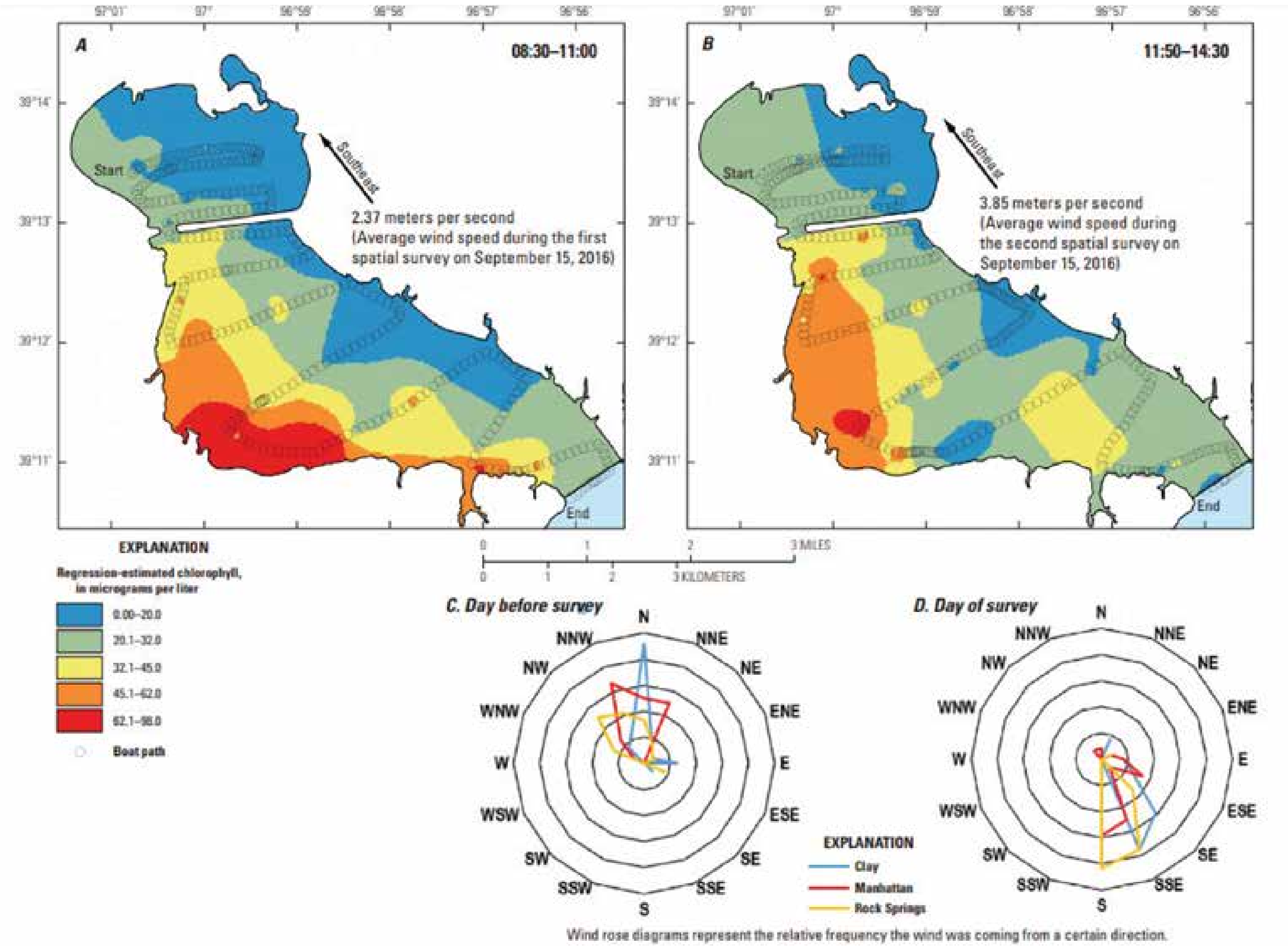


Figure. Regression-estimated microcystin concentration at a 1.5-meter depth in Zone C of Milford Lake, Kansas, on September 15, 2016. (A) first spatial survey; (B) second spatial survey; (C) wind rose diagram displaying relative frequency for hourly wind direction on September 14, 2016; and (D) wind rose diagram displaying relative frequency for hourly wind direction on the day of the spatial survey, September 15, 2016. Model censored data at 0.07 micrograms per liter. (From Foster and others 2019.)

Layers of data

Something that has not changed for HABs research is the relation of sensor data to discrete samples through time. As accurate, reliable, and rugged as water-quality sensors have become, many of the measurements they make are indirect and can suffer from biological fouling and sensor drift. Although there have been great strides made in eliminating these confounding factors, the "gold standard" remains data produced from analytical laboratories. These two techniques – sensor measurements and analytical methods – can be, and in some cases must be, used in concert. The connection can take several forms, but the combined use increases the quantitative value of each dataset.

An example of the power of connecting discrete and sensor measurements is the development of models that can be used to estimate a constituent not directly measured. This technique is not new, but the applications to HABs are still exploratory. The U.S. Geological Survey, for example, has published linear regression models (Figure 2) predicting the occurrence of algal toxins using algal fluorescence as the explanatory variable (Foster and others, 2019). Similarly, models using continuous turbidity and seasonal variables (e.g. time of year) to estimate the likelihood that taste-and-odor compounds relate to algae, are well documented (https://nrtwq.usgs.gov/). The key benefit of these models for water-quality managers is both their use in real-time and in examining HAB occurrence factors after a bloom event.

Another example of synergistic HAB technology is using a combination of cameras and sensor measurements to confirm and research blooms. Whether the camera is attached to a smartphone or a satellite, HABs provide clear visual cues that can be captured photographically. A greenish streak on the water can be many things, but when correlated to sensors, specifically (but not limited to) optical-based sensors like fluorometers or turbidimeters, it provides much more information. For instance, if color changes in the water can also be correlated with increases in an algal fluorescence signal it provides two lines of evidence that there is the presence of cyanobacteria, and

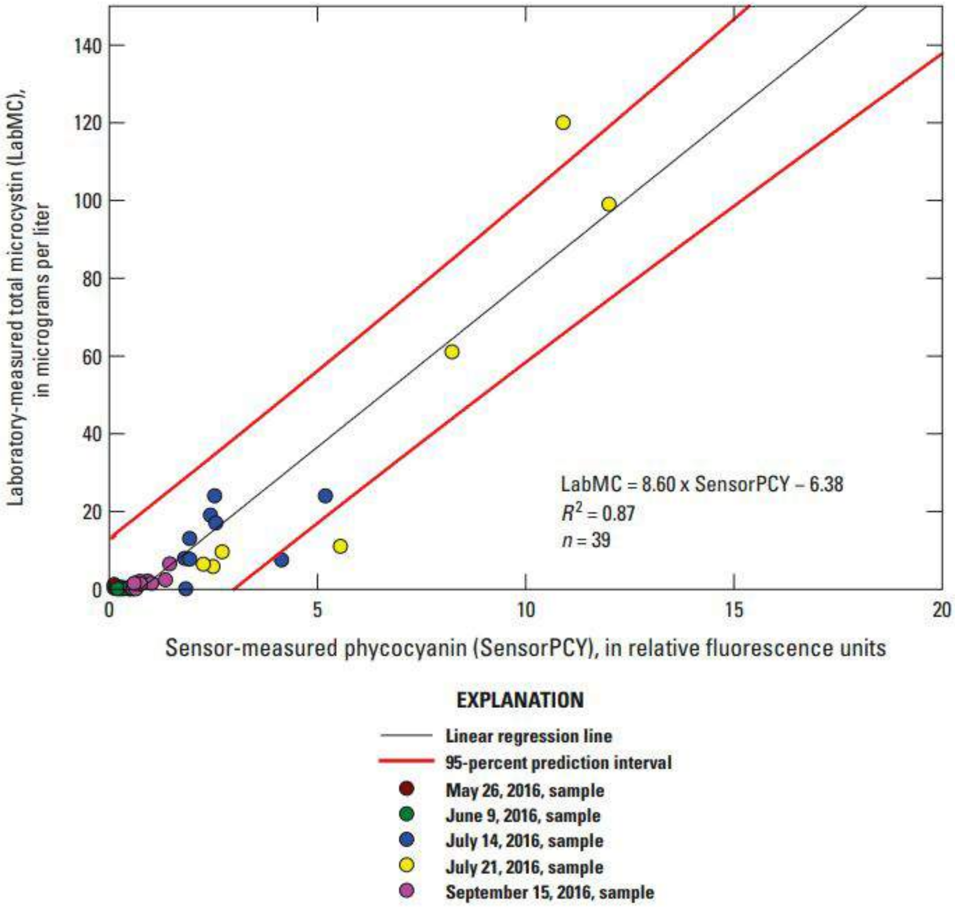


Figure 2. Comparison and resulting regression model between 0.5-meter depth sensor-measured phycocyanin and microcystin from data collections on May 26, June 9, July 14, July 21, and September 15, 2017, at Milford Lake, Kansas. (From Foster and others 2019.)

and shortens the time between collection of samples and results. In some cases, these systems are being used in remote, standalone deployments to identify cyanobacteria of concern.

The challenges ahead

Moving ahead, these synergistic approaches and technologies, as well as others not mentioned here, will be instrumental in forging the future of HAB research. The key will be integrating these technologies and standardizing data collection and interpretation methods across multiple disciplines to ensure consistent and comparable results. With the number of HAB events increasing worldwide there are more people collecting data, from academia to the public, than ever before. Comparing similar data of widely varying quality with various study designs and levels of detail is a current challenge. The real challenge inherent to these varied approaches is how to best collate and analyze these large datasets. The emergence of "big data" and "data science" and their integration into HAB research will be key to advancing understanding HAB dynamics and developing effective management and mitigation strategies. Additionally, the application of artificial intelligence and

perhaps a HAB. At a minimum, it indicates to water-resource managers that resources should be focused in specific locations to determine whether more research or mitigation action is needed.

On a much smaller scale, microscopic imaging technology is being used in several studies, although the technology is not quite at the point where it is widely and affordably available. Traditionally, algal classification and enumeration has remained a resource-intensive manual process, involving highly trained and experienced personnel visually analyzing samples. This work takes a great deal of resources since it is can take a long time and can be expensive. To help reduce this resource dependence, imaging flow cytometry (microscopes that take pictures of algae in real time, Figure 3) automates the process

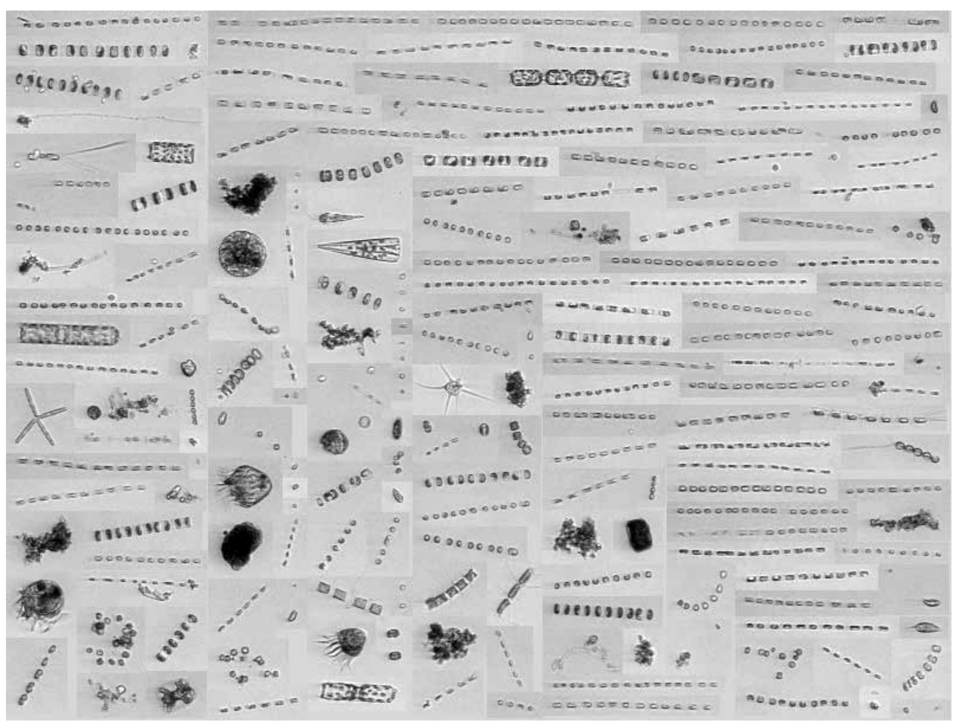


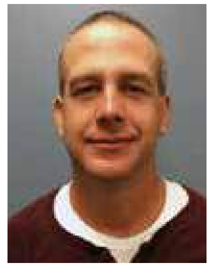
Figure 3. Example Imaging Flow Cytometry image from Fiddlers Cove, N. Falmouth, Massachusetts, taken on July 12, 2021. Data available at https://ifcb-data.whoi.edu/timeline?dataset=fiddlers.

machine learning will also need to be evaluated with respect to HAB research.

While all these sensors and approaches hold great promise moving through the 21st century and beyond, it should not be interpreted as diminishing the role of the on-site observer and the need for local knowledge. How this critical information makes its way to researchers will be another challenge. The only way all these elements can be tied together is through maximizing the use of available technologies, be they communication techniques or data collection. The potential for deeper understanding of HABs is just now being realized, which one can hope will eventually lead to management and prediction techniques that will lessen their harmful effects to people, pets, ecosystems, and economies.

References

Foster, G.M., J.L. Graham and L.R. King. 2019. Spatial and temporal variability of harmful algal blooms in Milford Lake, Kansas, May through November 2016: U.S. Geological Survey Scientific Investigations Report 2018–5166, 36 p., https://doi.org/10.3133/sir20185166.



Guy Foster currently serves as the Water Quality Networks & Research Section Chief at the New York Water Science Center. He oversees about 25 scientists located in three offices throughout the state. The Section conducts a wide variety of water-quality studies in freshwater and marine environments. Study focus ranges from local projects to national programs and includes high priority topics such as harmful algal blooms and PFAS. In addition, Guy co-leads the North Atlantic and Appalachian Region Harmful Algal Bloom Capability Team. A full professional bio can be found here.

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DNA from
Muddy Time Capsules

Hebah S. Mejbel, William Dodsworth, and Frances R. Pick

Using sediment DNA to track environmental change

The increasing intensity of cyanobacterial blooms is a growing concern in fresh and marine waters around the world. These harmful algal blooms have impacted ecosystem and human health in addition to causing substantial economic loss. However, the relative impacts of climate change, nutrient loading, and other stressors remains unclear due to a lack of long-term records. Lake sediments act as natural time capsules, preserving past and present communities, and can be used to help identify the potential drivers of cyanobacterial blooms. As such, environmental change can be reconstructed using biological, physical, and chemical remains. Typically, sediment cores are collected from a study site and sectioned into shorter segments (~0.5 - 2 cm) called intervals. Small sub-samples are collected from each interval and the target of interest (for example, small crustaceans) is then isolated and typically examined by microscopy. Some targets, such as pollen, have been used to infer climate variables such as temperature, but not all organisms leave behind some form of fossil or preserve well in sediments. In addition, the process of isolating the target indicator and then subsequently quantifying the indicator using microscopy can be labour intensive. Results are also somewhat unstandardized as data collection can depend on the expertise of the person doing the analyses. The use of sediment DNA (sedDNA) has recently emerged as a promising and complementary approach to traditional methods used in paleolimnology.

SedDNA offers the potential to provide precise results, to the species level, while speeding up the process of analyzing complex sediment samples. DNA from animals, plants, bacteria, viruses, fungi, and protists is released primarily through passive and active secretion or from cell lysis (i.e., cell breakdown after death or from waste). Once the DNA settles onto the sediment, negatively charged phosphate groups on the DNA are bounded onto positively charged ions (cations) in the sediment, forming cationic bridges, making the DNA stable in sediments for a very long time (Figure 1). The use of sensitive molecular approaches to identify the DNA is then applied to track changes within lake ecosystems, whether natural or anthropogenic.

Analyzing sedDNA

The analysis of sedDNA requires strict sampling and laboratory techniques, as DNA isolated from sediments can easily degrade. A strategic sampling approach is often necessary to ensure that the sediments collected are appropriate for

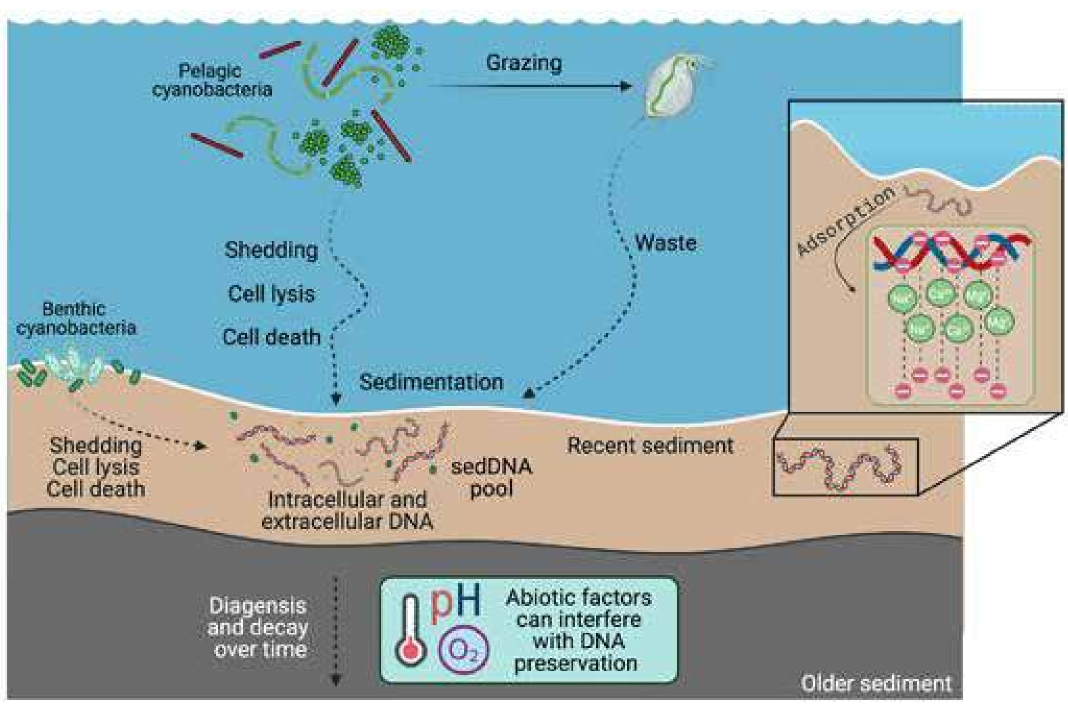

Figure 1. The release and deposition of DNA from pelagic (within the water column) and benthic (bottom-dwelling) cyanobacteria onto sediment. The sediment DNA (sedDNA) pool is a combination of extracellular DNA that is adsorbed and bounded onto the sediment through cationic bridges, and intracellular DNA found within structurally intact cells. Certain environmental conditions and abiotic factors such as temperature, pH, and oxygen can interfere with DNA preservation in sediment. Figure created in Biorender.

the research questions being addressed. For instance, sediments from Lake 227 at the International Institute of Sustainable Development-Experimental Lakes Area (IISD-ELA, Ontario, Canada) are very soft due to the high level of organic matter within the lake. Lake 227 is an experimentally manipulated lake that has been loaded with phosphorus and nitrogen for the past five decades. While this makes it an ideal lake to analyze the impacts of excess nutrient levels on phytoplankton dynamics, the high level of organic matter makes collecting useful sediment cores during the summer somewhat difficult. Instead, collecting freeze cores (Figure 2) from under the ice during the winter season is recommended. Freeze coring is a process that uses dry ice and methanol to freeze the sediment onto a solid piece of the corer that will prevent the mixing of different layers. Hammers or chisels are then used to gently free the frozen sediment from the corer. After sediments are collected and cores are sectioned into intervals (ideally in a cool and sterile environment), the samples are transferred into freezers for long-term storage. A small amount of sediment is removed from each interval to allow for dating of the sediment sample. Isotope dating techniques, such as ^{210}Pb and ^{137}Cs dating, can help determine the approximate age of the sediment intervals. This information can be used to assess how much has changed between specific timepoints (for example, comparing cyanobacterial abundance between pre- and post-European settlement).

DNA extractions and subsequent molecular analyses are typically performed in a dedicated and sterile environment to minimize contamination from other sources of environmental DNA. Before DNA can be extracted however, the specific choice of DNA extraction kit needs to be selected based on the target of interest. While the majority of DNA is estimated to be extracellular and bounded onto the sediment through cationic bridges, some DNA is found in structurally intact cells. For example, when conditions are unfavourable for growth, some cyanobacteria can produce specialized resting stages called akinetes. Akinetes can persist in sediments for centuries due to their enlarged size and thick cell walls. Different DNA extraction methods are used depending on the type of DNA being targeted (see Nagler et al. 2018).

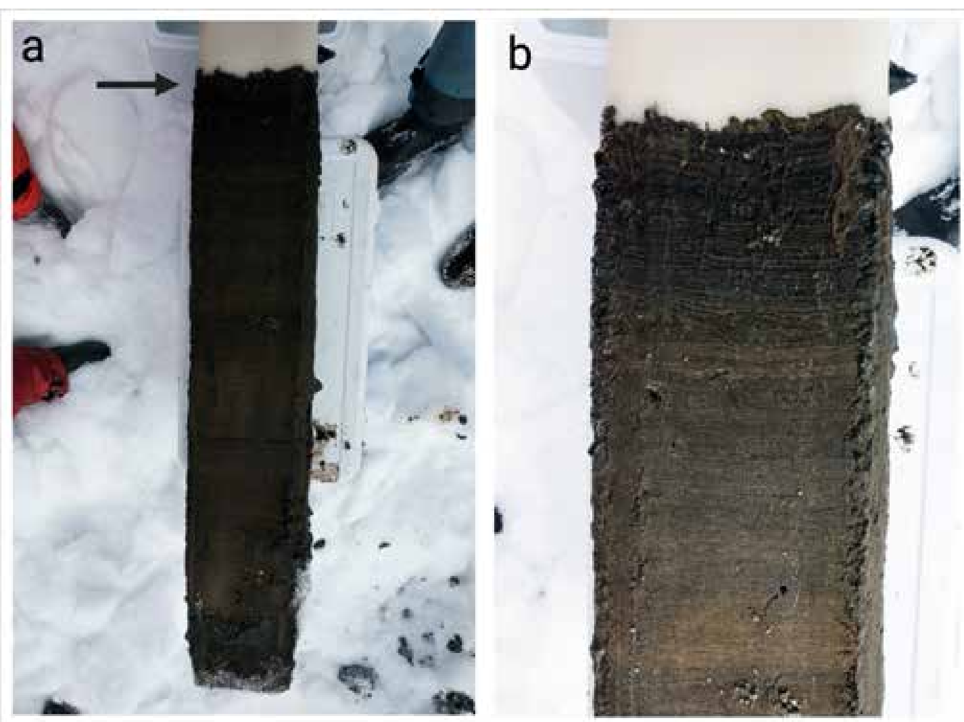

Figure 2. A freeze-core collected in March of 2018 from IISD-ELA Lake 227 (a) and a close-up of the top of the core (b). The arrow in (a) points to the top of the core (i.e., the most recent sediment). Annual laminated lake sediments, called varves, are visible in the close-up (b) and can be used to determine chronology (like tree-ring counting). Photo credits: Michael Paterson, IISD-ELA.

The techniques used to analyze DNA depend on the ecological research question and specific target. Over the past decade, most sedDNA analyses have used some form of polymerase chain reaction (PCR) technology to detect and quantify target genes. PCR is a fast and inexpensive technique used to create many copies, or "amplify" a gene of interest in a short period of time. Specific primers, which are short DNA sequences that flank the gene of interest, are designed to bind onto the DNA strand and provide the starting point for DNA amplification. Typically, enough DNA copies (millions to billions) are formed such that it can be further analyzed using other molecular approaches. Conventional PCR is a qualitative approach that determines the presence or absence of the target gene, but other forms of PCR, such as quantitative PCR (qPCR) or droplet digital PCR (ddPCR), are more precise and can provide information on the absolute quantity of the gene (Figure 3). PCR techniques have been successfully used to track cyanobacterial abundance changes in sediments (Pilon et al. 2019) and have made it easier to detect rarer genes.

There has also been an increase in the number of studies using DNA sequencing tools to obtain information about the diversity that is present in environmental samples. DNA sequencing is the process of determining the order of nucleotides (A, C, T, G) in a sample. A reference gene database, which is a collection of publicly availably nucleotide sequences, is then used to link the gene sequences to specific genomes or proteins found in different organisms. With this tool, hundreds of species can be identified simultaneously from a single sample. Collectively, the use of a combination of PCR and DNA sequencing tools can provide a qualitative and quantitative assessment of the abundance and community composition within sediment samples. This information can be used to understand how changing environmental conditions have impacted the dynamics of biota, including cyanobacteria, over centuries and possibly millennia.

While molecular based techniques for sediment DNA are becoming common, more research is needed to validate the

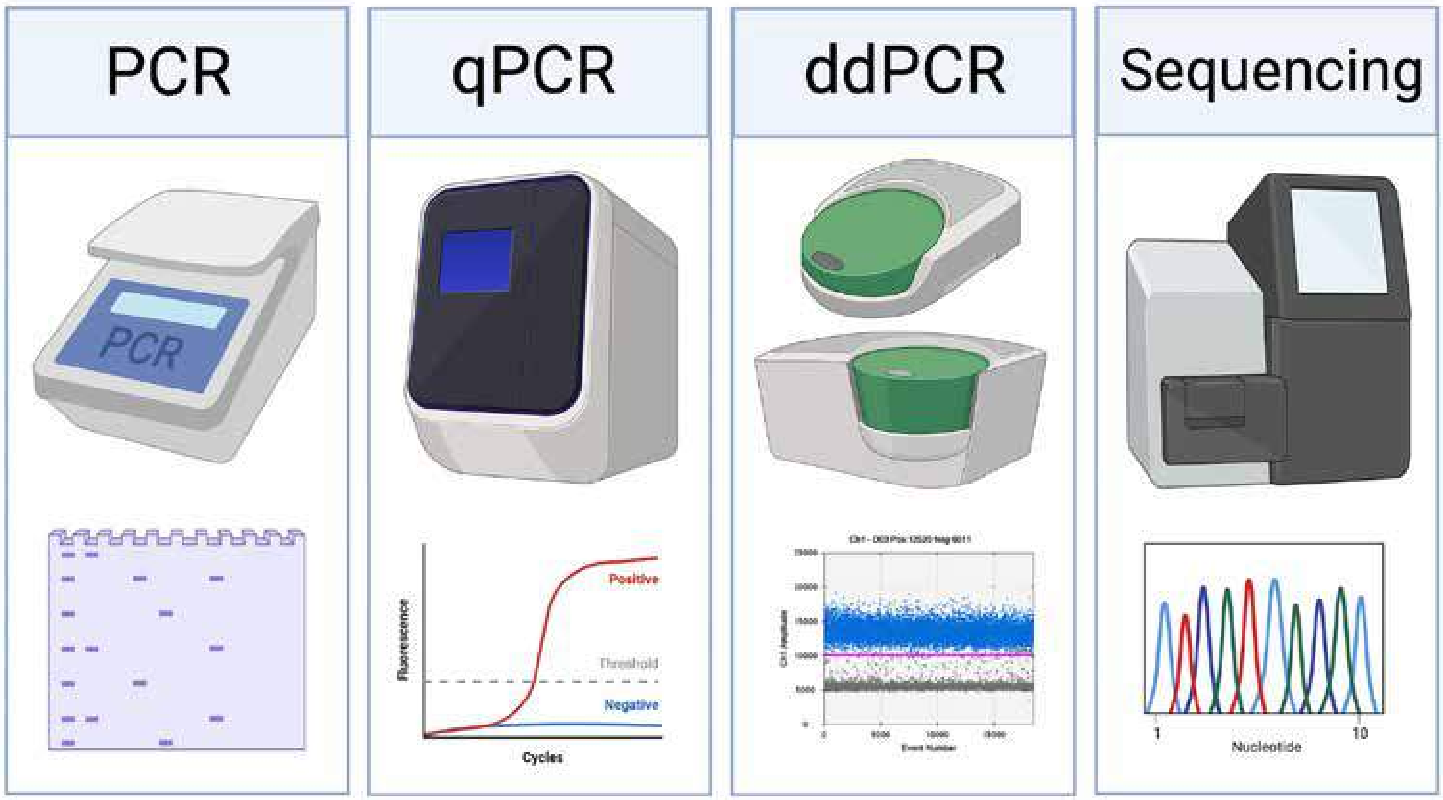

Figure 3. Common molecular tools used to analyze sediment DNA, including conventional PCR (far left), quantitative PCR (qPCR), droplet digitial PCR (ddPCR), and sequencing technologies (far right). Conventional PCR determines the presense or absense of a target gene but is not quantitative. qPCR technology is used for quantifing the relative and/or absolute abundance of a target gene. With ddPCR, absolute abundance values are determined based on the fraction of droplets positive for the target gene. Sequencing results involve the determination of the sequence of nucleotides (A, G, C, or T) in a DNA sample. Figure created in BioRender.

use of sedDNA to reconstruct historical lake dynamics. As part of an ongoing research project, we have quantified the abundance of the cyanobacteria 16S rRNA gene (as a proxy for the total amount of cyanobacteria) using ddPCR on sediments collected from several IISD-ELA lakes, including Lake 227. The ddPCR approach accurately reflected the significant rise in cyanobacteria associated with experimental fertilization that began in 1969 (Figure 4) (Mejbel et al. 2021). Results were compared to Lake 442 – a lake that has not been subjected to nutrient manipulation and has served as a reference lake to Lake 227 in previous studies. The use of sedimentary DNA records can be further validated by directly comparing surface water phytoplankton records with sedimentary records over the same time frame.

Advantages and limitations

One of the main advantages of using sedDNA is the detection of organisms that do not leave behind morphological remains (like cell walls and resting spores) but do leave DNA that can be identified using specific PCR primer sets. Additionally, sedDNA analyses are more standardized than traditional microscopy methods and are carried out in a consistent, repeatable manner. Traditional microscopy methods depend on the experience and expertise of the analyst, are labour intensive, and data processing can take time. Some molecular techniques targeting sedDNA can provide results within as little as a few hours. SedDNA methods also only use a small amount of sediment (sometimes less than 0.3 g) but can provide a wealth of information, including the absolute quantity of target genes and overall community composition. Molecular methods are highly sensitive and low concentrations of target genes can be detected using these approaches. It is also important to note that some cyanobacteria, like pico-cyanobacteria, are widespread and found in a wide range of environments (Pick 1991) but, because of their small size, are difficult to track using traditional methods alone.

While there are many advantages and benefits of using sedDNA in comparison to traditional methods, some limitations remain. One of the major limitations with DNA sequencing is the incompleteness of reference gene databases. This reduces the likelihood of classifying all sequences down to species. However, new sequences and genomes are continuously added to these public databases. Another limitation includes potential DNA degradation interfering with the taxonomic resolution and quantification of target genes. While the binding to clay material can slow down DNA degradation, some studies have found that certain abiotic factors can lead to DNA degradation. It is often assumed that cold, dark, anoxic conditions are the most ideal for DNA preservation, but several studies have successfully extracted and analyzed sedDNA from shallower and warmer sites (Domaizon et al. 2017). Other potential factors that can interfere with DNA decay rates include salinity, pH, and organic matter content. Diagenesis, or the physical and chemical changes of sediments through time, could

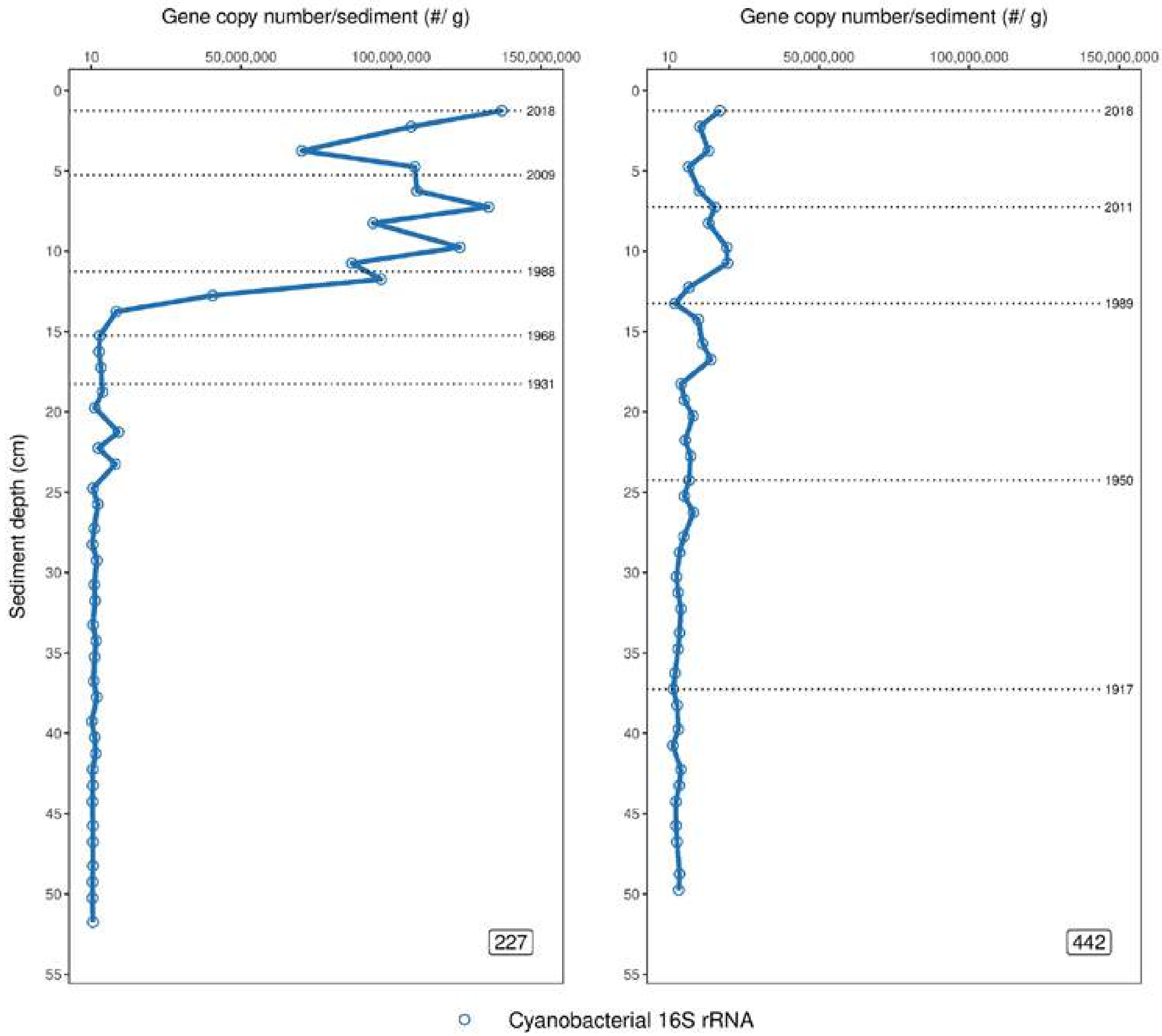

Figure 4. Total abundance of the cyanobacterial 16S rRNA gene, expressed per gram of wet sediment, determined from droplet digital PCR using sediments collected from IISD-ELA Lake 227 (left) and Lake 442 (right). Nitrogen and phosphorus were added into Lake 227 between 1969 and 1989, but only phosphorus subsequently. Lake 442 is an unmanipulated reference lake that has had very little human impact. Data from Mejbel et al. (2021) replotted.

also lead to DNA breakdown and interfere with data interpretation. Some of these limitations can be reduced by choosing shorter DNA fragments that are less exposed to these factors. The interpretation of community-based analyses can also be influenced by preservation differences between taxa. For example, in sediments of a deep alpine lake, cryptophyte (a type of eukaryotic algae) DNA was underrepresented when compared to the water column data (Capo et al., 2015). Despite these advances, more research is needed to analyze the combined effects of the factors interfering with DNA found in sediment.

The value in using sedDNA

When long term monitoring data are sparse and when traditional methods are unable to fully reveal ecosystem changes, sediment DNA can be used to address questions surrounding the evolution of ecosystems and the impacts of human activities on aquatic ecosystems. In addition, as PCR and sequencing costs continue to decline and as more studies validate these approaches, the use of sedDNA to reconstruct historical dynamics will likely increase. By analyzing how cyanobacterial abundance and community composition has shifted in response to changing environmental conditions (for example, higher phosphorus levels and/or warming temperatures), critical threshold values and the association between environmental conditions and harmful algal bloom formation can be determined. The investigation of cyanobacterial genes in sediments both quantitatively and qualitatively could lead to more effective management techniques in lakes affected by algal blooms by defining reference conditions and restoration targets.

References

Capo, E., D. Debroas, F. Arbau and I. Domaizon. 2015. Is planktonic diversity well recorded in sedimentary DNA? Toward the reconstruction of past protistan diversity. *Microb. Ecol*, 70: 865-875.

Domaizon, I., A. Winegardner E. Capo, J. Gauthier,and I. Gregory-Eaves. 2017. DNA-based methods in paleolimnology: new opportunities for investigating long-term dynamics of lacustrine biodiversity. *J. Paleolimnol*, 58.

Mejbel, H.S., W. Dodsoworth, A. Baud, I. Gregory-Eaves and F.R. Pick. 2021. Comparing quantitative methods for analyzing sediment DNA records of cyanobacteria in experimental and reference lakes. *Frontiers in Microbiology. In press.*

Nagler, M., S.M. Podmirseg, G.W. Griffith, H. Insam and J. Ascher-Jenull. 2018. The use of extracellular DNA as a proxy for specific microbial activity. *Appl. Microbiol. Biotechnol*, 102: 2885-2898.

Pick, F. 1991. The abundance and composition of freshwater picocyanobacteria in relation to light penetration. *Limnol. Oeanogr*, 36: 1457-1462.

Pilon, S., A. Zastepa, Z.E. Taranu, I. Gregory-Eaves, M. Racine, J.M. Blais, A.J. Poulain and F.R. Pick. 2019. Contrasting histories of microcystin-producing cyanobacteria in two temperate lakes as inferred from quantitative sediment DNA analyses. *Lake Reserv. Manag*, 35: 102- 117.

Hebah Mejbel is a Ph.D. candidate in the biology department at the University of Ottawa, Ottawa, Canada. Her research focuses on developing and validating methods for the quantification of cyanobacterial genes in sediment and on understanding the long-term impacts of eutrophication, acidification, and climate change on cyanobacterial dynamics. Through a combination of empirical studies, bioinformatics, and analytical fieldwork, her work has advanced our understanding of the factors regulating the abundance and diversity of cyanobacteria in freshwater systems and of the factors impacting cyanobacterial DNA preservation in sediment. She has helped validate the use of PCR and sequencing approaches for the reconstruction of historical cyanobacterial trends.

William Dodsworth is a research scientist and technician in the biology department at the University of Ottawa, Ottawa, Canada. He completed his MSc with Dr. Frances Pick where his research focused on analyzing the effects of nutrient loading and climate change on the formation of harmful algal blooms in Canadian temperate lakes. Using different molecular techniques, he quantified cyanobacterial trends over the past ~200 years using sediment DNA archives and determined the effects of depth and morphometry on DNA preservation. Currently, he works on refining sediment DNA analyses as well as teaching microbiology at Algonquin College, Ottawa, Canada.

Frances Pick is a professor of biology and environmental sciences at the University of Ottawa, Ottawa, Canada. Her research focuses on the ecology of freshwater ecosystems (lakes, rivers, wetlands, urban ponds) and particularly the structure and function of plant and algal/cyanobacterial communities. With chemists, she has worked on developing analytical methods for various hepatotoxins and neurotoxins produced by cyanobacteria. With molecular biologists, her lab is applying molecular tools for in situ detection of cyanobacterial and toxin genes in both present day and ancient eDNA preserved in sediments. She has been a NALMS member for over 25 years, a past Board Director for Region 11 and co-chair of the symposium in Toronto, Canada.

ITRC Cyanobacteria Guidance Is Now Available

Angela Shambaugh

The Interstate Technology and Regulatory Council (ITRC) has released a new guidance document on cyanobacteria – *Strategies for Preventing and Managing Harmful Cyanobacteria Blooms (HCBs).*

This document brings together information about all aspects of cyanobacteria, providing links and resources that allow you to read more about topics of interest. The guidance:

- provides an overview of our current understanding of cyanobacteria and cyanotoxins, including economic impacts;
- helps you identify monitoring approaches and build a monitoring plan to meet your needs;
- presents the important elements of a cyanobacteria response and communication plan;
- reviews in-lake options commonly used for cyanobacteria management and control;
- reviews nutrient management approaches that can help prevent HCBs; and
- includes several interactive web tools to help you quickly and easily compare information about management and monitoring approaches presented in the document.

The 2021 guidance document is available online at https://hcb-1.itrcweb.org/. Internet-based training, where team members walk you through the material presented in the document, is also available. To see the upcoming training schedule or find recorded training materials, please visit https://www.itrcweb.org/Training. The 2021 guidance is focused primarily on planktonic cyanobacteria. Additional guidance for benthic cyanobacteria is scheduled for release early in 2022.

A Hidden Source of **Phosphorus Loading**

Stephen J. Souza and Alan Fedeli

Could tap water be accelerating the eutrophication of urban and suburban lakes?

Introduction

Controlling and reducing phosphorus loading is typically the cornerstone of a successful lake restoration and management plan. To do so entails the identification and accurate quantification of all phosphorus sources. However, for urban and suburban lakes, one source that is rarely considered is tap water, a possible significant, "hidden" source of phosphorus loading. Little is known about this possible "hidden threat," its potential impact on lake productivity and what to do about it.

Cupsaw Lake (Figure 1) is a 66-acre suburban waterbody located in northeastern New Jersey. The lake's watershed is relatively undeveloped, but very high phosphorus concentrations are routinely measured in the streams at their point of discharge into the lake as well as within the lake itself. Water quality sampling of the lake's tributaries during storm and base flow conditions, as well as comprehensive watershed modeling, ruled out stormwater as being responsible for the documented high phosphorus concentrations. Likewise, the lake's internal phosphorus load is controlled, so the source was not linked to regeneration of phosphorus from the lake's sediment. If not stormwater or internal loading, where was this phosphorus coming from? As the lake community came to discover, the source appeared to be the community's tap water, with testing confirming the presence of very high concentrations of orthophosphate in the tap water samples.

Figure 1. Cupshaw Lake, New Jersey.

Lead contamination of potable water

Over the past decade we have become increasingly aware of lead contamination in potable water. The problem, which tends to be most acute in older developed areas, is directly linked to the historical use of lead water supply pipes as well as lead soldered pipe fittings and even lead soldered fixtures. A common means used to mitigate lead contamination is to implement a corrosion control treatment (CCT) program. This often involves the introduction of a phosphate-based material into the water supply system to create a precipitate that adheres to the interior wall of the water supply pipe. Referred to as "passivation," this process results in a protective lining that inhibits/prevents the dissolution of lead into the drinking water. Passivation has proven to be very effective and far less expensive than replacing lead service lines. CCT occurs within the water treatment plant, as a final step in the processing of drinking water. The most commonly used products are various formulations of orthophosphates and blended ortho/polyphosphates, including zinc-phosphate. The water supply industry has used various phosphate-based, corrosion inhibitors for well over a century, with zinc-phosphate treatment techniques dating back to the 1970s.

The passage of the United States Environmental Protection Agency's (USEPA) Lead and Copper Rule in 1991 set limits on the allowable concentrations of lead and copper in potable water. To satisfy drinking water requirements, water suppliers expanded the use of CCTs involving orthophosphate products. The typical concentration of orthophosphate present in CCT water leaving a water treatment plant ranges from 0.1-0.6 mg/L. These concentrations are at least between 2 and 10 times the maximum allowable concentration for total phosphorus in lakes (0.05 mg/L) as set in New Jersey's Surface Water Quality Standards (NJAC 7:9B).

For most north-temperate lakes, phosphorus is recognized as the primary driver of lake productivity. Essentially, the more phosphorus, the more productivity, with much of the productivity expressed as phytoplankton, including cyanobacteria. This is especially true of New Jersey's lakes, thus the emphasis on controlling and limiting phosphorus loading. An important part of preparing a lake management plan is the identification of all major sources of phosphorus loading and quantification of the amount of phosphorus attributable to each source, whether internal or external. With respect to external sources of phosphorus loading, the amount of phosphorus contributed by stormwater runoff and septic systems is usually closely examined and detailed. But what about the phosphorus present in drinking water, more specifically tap water used for irrigating lawns and gardens, outdoor cleaning, water fountains and other types of outdoor use? Usually, little thought is given to this source or the ramifications it may have on lake productivity and harmful algae blooms (HABs).

Cupsaw Lake and the Cupsaw Watershed

Cupsaw Lake is managed by the Cupsaw Lake Improvement Association (CLIA). The lake was created by the damming of Cupsaw Brook. The lake is a relatively shallow, with an average depth of only 8-10 feet and a maximum depth of only 30 feet. The lake's watershed encompasses 2,816 acres (including 1,000-acre Sheppard's Lake). Over 79 percent (2,225 acres) of the watershed is undeveloped forested land. Most of the developed land (223 acres) occurring within the watershed is immediately adjacent to the lake's shoreline. There are 600 family members in CLIA, with many of the homes dating back to the 1960s and earlier. The lake community is supplied potable water by North Jersey District Water Supply Commission, one of New Jersey's major water purveyors. Wastewater is managed by individual septic systems. Regionally, the native soils are listed by NJDEP as being somewhat ineffective in managing septic leachate. The significance of this will be discussed later.

The lake's water quality data show mid-summer total phosphorus (TP) and orthophosphate (PO_4) concentrations to be very high (Figures 2 and 3). The in-lake TP and PO_4 concentrations often exceed the State's maximum allowable total phosphorus concentration for lakes (0.05 mg/L) and are often well in excess of the CLIA's lake management threshold for TP (0.03 mg/L) and PO_4 (0.02 mg/L).

Secchi clarity data also collected by the CLIA Environmental Committee has documented seasonal declines in mid-summer clarity linked to increases in mid-summer lake productivity. Although the lake has not experienced a HAB since 2018, the increase in mid-summer phytoplankton densities and loss in clarity are a major concern to CLIA and the users of Cupsaw Lake.

Where is all this phosphorus coming from?

CLIA has implemented a number of measures to control phosphorus loading to the lake. To control internal loading, CLIA operates a diffused air system that

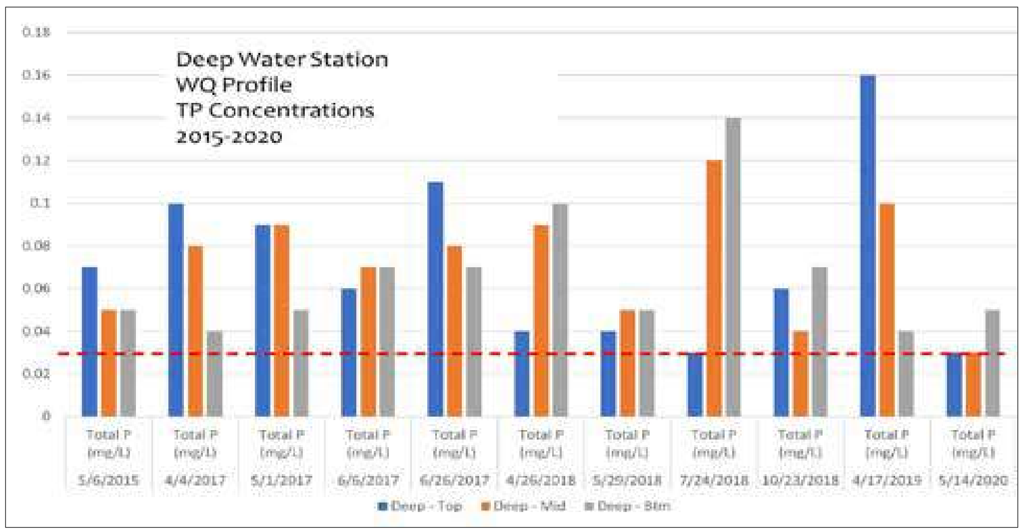

Figure 2. Measured in-lake total phosphorus concentrations.

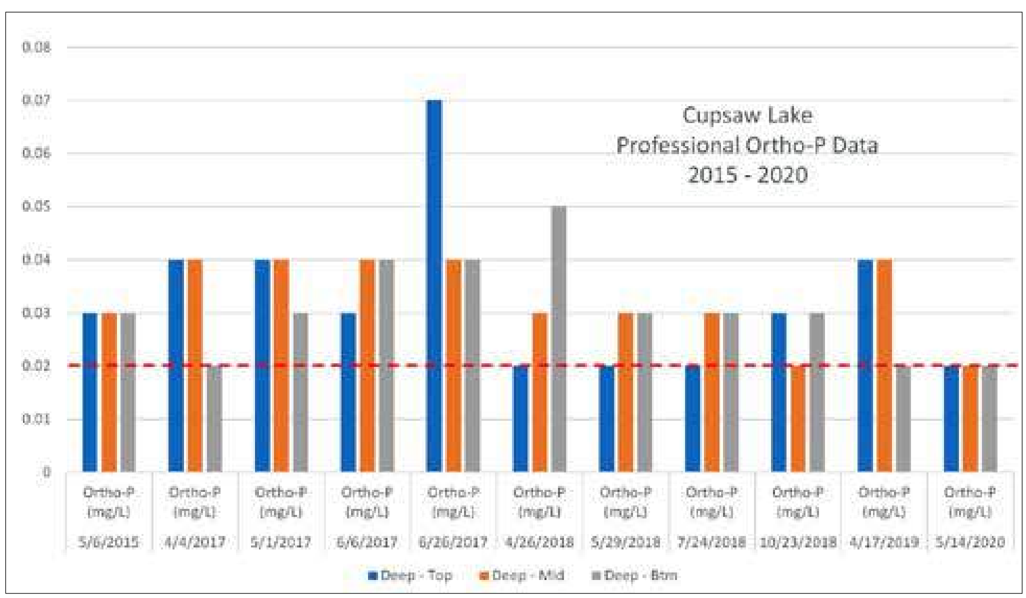

Figure 3. Measured in-lake orthophosphate concentrations.

prevents stratification, maintains positive dissolved oxygen concentrations from the surface to the bottom of the lake, and effectively inhibits large scale internal phosphorus loading. CLIA also requires residents to conduct mandatory septic pump-out (once every three years) and has implemented goose control measures, all aimed at controlling phosphorus loading. To further control external phosphorus loading, CLIA has educated and supported homeowner green infrastructure stormwater projects (rain gardens, rain barrels and lakeshore buffers). These measures have prevented the lake from experiencing a HAB and were therefore deemed effective and successful. However, even with all of these measures the lake's mid-summer total phosphorus and orthophosphate concentrations remained elevated, especially when compared to many of the other lakes in this same region of New Jersey.

The lake's total annual external TP load, as computed by Princeton Hydro (2021), is only 306 kg/yr. Of the total annual TP load, less than 12 percent (36.5 kg) is attributable to overland runoff (Princeton Hydro 2021). Yet the concentration of orthophosphate measured in each of the lake's main tributaries is unusually high (Table 1), with early summer means ranging between 0.019 and 0.079 mg/L and late summer means ranging between 0.056 and 0.148 mg/L. These are exceptionally high orthophosphate concentrations, especially for a watershed that is largely forested. It should be noted that these water samples were collected close to the lake proper, at the mouth of the streams and at the outfall of major pipes. Based on the field measured orthophosphate data (Table 1), the mean growing season orthophosphate concentration is 0.075 mg/L. Using this mean concentration with the annualized flow data computed by Princeton Hydro (2021) for the Cupsaw Lake watershed (5.5 million M^3) yields an **annualized estimated orthophosphate watershed load** of approximately 417 kg, which is greater than the **annualized computed total phosphorus watershed load**. The discrepancies between the Princeton Hydro modeled TP loading data, the mass-balance computed orthophosphate load, and the measured in-lake orthophosphate concentrations suggest there exists a phosphorous source not accounted for by the watershed model. Orthophosphate is highly bioavailable and, in most lakes, it is quickly assimilated. As a result, during the growing season, it is usually measured at very low concentrations. So, what is accounting for this additional phosphorus, and the especially high measured in-lake and in-stream concentrations of orthophosphate?

In attempting to answer this question, CLIA started measuring the concentration of orthophosphate present in drinking water. Table 2 shows that the community's tap water contains very high concentrations of orthophosphate! As previously noted, CCT using phosphate-based products is a commonly implemented means by which to mitigate potable water lead contamination. The City of Newark, NJ, is aware of elevated lead concentrations in the city's water supply directly as a result of the corrosion of old water supplies lines. The City has been working with New Jersey Department of Environmental Protection (NJDEP) to address and mitigate these problems. Part of the solution, as recommended in the city's Optimal Corrosion Control Treatment plan, calls for the treatment of the city's water supply with an orthophosphate corrosion inhibitor and maintenance of orthophosphate concentrations of at least 0.4 mg/L in the water supply. The Cupsaw Lake community obtains its potable water from the same supplier as the City of Newark. As such, it appears the elevated concentrations of orthophosphate

Table 1. Field Measured Stream Orthophosphate Concentrations.

Station	Sampling Date and Measured Concentration of Orthophosphate (mg/L)									
	7/2 2020	6/6 2019	6/5 2018	6/30 2017	6/11 2016	9/10 2020	9/19 2019	9/10 2018	9/8 2017	9/23 2016
South Brook	0.09	0.08	0.08	0.03	0.12	0.09	0.09	0.11	0.08	0.07
Glenn Brook	0.03	0.04	0.03	0.01	0.07	0.06	0.04	0.06	0.02	0.03
East Point Brook	0.07	0.16	0.03	0.02	0.07	0.1	0.37	0.12	no flow	no flow
Cascade Brook	0.07	0.04	0	0.01	0.04	0.04	0.09	0.07	0.03	no flow
Cupsaw Brook	0.03	0.04	0.02	0.01	0.03	0.05	no flow	0.1	0.01	0.03
Hickory Brook	0.09	0.09	0.08	0.04	0.08	0.05	no flow	0.07	0.08	0.09
Kendal Drain	0.08	0.1	0.05	0.01	0.1	0.05	no flow	0.21	0.36	0.06
Mean	0.066	0.079	0.041	0.019	0.073	0.063	0.148	0.106	0.097	0.056

Table 2. Results of Tap Water Sampling for Orthophosphate.

Tap Water PO_4 mg/L	9/10/2019	7/2/2020	7/27/2020	9/10/2020	10/6/2020	Mean
	0.55	0.48	0.53	0.53	0.41	0.5

measured in the lake and its tributaries is the result of the systematic addition of an orthophosphate corrosion inhibitor used to prevent lead and copper related potable water supply problems.

Given the high ortho-phosphorus concentrations measured in the tap water, routine daily household activities (bathing, laundry, dish washing, etc.) could be unknowingly adding phosphorus to the lake via septic systems. As noted, the area's native soils are not exceptionally conducive to septic management owning to slope, shallow depth to groundwater, bedrock and a fragipan. Plus, given the age of many of the homes, the phosphorus removal capability of the septic fields may be limited. Additional loading could also be occurring as a result of irrigation practices, car washing and other uses of tap water resulting in the direct overland flow of water into the lake. Also, the routine back-flushing of the potable water lines conducted by the water supplier is suspected of periodically discharging large amounts of phosphorus into the lake, its tributaries and the stormwater collection system. Given that most of the watershed development is concentrated relatively close to Cupsaw Lake, is it possible that tap water is a "hidden" source of the lake's phosphorus load and responsible for the aforementioned high in-lake concentrations of TP and PO_4 (Tables 1 and 2)?

CLIA has begun to examine how best to deal with this source. This includes discussions with the water supplier about their CCT program. This could involve requesting the water supplier treat pipes using less zinc phosphate, as part of the initial remediation dose as well as any NJDEP required maintenance dose. Similarly, the timing of the system-wide back-flushing operations need to be discussed so as to avoid acute loading during the peak of the growing season. CLIA will also be conducting more sampling to further quantify the tap water PO_4 load, and looking more closely at how this phosphorus could be entering the lake.

In terms of what to do about this loading, at the community level some of the options currently being evaluated include:

- Alum treatment of septic systems. This would involve the introduction of small amounts of alum into the wastewater stream exiting a home, in advance of the septic tank and septic field. Such a treatment system is being evaluated at two nearby lake communities. This could help enhance the phosphorus removal capacity of older or even under-sized and under-performing septic fields.
- Increased use of rain gardens, lakeside buffers and other green infrastructure. These measures are intended to intercept runoff and adsorb and attenuate any orthophosphate prior to the runoff entering the lake or the lake's shallow aquifer. They also represent a means of attenuating PO_4 introductions linked to outdoor use of tap water (irrigation, car washing, etc.)
- Education of community on water conservation practices. This is intended to decrease water use in general, thus decreasing septic loading and overland runoff.
- Promotion of turf options and alternative lawn covers that do not require irrigation.
- The installation of flow activated stream and stormwater catch basin alum injectors.
- The use of biochar-infused catch basin inserts, and
- Expanded in-lake alum treatments to actively bind orthophosphate at the onset of the growing season.

Conclusion

The routine corrosion control treatment of potable water supply lines with various phosphate products, while helpful in addressing lead and copper toxicity problems, may represent a "hidden" source of phosphorus loading to urban and suburban lake systems. This may be the case with Cupsaw Lake. The lake's exceptionally high summer concentrations of TP and PO_4 are concerning, especially with respect to the potential for algae blooms and HABs. Even though CLIA and the Environmental Committee have implemented various lake and watershed measures to reduce nutrient loading and control algal productivity, the lake still experiences a mid- to late-summer decline in lake clarity attributable to escalating phytoplankton densities. The confirmation that tap water has very high concentrations of orthophosphate may be a driver of this increase in productivity. Increased water use at this time of year may be unsuspectingly adding phosphorus to the lake independent of storm even and internal loading processes. Management of this "hidden" source of phosphorus is not easy. However, CLIA is examining options by which to decrease phosphorus loading, including enhanced septic management, alternative lawn covers, green infrastructure stormwater management solutions and in-lake alum treatments.

References

CDM Smith. 2019. City of Newark Lead and Copper Rule Compliance Study Wanaque Gradient.

Princeton Hydro, 2021. An Assessment of the Lakes and Watersheds of Ringwood Borough, Borough of Ringwood, Passaic County, New Jersey.

USEPA. 2016. Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems. EPA 816-B-16-003.

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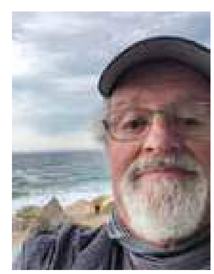


Alan Fedeli has been a member of the Cupsaw Lake community for 50 years. He has served as past president and chair of the CLIA Environmental Committee. He also serves on the Ringwood Township Board of Health and is on the Board of the New Jersey Coalition of Lake Associations. It was because of Alan's involvement in the monitoring and management of Cupsaw Lake's water quality that attention was focused on the potential impact of potable water on the lake's trophic state.

CyAN's New Web-Based Interface

Brad Autrey, Jana Compton, Mike Galvin, John M. Johnston, Michelle Latham, and Blake Schaeffer

Mapping harmful cyanobacteria blooms from your home

In 2019, EPA and its partners in NASA, NOAA, and USGS launched the Cyanobacteria Assessment Network mobile application (CyAN app). The app is run on mobile devices that use the Android operating system and it uses satellite data to provide users with information about cyanobacteria concentrations in thousands of U.S. water bodies as a way of helping people be aware of, and possibly avoid, harmful cyanobacteria blooms (HCBs). In 2021, a web-based version of the app will be available for desktop computers or any mobile operating system.

Since the app was launched, it has been downloaded thousands of times and is in use across the country helping people get a better idea about the risk of encountering HCBs at their local beaches. The app is designed to be easy to use in the mobile environment so people can check on nearby waters. This makes the CyAN app very local and community-focused in its use. You can learn more about the CyAN app, the reason it was launched, and the science behind its development in previous *LakeLine* issues from Mattas-Curry et al., A Space Satellite Perspective to Monitor Water Quality Using your Mobile Phone, and Schaeffer et al., Satellite-Detected Cyanobacteria in Large U.S. Lakes on Your Android Phone.

One thing that CyAN's developers have noticed is that not only is the app being used to help beachgoers decide if it's safe to swim, but it is also being used by state and local resource managers to look out for HCBs and help make decisions about things like beach closures. For example, when New Jersey developed its 2020 Cyanobacterial Harmful Algal Bloom (HAB) Freshwater Recreational Response Strategy [PDF], it incorporated data from the CyAN app into its screening process to help inform actions to be taken by the state. Another example is the Grant County Health District in Washington who was thinking of approaching the problem of identifying HCBs by using citizen science strategies but ended up being able to use the CyAN mobile app for the same purpose. They note that this CyAN app is important to them because this approach has the added benefit of placing no strain on the county or state's budget. You can read more about these and other community impacts from the CyAN mobile app in CyAN App Used for Early Detection of Harmful Algal Blooms in Communities Across the Nation (EPA's *Science Matters Newsletter*).

In order to accommodate these and other uses of the CyAN data, the EPA CyAN team has put together a web-based interface for the app that is accessible from desktop computers, tablets and other mobile devices, and just about any other device used to browse the internet. The team thinks this will help existing CyAN users access potential HCB data more efficiently and will also greatly expand the number of users who will be able to access the data routinely. The app and web-based interface have been updated to include both weekly and daily images from the Sentinel-3A and Sentinel-3B European Space Agency Earth observational satellites. The web-based interface will use the same satellite data as the CyAN mobile app. The only real difference between the two will be the types of devices you can use to view CyAN. See Figure 1, Figure 2, and Figure 3 for some screenshots of how to use the website and app to visualize blooms and satellite data.

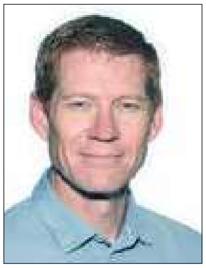
The web-based interface version of the app can be accessed via https://www.epa.gov/water-research/CyANapp. This web link also contains more information about the web-based and mobile versions of CyAN, including comprehensive user guides.

References

Mattas-Curry, Lahne, Blake A. Schaeffer, Robyn N. Conmy and Darryl J. Keith. 2015A Space Satellite Perspective to Monitor Water Quality Using your Mobile Phone. NALMS *LakeLine*, Summer 2015.

Schaeffer, Blake A., Robyn N. Conmy, Mike Galvin, John M. Johnston, Darryl J. Keith and Erin Urquhart. 2019. Satellite-Detected Cyanobacteria in Large U.S. Lakes on Your Android Phone. NALMS *LakeLine*, Summer 2019.

US EPA. CyAN App Used for Early Detection of Harmful Algal Blooms in Communities Across the Nation. EPA *Science Matters*, September 1, 2020.



Brad Autrey is a member of the communications staff in EPA's Center for Environmental Measurement and Modeling. He works with researchers and other EPA staff to help create more awareness of the great work EPA scientists are doing and to help make that work accessible to scientists and non-scientists alike. You can contact Brad at autrey.brad@epa.gov.

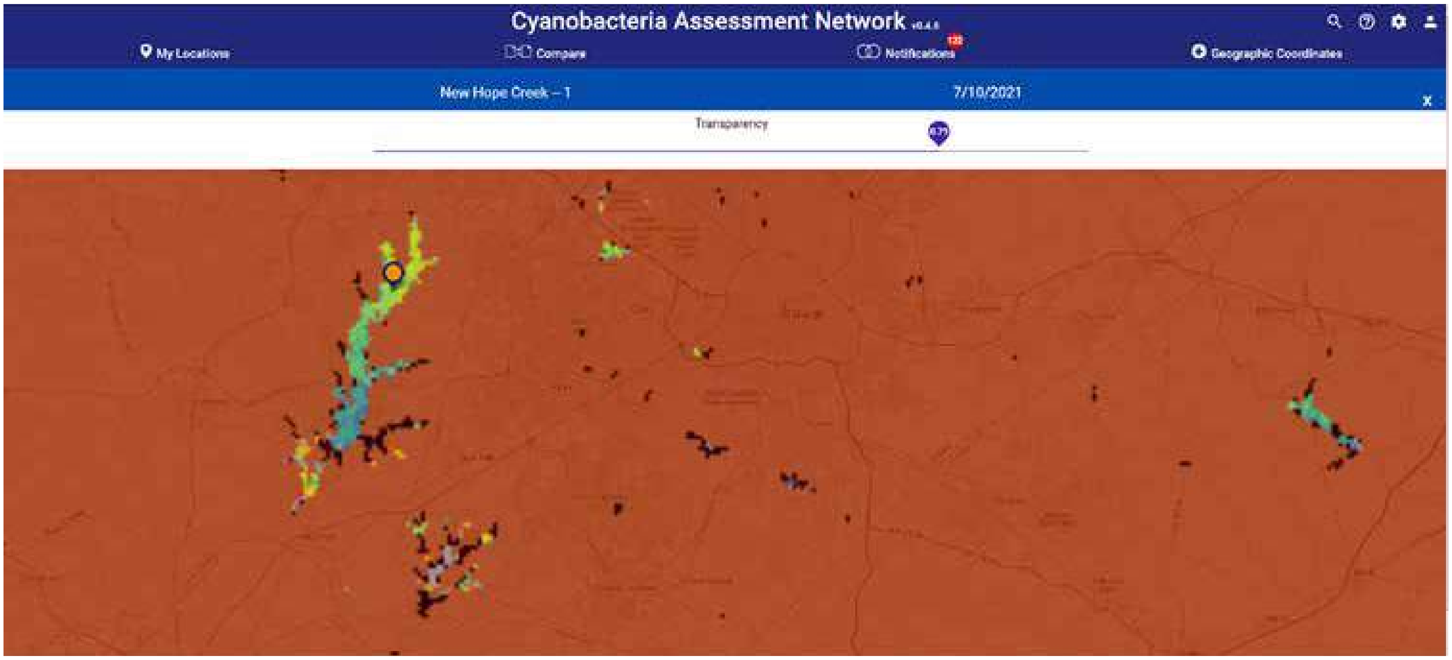


Figure 1. By placing a pin marker on a map or selecting an existing marker, users can see the latest cyanobacteria concentration level at the location, in this case a marker for Lake Apopka, FL.

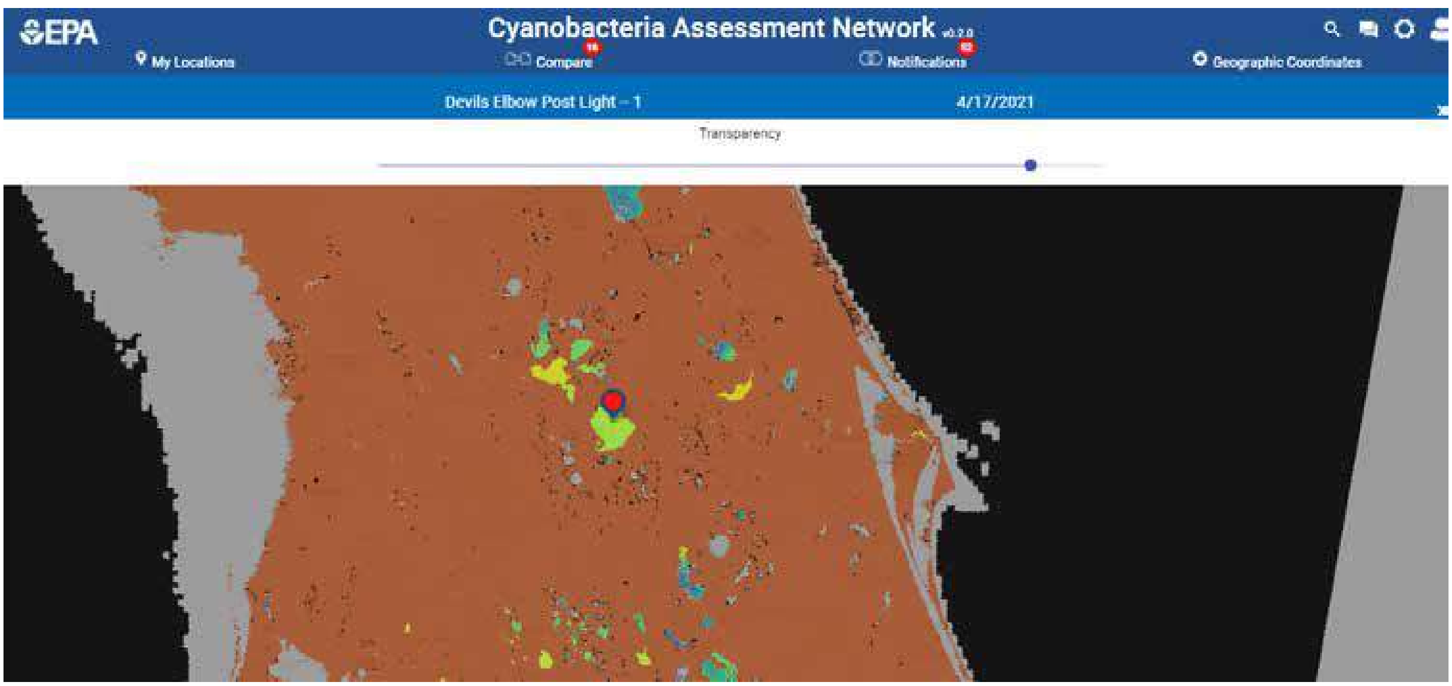


Figure 2. By placing a pin marker on a map or selecting an existing marker, users can opt to view the latest satellite data at the marker location. The image shows the entire satellite data tile that contains the marker location, in this case for Lake Apopka, FL.

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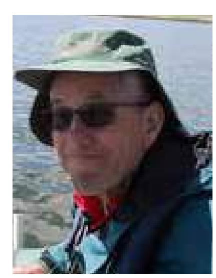

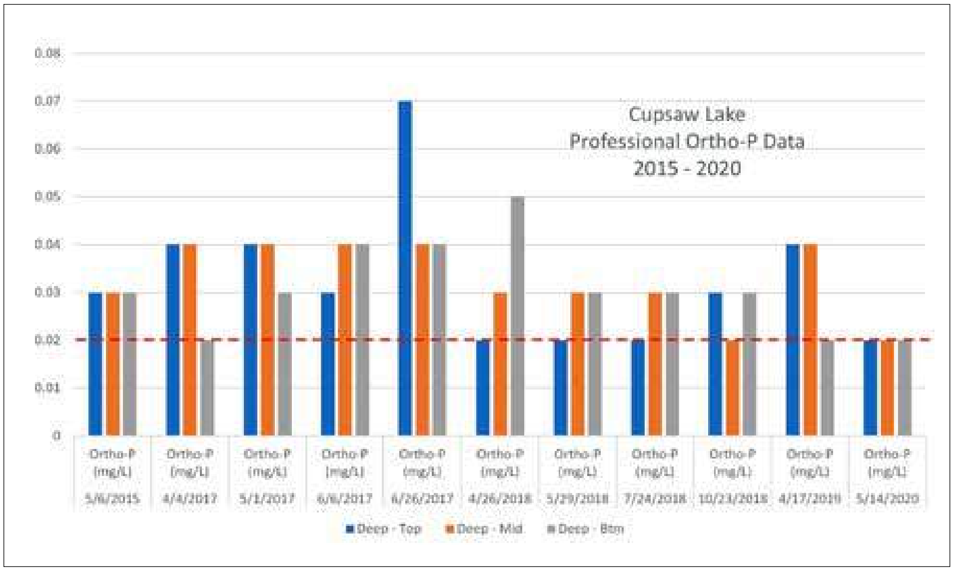

Figure 3. Users can select a location from a list of pin markers to access the satellite imagery available for the location. This example shows the most recent satellite data image overlaying the map for Lake Apopka, FL, and, to the right, a selectable list of data images that can be overlaid on the map.

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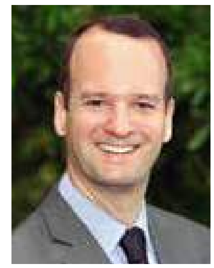

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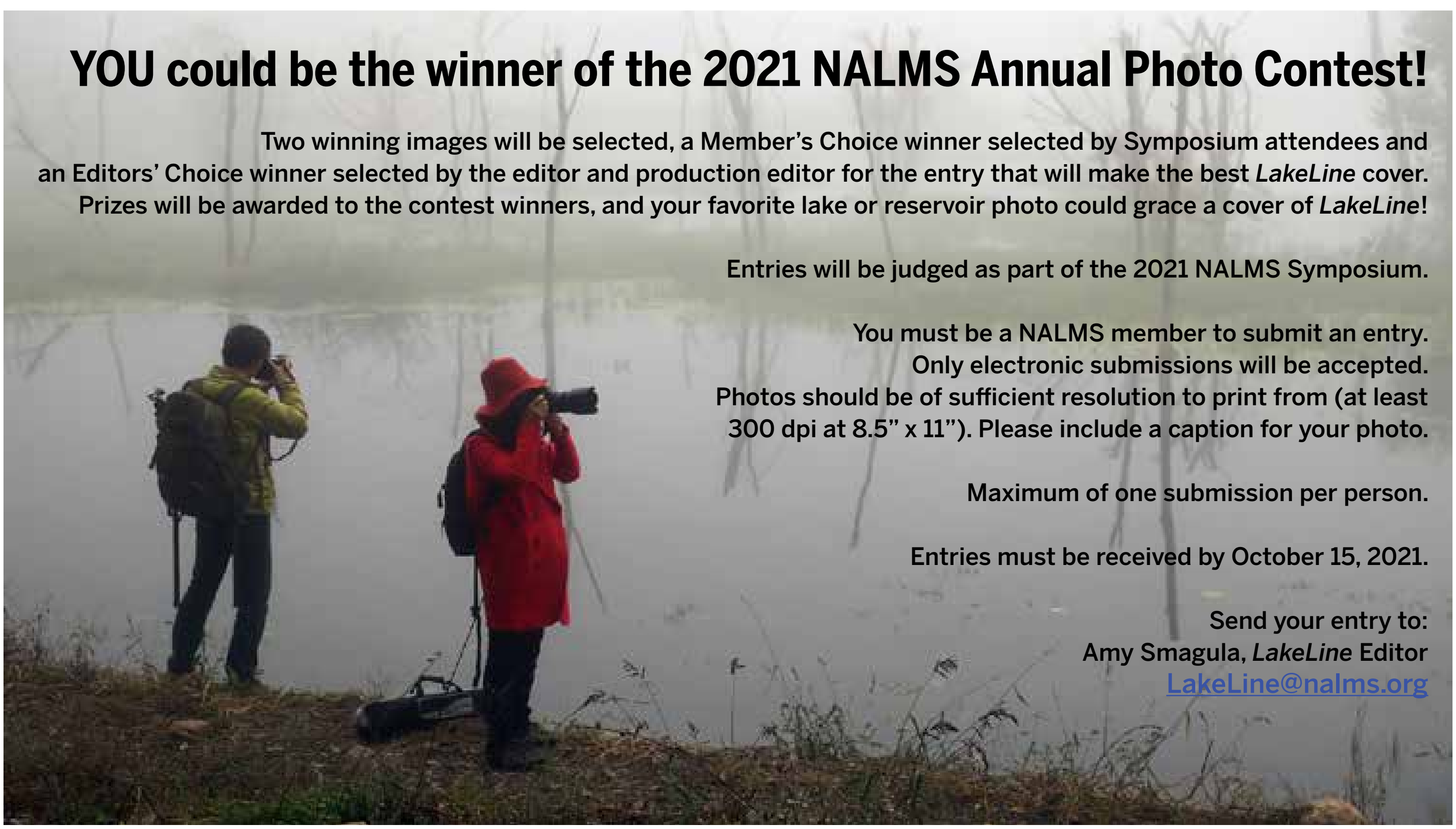

Regional Differences in **CyanoHAB Outreach Methods in the US**

Ellen P. Preece and F. Joan Hardy

Cyanobacteria harmful algal blooms (cyanoHABs) are proliferating in waterbodies worldwide, and climate changes are expected to intensify occurrences by elevating water temperatures causing stronger vertical stratification, increasing nutrient inputs, and producing flashier precipitation events (Figure 1). As cyanoHABs occur more frequently, so will associated cyanotoxins that pose potential health impacts to humans and animals. The predicted increase in cyanoHAB events raises the need for education and notification programs to communicate health risks associated with the blooms. While cyanoHABs occur in waterbodies across the United States, the response to these blooms varies greatly from state to state, including how local and regional health officials communicate to the public about these bloom events. Further complicating educational and outreach efforts is that various methods are used to address different exposure pathways (i.e., drinking water versus recreational exposure).

A number of groups, including the Environmental Protection Agency and International Technology and Regulatory Council, have provided tools to support states, tribes, territories, and local governments in the development of cyanoHAB risk communication, education, and outreach materials. Implementation of these or similar materials across the country has a range of financial support, from none in some states to fully funded programs in other states. The purpose of the work described in this article was to identify and compare outreach programs and methods used by different states to implement drinking water and recreational cyanoHAB outreach and education, with the intent of providing baseline information on the subject to help identify future needs. Full results of this study are provided in Hardy et al. (2021). One investigation objective was to determine if there were regional differences in how states implement cyanoHAB outreach and educational programs. Here, we explore these regional differences for recreational cyanoHAB outreach and educational programs. We also discuss preferred recreational outreach methods.

Figure 1. CyanoHAB at Cottage Lake in King County, Washington.

Survey distribution

To investigate the status of outreach and monitoring programs by states and regions in the United States, we developed and distributed two questionnaires (i.e., a recreational survey and a drinking water survey) nationally to health/environmental departments through the Survey Monkey platform.

Prior to survey distribution, draft questions were reviewed and edited by state and federal personnel familiar with cyanoHAB outreach and monitoring programs. Pilot surveys were then distributed to states in EPA Region 10 (Washington, Idaho, Oregon, Alaska). Results and comments from the pilot surveys were used to refine questions before national distribution. Final surveys were distributed from October 2017 through March 2018 via email to state contacts through a variety of pathways. All 50 states plus the District of Columbia responded to the recreational survey.

Regional assessment

States were categorized in four ways based on geography to determine whether there were any regional variations in survey responses: (1) east and west of the

Rocky Mountains, (2) east and west of the Mississippi River, (3) USEPA's 10 regions, and (4) northern versus southern states. There were no significant differences in categories 1 and 2, and not enough data for statistical analysis in category 3 (USEPA regions). Northern and southern states were divided based on the US Climate Regions identified by the National Oceanic and Atmospheric Administration (NOAA 2019) with southern states defined as those in the West, Southwest, South, and Southeast climate regions. Northern states were defined as those in the Northwest, West North Central, East North Central, Central, and Northeast climate regions.

There were significantly fewer cyanoHAB outreach programs in southern states relative to northern states ($p = 0.03$; Fisher's exact test; Figure 2). Reasons for this geographical difference in recreational outreach efforts remain unknown; however, there are several possible explanations for why this regional difference was observed.

First, differences may be related to the percentage of surface water in northern versus southern regions. Northern states have greater total surface area covered by water (9.3 percent) compared to southern states (4.8 percent; USGS 2020). However, even some northern states with high percentages of water surface area, such as Michigan (41 percent) and Alaska (14.2 percent), did not report having cyanoHAB outreach programs at the time of the surveys. Further, the 2012 National Lakes Assessment conducted by the USEPA (2020) showed that most natural lakes are in the Upper Midwest, Northern Appalachians, Temperate Plains, Coastal Plains, and the Western Mountains. Thus, there might be a tendency for states with more water and natural lakes to have cyanoHAB outreach programs, but there are exceptions.

Second, drought conditions may influence the presence or absence of outreach programs. Many of the states classified as southern states in our analysis were in severe to exceptional drought conditions in the last decade, including during October 2017 when the survey was initiated (United States Drought Monitor 2020). Droughts may divert resources from cyanoHAB-related issues as states deal with the higher priority issue of drought. However, this is a complex issue, because drought is also associated with more severe cyanoHAB issues.

Third, the difference in outreach programs may be related to seasonal differences in peak bloom occurrence. A study by Coffer et al. (2020) found in the Southeast and South, cyanobacterial bloom percentage reached a maximum in the winter rather than the summer. Since more recreational exposure occurs during summer periods, this may indicate that peak bloom season in the south is occurring outside of the peak recreation season. Thus, there may be less rationale for states to invest money into funding outreach programs in these locations.

Finally, an additional factor could be differences in recreational pressure and demand between states. Interestingly, no significant regional differences were identified regarding which cyanotoxins are monitored or how states use cell counts or cyanotoxin guidance values in recreational advisories. Most states monitor microcystins (33), with anatoxin-a (22), cylindrospermopsin (23), saxitoxins (9), lyngbyatoxins (1) and

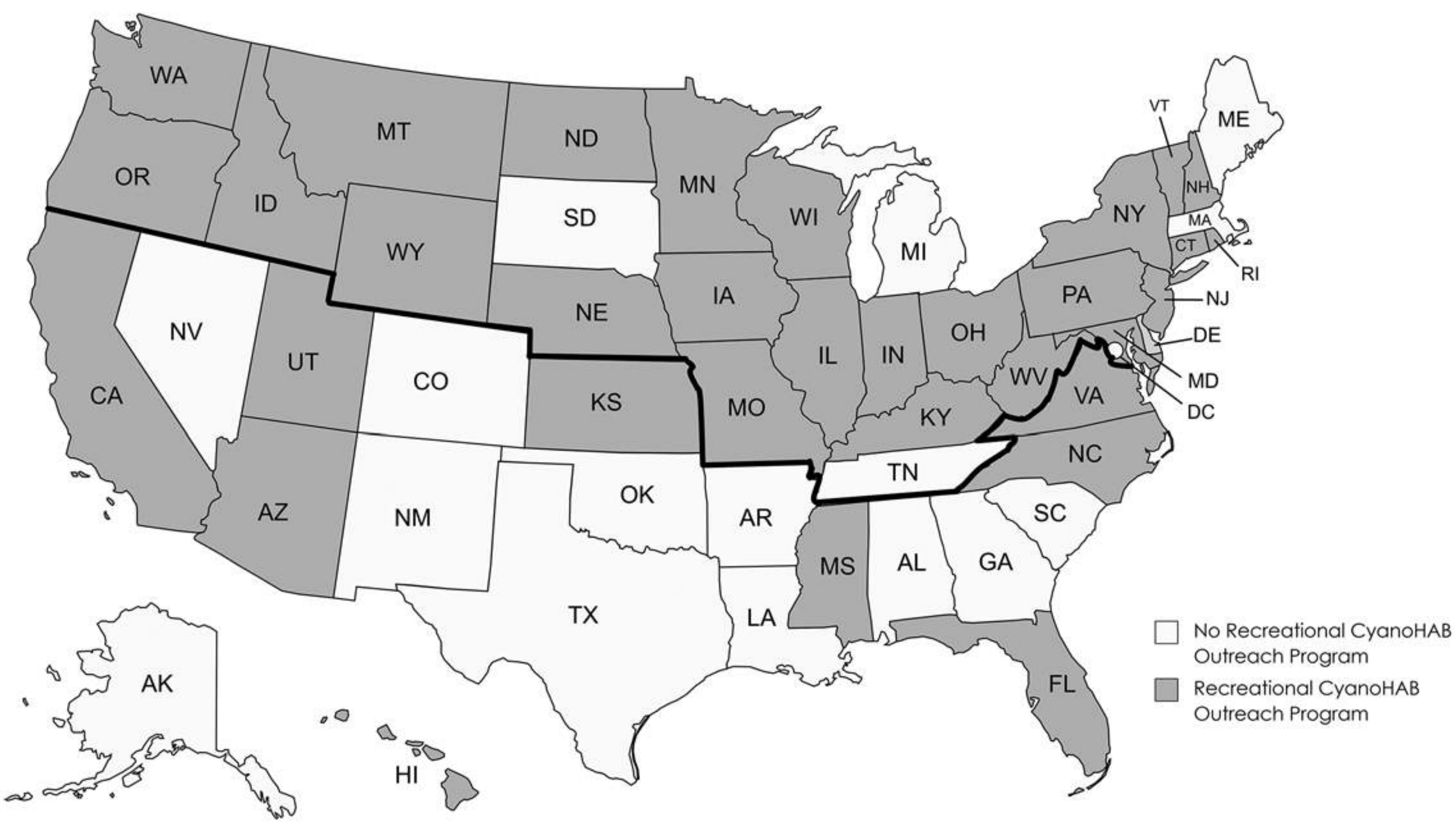

Figure 2. Map that shows summary of states with CyanoHAB outreach programs (2018) for recreation. The solid black line shows northern and southern states based on US Climate Regions identified by the National Oceanic and Atmospheric Administration. Created with mapchart.net.

BMAA (2) monitored in fewer states. Also, more than 50 percent of states identified *Aphanizomenon, Dolichospermum*, and *Microcystis* as genera of concern, with fewer than 40 percent of states identifying *Cylindrospermopsis*, *Lyngbya*, or *Oscillatoria* as genera of concern in recreational exposure.

Preferred recreational outreach methods

Forty-five of the fifty states responded to the survey question about preferred recreational outreach and educational methods. Survey results indicate that states use a variety of techniques to reach recreational users of waterbodies (Figure 3). Press releases, social media, and posters were the most common methods used to notify the public of cyanoHABs. See Figure 4 for an example of an informational sign (poster) used in Washington State waterbodies that have a history of blooms. Brochures and veterinary outreach were also widely used, and fifteen states use five or more methods to communicate information on cyanoHAB recreational exposure. Mailers and workshops were the least preferred methods for distributing cyanoHAB outreach materials. Mailers, in general, appear to be decreasing in popularity as an outreach method, in part due to the costs needed to ensure the message reaches its target audience. The survey was distributed prior to the COVID-19 pandemic when many workshops were held in person. With the move to more virtual workshop options, this method will likely gain in popularity.

Results indicating preferred outreach and educational methods can be used by jurisdictions to develop new or expanded cyanoHAB outreach and educational programs. However, funding is an important component that is missing for many states, as identified in survey results. Funding for recreational outreach and education is intermittent in some states and nonexistent in others (20 states report no funding). For those states that did receive funding it was generally below $10,000 annually. It is difficult for states to effectively reach out to citizens if funds are not available to create appropriate messaging or if there is no funding for state workers to develop and

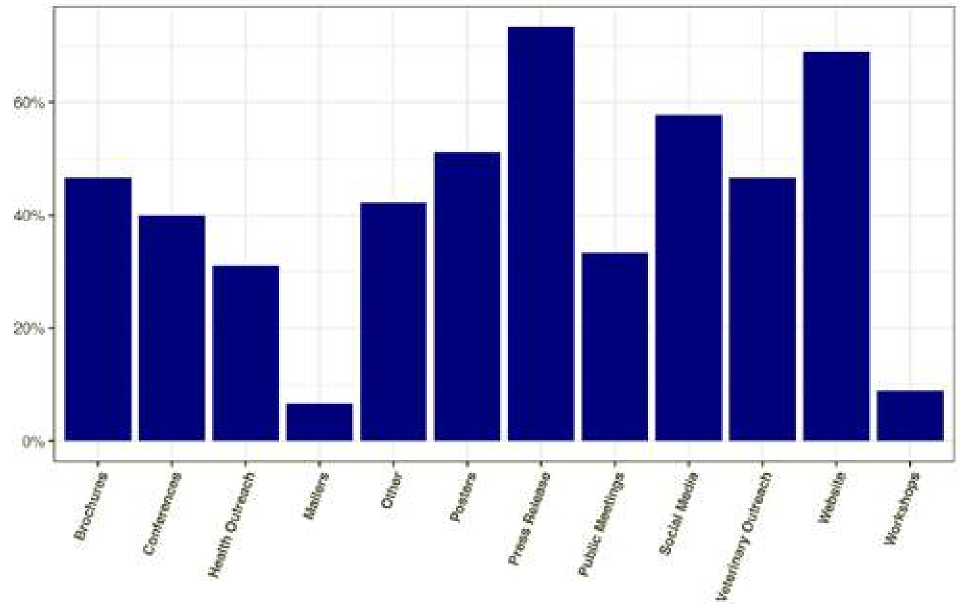

Figure 3. Graphic showing preferred recreational outreach and educational methods indicated by states.

Figure 4. Washington State CyanoHAB informational sign.

distribute such materials. Nevertheless, effective outreach and education efforts associated with recreational cyanoHAB exposure would be helpful in reducing public health risks, particularly with increased toxic blooms expected as the climate continues to change.

Future Work

This project provides a snapshot of state outreach and monitoring efforts over a short period of time. At the time of the survey, 84 percent of respondents identified their level of public health concern for recreational exposure to cyanoHABs as important to extremely important. Since then, many states have expanded their cyanoHAB programs to educate the public and notify lake users when blooms occur. For updates on the most current monitoring and outreach efforts by state please visit https://www.epa.gov/cyanohabs/state-habs-monitoring-programs-and-resources. It will be important to continue tracking growth and expansion of communication tools as states recognize the importance of preventing the public's exposure to cyanotoxins.

An aspect that our survey did not explore are regional preferences in how people like to receive cyanoHAB educational and notification materials. A follow-up survey was distributed to learn the types of cyanoHAB outreach materials that are most effective and preferred. Results from this survey are currently being processed, but information from the follow-up study can be used in combination with the results presented here to determine how best to distribute future cyanoHAB outreach materials. Our initial study did show that a local or regional approach is important to focus messaging for specific target audiences.

Based on project outcomes, a more thorough evaluation of differences in cyanoHABs presence, extent, and duration of blooms in northern and southern states is warranted. Results will be particularly interesting in the face of climate change as lakes in northern latitudes begin to experience similar water temperatures as those in southern latitudes.

References

Coffer, M.M., B.A. Schaeffer, J.A. Darling, E.A. Urquhart and W.B. Salls. 2020. Quantifying national and regional cyanobacteria occurrence in US lakes using satellite remote sensing. Ecological Indicators. https://doi.org/10.1016/j.ecolind.2019.105976

Hardy, F.J., E.P. Preece and L. Backer. 2021. Status of state cyanoHAB outreach and monitoring efforts, United States. *Lake and Reservoir Management*. doi.org/10.1080/10402381.2020.1863530

[NOAA] National Oceanic and Atmospheric Administration. 2019. Climate diagnostic center; [cited 5 Dec 2019]. https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php.

United States Drought Monitor. 2020. U.S. drought monitor map comparison slider; [cited 15 Jan 2020]. https://droughtmonitor.unl.edu/Maps/ComparisonSlider.aspx.

USGS (United States Geological Survey). 2020. How wet is your state? The water area of each state; [cited 15 Jan 2020]. https://www.usgs.gov/special-topic/water-scienceschool/science/how-wet-your-state-water-area-each-state?qtscience_center_objects=0#qt-science_center_objects.)

USEPA (United States Environmental Protection Agency). 2020. National aquatic resource surveys; [cited 15 May 2020]. https://www.epa.gov/national-aquatic-resource-surveys/national-highlight-comparing-natural-lakes-and-manmade-reservoirs.

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UPCOMING IN *LAKELINE*

• FALL ISSUE – The fall issue of *LakeLine* will be the fun and spooky topic of "Haunted/Spooky Lakes," but with some scientific explanations! If you have any good histories or stories about haunted lakes or lakes with interesting histories (within lake or nearshore area), please share! Please feel free to think outside of the box with this one, for example, how about a story of a lake that turned blood red under the ice (cyanobacteria blooms, etc), disappearing lakes, bizarre gases, colors or other phenomena.
Articles are due by September 15, for publication in October.

• WINTER ISSUE – "Urban Lakes" will be the focus on the winter issue of *LakeLine*. These important resources tend to be highly impacted due to population densities, land uses that are high in impervious surfaces, and runoff with excess nutrients and other contaminants. Please consider sharing articles that relate to the common problems observed in urban systems, partnerships for restoration, rehabilitation of these systems for recreational uses, what urban lakes mean to those who live near them, or other angles related to studying and managing urban lakes.
Articles for the winter issue are due by December 15, for publication in January.

Citizen Science Advances the Understanding of **CyanoHABs in New York State Lakes**

David Matthews, Monica Matt, Nancy Mueller, and Stephanie June

Introduction

Monitoring cyanobacterial harmful algal blooms (cyanoHABs) in lakes is a difficult challenge because they are dynamic in both time and space. They may persist for only hours or days and occur only in a particular bay or along a short segment of the shoreline. Traditional water quality monitoring programs are not designed to capture these short-term, small-scale dynamics, which may result in cyanoHABs going undetected. As a result, data sets that can support large scale comprehensive studies of cyanoHABs are rare and often include only one or two samples per lake. This limits our ability to detect and quantify cyanoHABs, and constitutes a major impediment to the development of a more complete understanding of the factors that contribute to cyanoHABs. Citizen science monitoring programs have the potential to provide relevant environmental data at spatial and temporal scales that would be financially and logistically impractical for traditional institutional monitoring programs. Lake residents and other users are most affected by cyanoHABs and also well-positioned to perform the intensive monitoring required to document them.

The frequency and intensity of cyanoHABs has increased in recent decades (Ho et al. 2019), threatening public water supplies and limiting recreational opportunities. Because common bloom-forming cyanobacteria may produce toxins that affect the liver, nervous system, and skin, cyanoHABs have raised public health concerns across the globe. Researchers have identified a host of factors potentially linked to the expansion of cyanoHABs, including increased or more episodic nutrient loading, changes in nutrient ratios, selective feeding, and increased nutrient recycling by invasive dreissenid (zebra, quagga) mussels, and increased water temperature due to climate change. The interactive effects of eutrophication and climate change are expected to increase cyanobacterial dominance in the future (Carey et al. 2012), highlighting the need for large scale multi-system studies that document the occurrence, severity, and spatiotemporal distribution of cyanoHABs in lakes.

Traditionally, cyanoHABs have been considered a symptom of cultural eutrophication that is effectively controlled when total phosphorus (TP) concentrations are below 20-50 µg/L (Fastner et al. 2015). This paradigm is supported by a long history of success in reducing cyanobacterial abundance in eutrophic lakes through reduced P loading (Schindler et al. 2016). However, cyanoHABs are increasingly documented in lakes with low to moderate P concentrations, underscoring the many physical, chemical, and biological factors that contribute to cyanobacterial dominance. Large multi-system studies have the potential to increase our understanding of cyanoHABs and inform management strategies for affected lakes.

In this study, data collected from 168 New York lakes by the Citizens Statewide Lake Assessment Program (CSLAP) during 2012-2017 were used to document the occurrence of cyanoHABs and to gain insights into factors associated with cyanoHABs and elevated concentrations of microcystin, the most common cyanotoxin in New York. The data set is unusual in that it includes results from both fixed frequency (biweekly) monitoring of main lake sites and samples collected from shoreline blooms whenever they were observed. The wide range of lake morphologies, trophic conditions, and watershed land cover of CSLAP lakes makes this information set particularly valuable for investigating the physical, chemical, and biological factors that influence the occurrence and severity of cyanoHABs. We were particularly interested in better understanding the conditions that promote cyanoHABs in oligotrophic and mesotrophic lakes. We also sought to demonstrate that a managed volunteer monitoring program can contribute to our understanding of cyanoHABs.

The Citizens Statewide Lake Assessment Program (CSLAP)

CSLAP is a volunteer lake monitoring and education program that is managed by the New York State Department of Environmental Conservation (NYSDEC) and the New York State Federation of Lake Associations (NYSFOLA). The goal of CSLAP is to collect water quality information representative of New York State's 7,500 lakes, ponds, and reservoirs to identify problems and support public education and outreach. NYSDEC and NYSFOLA provide training, equipment, and supplies to volunteers, who collect, process, and ship water samples for analysis to a certified laboratory. Since the inception of the program in 1985, CSLAP volunteers have sampled more than 260 lakes across New York State.

Each lake was sampled by trained volunteers at a frequency of approximately biweekly from late spring to early fall. This period represented the duration of the cyanoHAB season in most lakes, although some lakes exhibited cyanoHABs into mid fall. Open water samples were collected eight times per year at the deepest point in the lake with a Kemmerer sampler from a depth of 1.5 meters. In addition, shoreline cyanoHABs samples were collected as surface skims when volunteers observed a suspected cyanoHAB in nearshore areas (Figure 1) and were able to collect a sample. CSLAP samplers (Figure 2) received training in standardized methods for identifying suspected cyanoHABs and collecting accurate and representative samples.

Field measurements of water temperature at 1.5 m depth and Secchi disk transparency were made during each sampling trip. Water samples were analyzed for total phosphorus, total nitrogen (TN), nitrate+nitrite, total ammonia, chlorophyll-*a* (Chl-*a*), specific conductance, pH, color, and total calcium using standard methods. Cyanobacterial abundance was estimated on raw water samples immediately upon receipt in the lab using a FluoroProbe®. Samples with high cyanobacterial abundance were also analyzed for microcystin (MC). Land cover, lake area and depth, and the presence of dreissenid mussels were also considered as factors that might contribute cyanoHABs (Figure 3).

The study lakes

During the 2012-2017 study interval, 168 lakes were monitored for at least one year and 148 lakes of these lakes were monitored for multiple years. The study lakes were distributed throughout the state and located within 16 of the 17 major drainage basins in New York (Figure 4). Approximately 50 study lakes serve as potable water supplies, and more than 70 have public swimming beaches. Twenty-one of the study lakes experienced beach closures during the study period due to cyanoHABs, with several lakes exhibiting more than one month of closures in at least one year. More than 95 percent of the study lakes are actively used for contact recreation by lakefront residents and visitors.

The study lakes represent a wide range of physical, chemical, and watershed land cover characteristics potentially associated with the occurrence of cyanoHABs. Lake surface areas ranged from 2 to 42,000 acres, although most lakes were smaller than 250 acres. The study lakes were predominately shallow, with most lakes having mean depth <5 meters. Using TP as the trophic state indicator (Cooke et al. 2005), 26 percent of the lakes were oligotrophic (TP<10 µg/L), 46 percent mesotrophic (10<TP<25 µg/L), 24 percent eutrophic (25<TP<100 µg/L), and 4 percent hypereutrophic (TP>100 µg/L).

Defining cyanoHABs and cyanoHABs with high toxins

Not all cyanoHABs are alike, and community composition and toxin production can be widely variable. For this study, the occurrence of cyanoHABs and cyanoHABs with high toxins (cyanoHABs-HT) was determined according to NYSDEC protocols, which are based on interpretations of the World Health Organization thresholds for moderate to high probability of adverse health effects. Samples with cyanobacterial Chl-*a* $\geq$ 25 µg/L, as

Figure 1. Accumulation of cyanobacteria along the shoreline of Lake Ronkonkama, New York.

Figure 2. A cyanobacterial bloom at Hidden Lake, New York.

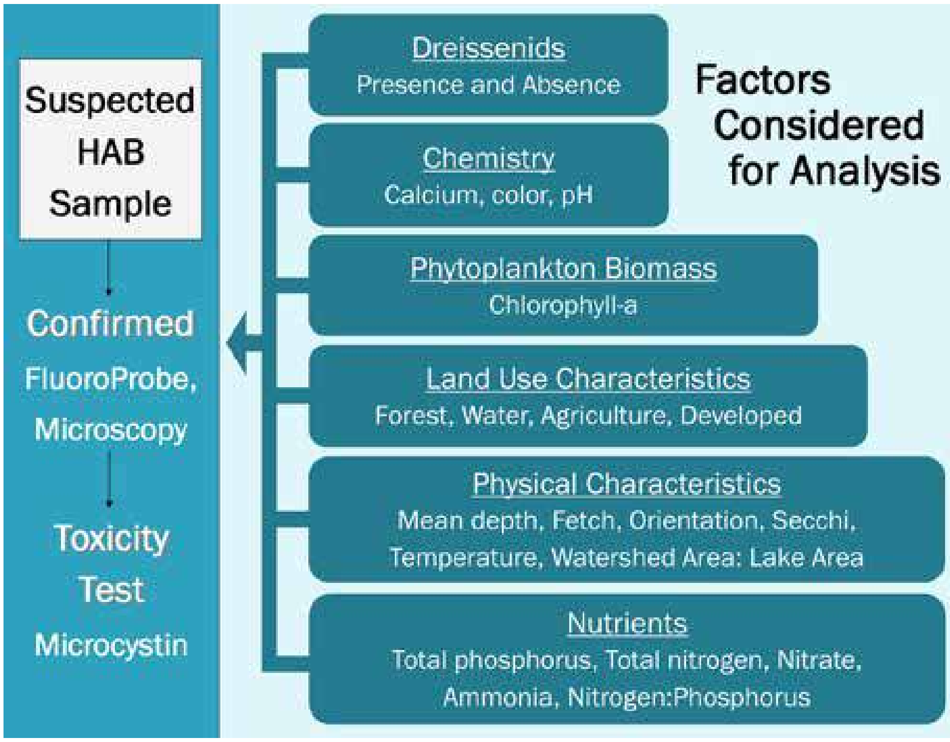

Figure 3. Factors potentially associated with cyanoHABs.

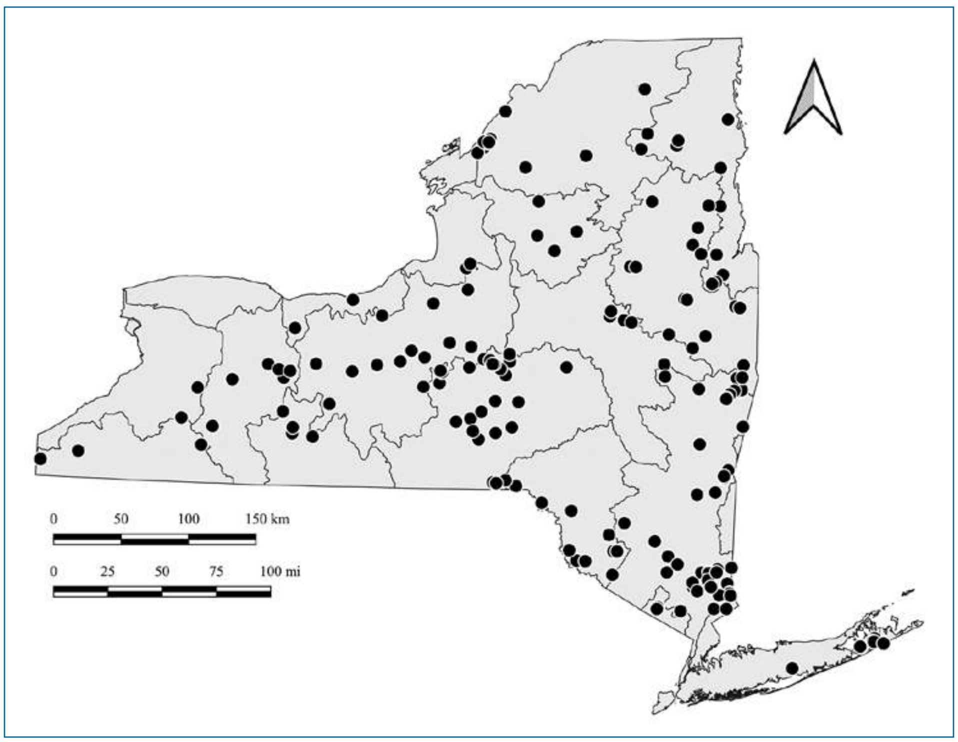

Figure 4. Location of study lakes within the 17 major drainage basins of New York State.

determined by FluoroProbe®, and dominated by cyanobacteria, as determined by microscopy, were classified as cyanoHABs. Confirmed cyanoHABs with MC concentrations ≥ 20 µg/L for shoreline samples or ≥ 10 µg/L for open water samples were classified as cyanoHABs-HT. The goal was to identify factors associated with cyanoHABs across a diverse population of lakes rather than to explain year-to-year variations in the occurrence of cyanoHABs. Therefore, cyanoHABs, cyanoHABs-HT, and dreissenids were treated as either present or absent, such that a single "present" recorded in any year resulted in an overall "present" designation for that lake.

The spatial and temporal distribution of cyanoHABs

While cyanoHABs occurred throughout the spring to fall period, they were most common during July-September. The seasonal distribution of cyanoHABs was generally correlated with the temporal pattern of surface water temperatures. However, cyanoHABs occurred frequently in September and persisted into October despite decreasing water temperatures. Blooms were relatively uncommon in the open water as compared to the nearshore. In August, for example, 50 open water blooms were reported in 23 lakes compared to 142 shoreline blooms in 54 lakes. MC was detected in 19 percent of open water blooms and no open water samples with MC >20 µg/L were reported. In contrast, 54 percent of nearshore blooms had detectable levels of MC and 29 percent had MC >20 µg/L.

Factors associated with cyanoHABs

As one may expect, cyanoHABs and cyanoHABS-HT were most common in eutrophic and hypereutrophic lakes, or those with high TP, TN, and Chl-*a* concentrations and low Secchi disk transparency. However, cyanoHABs also occurred in waterbodies that would not seem to be vulnerable to blooms based on these traditional measures of water quality. We suspected that the presence of cyanoHABs in 15 oligotrophic lakes and 41 mesotrophic lakes included in our study was related to factors beyond classical nutrient enrichment. We found that the presence of dreissenid mussels increased the likelihood of both cyanoHABs and cyanoHABs-HT, especially in less productive lakes (Figure 5). In oligotrophic lakes (Chl-*a*<4 µg/L), the presence of dreissenid mussels nearly doubled the occurrence of cyanoHABs and increased cyanoHABs–HT nearly 20-fold (Figure 5). Productive lakes with TP> 30 µg/L and Chl-*a*>15 µg/L had a high probability (>75 percent) of cyanoHABs regardless of the presence of dreissenids.

In addition, we found that lakes in watersheds with higher percentages of forest cover had a significantly lower probability of cyanoHABs and

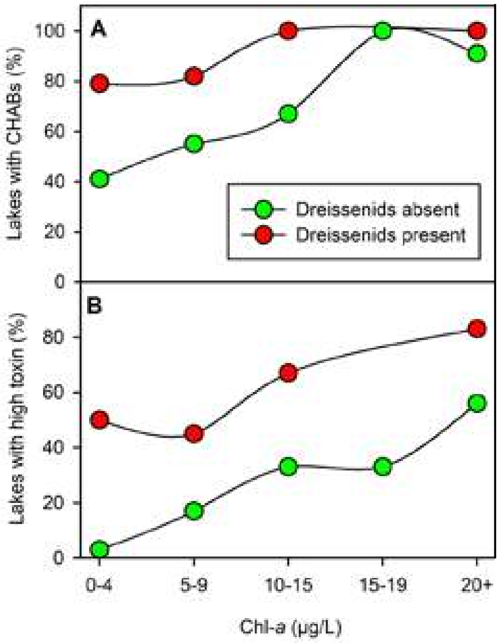

*Figure 5. The occurrence of cyanoHABs as a function of Chl-*a *and the presence of dreissenid mussels: (A) percentage of lakes with cyanoHABs, and (B) percentage of lakes with cyanoHABs-HT.*

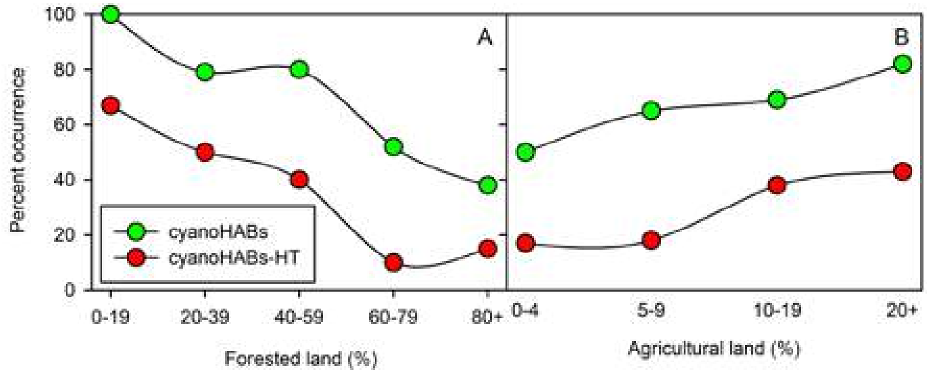

Figure 6. The occurrence of cyanoHABs and cyanoHABs -HT as a function of land cover: (A) forested land, and (B) agricultural land.

cyanoHABs-HT (Figure 6A). In contrast, lakes in watersheds with more agricultural land cover had an increased likelihood of cyanoHABs and cyanoHABs-HT (Figure 6B). The relationship between cyanoHABs and developed land use was less clear. The occurrence of cyanoHABs and cyanoHABs–HT increased as developed land use increased from 0-2 percent to 5-9 percent but decreased at higher levels.

Overall, 63 percent of the lakes had cyanoHABs reported at some point during 2012-2017 and 27 percent had cyanoHABs-HT. We sought to develop a simple model that might explain why some of the study lakes had cyanoHABs and others did not. We used classification analysis to identify a rule set that best explained the occurrence of cyanoHABs in the study lakes. The analysis divided the lakes into three groups (Figure 7): (1) lakes with summer average Chl-*a*<22 µg/L without dreissenids, (2) lakes with Chl-*a*<22 µg/L with dreissenids, and (3) lakes with Chl-*a*>22 µg/L. Of the 110 lakes that were less productive (Chl-*a*<22 µg/L) and had no dreissenids, 57 percent had cyanoHABs and 20 percent had cyanoHABs-HT. The probability of cyanoHABs dramatically increased to 83 percent in the 29 lakes with dreissenid mussels and similar summer Chl-*a* concentrations. More than half (52 percent) of this group of less productive lakes with invasive mussels also experienced cyanoHABS-HT. Just 2 percent of oligotrophic lakes without dreissenid mussels had cyanoHABs-HT whereas 46 percent of oligotrophic lakes with the invasive species present had blooms with high toxins. In the more eutrophic lakes with summer average Chl-*a*>22 µg/L, the occurrence of cyanoHABs and cyanoHABs-HT increased further to 93 percent and 61 percent, respectively.

Conclusions

Analysis of data collected from a diverse array of 168 New York lakes during 2012-2017 identified nutrient levels and trophic status as key determinants of cyanoHABs and high

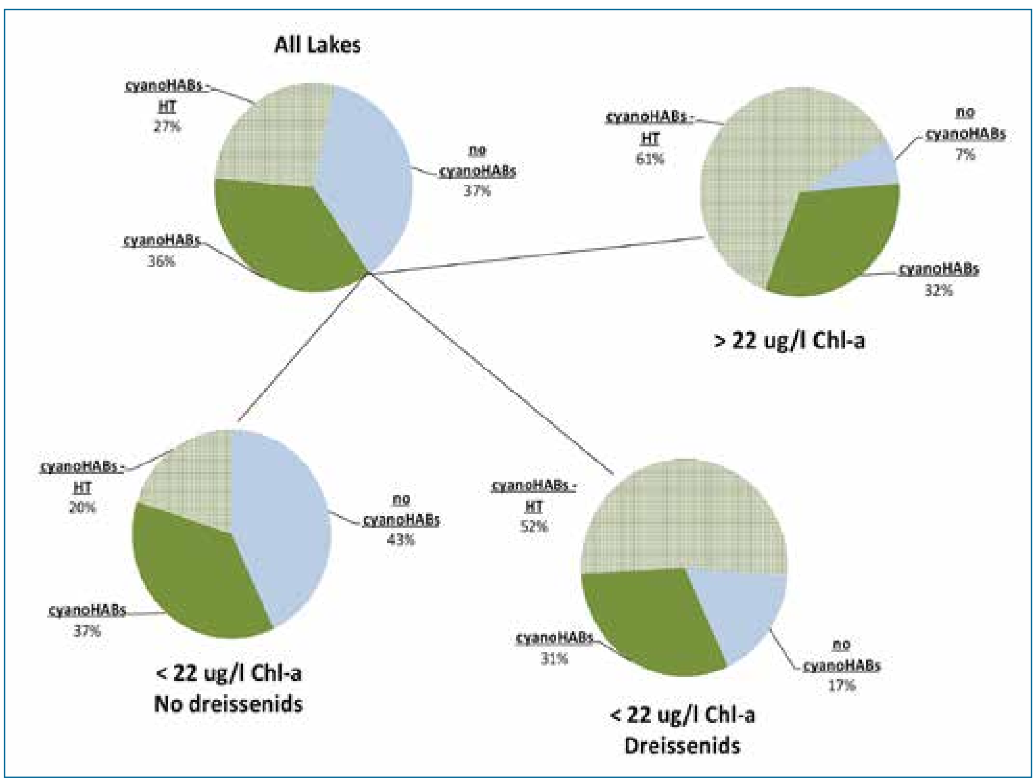

*Figure 7. Classification of lakes with cyanoHABs and cyanoHABs-HT according to phytoplankton abundance (Chl-*a*) and the presence of dreissenid mussels.*

microcystin concentrations. The presence of dreissenid mussels was found to promote cyanoHABs in lakes with low to moderate nutrient levels. Although interpretation of the association between dreissenid mussels and cyanoHABs is currently limited by the lack of mussel density information for most lakes, enhanced nutrient recycling and selective filtering are expected to promote cyanoHABs. Higher proportions of agricultural and developed land cover were also associated with increased likelihood of cyanoHABs, presumably a reflection of increased nutrient loading caused by these intensive land uses. CyanoHABs were predominately a shoreline phenomenon and risk of exposure to high microcystin concentrations is likely to be greatest in surface scums accumulated along shorelines.

Large-scale multi-system lake studies are often limited by the collection of samples from a single date and location in each lake. This limitation is particularly problematic in studies of cyanoHABs because cyanobacterial density in lakes is spatially and temporally dynamic. This limitation was overcome in the current study through the efforts of citizen science volunteers participating in a statewide lake monitoring program. CSLAP volunteers not only collected useful environmental data, but also became engaged and educated regarding the causes and consequences of cyanoHABs. The need for environmental monitoring is likely to continue to outpace available resources in the future, and citizen-volunteer programs have demonstrated that they can effectively bridge this gap.

While long considered to be a symptom of excessive nutrient loading, cyanoHABs are now affecting lakes with low-to-moderate nutrient concentrations. These tend to be high value lakes that provide important ecosystem services, including aesthetics, biodiversity, recreation, and drinking water. While multiple studies have identified dreissenid mussels as an important cause of cyanoHABs in the Great Lakes region, further research is needed to establish the linkage between mussel metabolism and the occurrence of cyanoHABs. This highlights the need to control the spread of dreissenid mussels and other aquatic invasive species with unknown long-term impacts to lake food webs. Continued efforts to reduce nutrient loading in both agricultural and urban settings are recommended to decrease the frequency, severity, and toxin content of cyanoHABs. Finally, land acquisition and reforestation should be considered in particularly important watersheds, such as those that support drinking water supplies or threatened ecological communities, given the strong relationship shown here between more intensive land uses and vulnerability to cyanoHABs.

Acknowledgments

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References

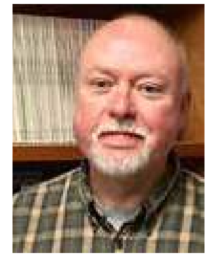
Carey, C.C., B.W. Ibelings, E.P. Hoffmann, D.P. Hamilton and J.D. Brookes. 2012. Eco-physiological adaptations that favour freshwater cyanobacteria in a changing climate. *Water Research*, 46: 1394-1407.

Cooke, G.D., E.B. Welch, S.A. Peterson and S.A. Nichols. 2005. Restoration and management of lakes and reservoirs. Taylor and Francis, CRC Press, Boca Raton, FL. 591 pp.

Fastner, J., S. Abella, A. Litt, G. Morabito, L. Voros, K. Palffy, D. Straile, R. Kummerlim, D. Matthews, M. Phillips and I. Chorus. 2015. Combating cyanobacterial proliferation by avoiding or treating inflows with high P load – experiences from eight case studies. *Aquatic Ecology*, 50: 367-383.

Ho, J.C., A.M. Michalak and N. Pahlevan. 2019. Widespread global increase in intense lake phytoplankton blooms since the 1980s. *Nature*, 574: 667-670.

Schindler, D.W., S.R. Carpenter, S.C. Chapra, R.E. Hecky and D.M. Orihel. 2016. Reducing phosphorus to curb lake eutrophication is a success. *Environ. Sci. Technol*, 50: 8923-8926.



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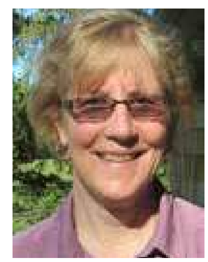

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Reservoir Observer
Student Scientists

Emily Kinzinger and Rebecca North

A high school community science program for year-round water quality monitoring

Cyanobacterial blooms are an ongoing threat to water quality worldwide. They can form dense, mucilaginous surface scums, produce taste and odor compounds, and deplete waters of oxygen. Some species of cyanobacteria can produce toxic secondary metabolites that are dangerous to humans and animals. Cyanobacterial blooms can damage local economies though increased drinking water treatment costs, decreased property values, and lost revenue from lake and reservoir closures (Figure 1).

Although cyanobacterial blooms are commonly found in the summer and early fall, there have been occasional observations in the winter (Wejnerowski et al. 2018). There is a recognized knowledge gap regarding winter lake processes. From the few available year-round studies, we know winter cyanobacterial blooms can produce toxins. One year-round study found concentrations of the cyanotoxins microcystin and anatoxin did not vary significantly by season (Wiltsie et al. 2018). Satellite remote sensing imagery indicates that we may be underestimating the frequency of winter cyanobacterial blooms (Coffer et al. 2021). Many water quality monitoring programs focus on collecting samples during the summer "growing" season, but we need to know what is happening year-round to effectively manage lakes and reservoirs and protect human health. Running a year-round monitoring program can be logistically complicated with potential winter safety issues (Block et al. 2019), high costs associated with frequent visits

Figure 1. One our study systems, Stephens Lake, closed due to a cyanobacterial bloom in Fall 2018.

to sampling sites, and lack of available personnel to collect and analyze a high volume of samples. The Reservoir Observer Student Scientists (ROSS) program was created as a community science initiative to ease these complications and engage students in water quality monitoring.

What is the Reservoir Observer Student Scientists (ROSS) Program?

ROSS is a novel water quality monitoring program that teaches high school students about limnology and trains students to collect year-round water samples. At the heart of the ROSS program is education. Our goal is to teach the next generation of scientists and decision makers about their local lake or reservoir and empower them to understand the impacts of water quality in their community. We create a customized presentation for each class that we partner with, and teach students about their local lake or reservoir, including its history, purpose, major uses, and how watershed use may impact the system. We also teach the students basic limnological principles, identify the problems associated with cyanobacterial blooms, and explain how we can use physical and biological parameters to monitor water quality.

After students have learned about water quality, we provide hands-on water sampling training. The University of Missouri (MU) Limnology Laboratory supplies all necessary equipment. We take the students to their lake or reservoir, pick out a shoreline sampling location, and teach them how to collect a surface water grab sample. Students also learn how to take high-quality field notes by properly recording date and time information, making observations about water conditions, documenting ice cover or anything unusual, and noting weather conditions.

Back in the classroom "lab," we teach students how to process the water for preservation and analysis. We provide hands-on training for filtering water and distributing the sample into the appropriate bottles for future analysis, all while teaching students how to prevent contamination of the sample bottles (Figures 2 and 3). Students learn the importance of correctly labeling bottles and recording pertinent notes. We explain how to store samples for proper preservation, and we make sure all students are comfortable with the process. Samples are analyzed by the MU Limnology Lab for total nitrogen, total phosphorus, nitrate, ammonium, chlorophyll-*a*, phycocyanin, total suspended solids, microcystin, cylindrospermopsin, and phytoplankton identification.

Approximately quarterly, we visit the students to pick up the samples and to sample side-by-side with the students. Side-by-side sampling allows us to evaluate the quality of the data collected by the students. Over the last three years of the ROSS program, we have found no significant difference between mean values for samples collected by trained lab technicians and high school students for total nitrogen, total phosphorus, chlorophyll-*a*, microcystin, nor cylindrospermopsin using a Kruskall-Wallis test at the 5 percent confidence level. Students are able to collect and process water samples that lead to high quality data.

From its inception in the fall of 2017 through the spring term of 2021, approximately 300 students at four different high schools have been part of the ROSS program. Student outcomes of the ROSS program are assessed through a survey before and after their participation. Post-survey results indicate that students correctly answered 76 percent of the questions about limnology. We also asked students open-ended questions about what they liked about the ROSS program and to list one thing they learned from

*Figure 2. Students learn how to filter samples for chlorophyll-*a.

Figure 3. Students process a water sample collected from Cheney Reservoir in Maize, Kansas.

participation in the program. Select student responses are illustrated in Figures 4 and 5. Once the samples have been analyzed at the MU Limnology Lab, data are shared with the teachers to incorporate into their lessons so students can learn about data analysis and visualization.

ROSS student success

ROSS participants from Maize High School in Maize, Kansas were inspired by learning about cyanobacterial blooms in Cheney Reservoir, their local drinking water reservoir, to take action against cyanobacterial blooms. These students were semi-finalists in the 2018 Lexus EcoChallenge and were awarded $10,000 in grants and scholarships for their research. They also deployed their own thermistor chain in Cheney Reservoir to study stratification patterns. They used the temperature data they collected and cyanotoxin data we provided from their samples and presented this research at the 2019 Great Plains Limnology Conference, winning an award for Best Undergraduate Presentation. These ROSS participants also traveled to other high schools in Kansas to teach Future Farmers of America groups about cyanobacterial blooms so the next generation of farmers could understand the importance of nutrient management to help prevent blooms.

ROSS research questions

Data from the ROSS Program are invaluable in helping to answer important research questions. These data will help us understand how cyanotoxin concentrations vary throughout the year and how the presence and concentration of cyanotoxins relate to physical and chemical drivers. A research article with findings from two of the ROSS study systems is currently in submission. Data from the paper has been published and is available online (Kinzinger and North 2021). As the ROSS program continues to collect more data, we will be able to analyze the annual variability in cyanotoxin presence and concentration and determine if and how drivers of cyanotoxins change throughout seasons. Collecting year-round water quality data is vital for understanding the seasonal risks of cyanotoxins in recreational and drinking water systems.

Figure 4. Selected student responses to the prompt: "What do you like about the ROSS project?"

Figure 5. Selected student responses to the prompt "Please list one topic that you learned from the ROSS project."

Vision for the future

Community science programs, like ROSS, are invaluable for both participants and scientists. Students can gain a deeper understanding of- and desire to care about- their local natural resources through engaging in research. Participation in community science also makes science attainable to students and shows them that their contributions are important towards advancing scientific knowledge. By sharing data with students, they are able to learn how to ask questions, form hypotheses, and explore how the data can be used to inform their questions. The collaboration between students and scientists also teaches students valuable skills in working with others.

Scientists are able to educate students about their research topic and collect a high volume of data that would otherwise be unattainable. The ability of scientists to collect samples or record observations is often limited by time and distance. By partnering with community scientists, data can be gathered at a high frequency from sites far away from their home base. Community science programs have a tremendous potential to educate students and make important contributions to research.

Conclusions

The ROSS Program teaches high school students about limnology and water quality issues their local lake or reservoir may be facing. Students gain hands-on experience collecting real-world data that will contribute to expanding our knowledge regarding year-round aquatic processes. This community science monitoring program is a successful way to educate the next generation of thinkers while also collecting important data. The MU Limnology Lab is continuing to expand the ROSS Program to include additional schools in states throughout the US. Our goal is to include lakes and reservoirs from a latitudinal gradient to study systems with varying degrees of ice cover during winter months. If you know of an interested high school teacher with a lake or reservoir nearby, please contact Dr. Rebecca North at northr@missouri.edu.

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References

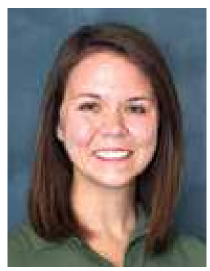
Block, B.D., B.A. Denfeld, J.D. Stockwell, G. Flaim, H. P.F. Grossart and L.B. Knoll et al. 2019. The unique methodological challenges of winter limnology. *Limnol. Oceanogr. Methods* 17, 42-57. doi:10.1002/lom3.10295.

Coffer, M.M., B.A. Schaeffer, W.B. Salls, E. Urquhart, K.A. Loftin and R.P. Stumpf et al. 2021. Satellite remote sensing to assess cyanobacterial bloom frequency across the United States at multiple spatial scales. *Ecol. Indic*. 128, 107822. doi:10.1016/j.ecolind.2021.107822.

Kinzinger, E.C. and R. and North. 2021. Water Quality Data from Bethel and Stephens Lakes, Columbia, Missouri 2017-2019 ver 1. doi:doi:10.6073/pasta/5f29f3e04e78922879fcca5932ddc54f.

Wejnerowski, Ł., P. Rzymski, M. Kokociński and J. Meriluoto. 2018. The structure and toxicity of winter cyanobacterial bloom in a eutrophic lake of the temperate zone. *Ecotoxicology* 27, 752–760. doi:10.1007/s10646-018-1957-x.

Wiltsie, D., A. Schnetzer, J. Green, M. Vander Borgh and E. Fensin. 2018. Algal blooms and cyanotoxins in Jordan Lake, *North Carolina. Toxins*, 10. doi:10.3390/toxins10020092.



Emily Kinzinger is an M.S. candidate in natural resources at the University of Missouri in Columbia, Missouri, under the supervision of Dr. Rebecca North. Her research focuses on an assessment of the year-round presence of cyanobacterial harmful algal blooms and their associated toxins.

Rebecca L. North is an assistant professor at the University of Missouri, in Columbia, Missouri. She received her Ph.D. in limnology from the University of Waterloo in Ontario, Canada in 2008. Rebecca is an emerging researcher in aquatic ecology and biogeochemistry with expertise on nutrient and phytoplankton dynamics in water bodies. She addresses questions regarding the sources and timing of nutrient loading from land to lake.

Algal **rating system**

Steve Lundt, CLM

"...signs, signs, everywhere a sign..."

And the lake sign should be an "Algalmeter." Yes, an Algalmeter. I do get tired of signs, especially when I visit a beautiful lake, but I have recently created and installed an algal rating system at a local state park (Figure 1). I based it on the National Fire Danger Rating System (NFDRS) and incorporated it with my lake monitoring events to help with public safety and awareness. Harmful algal blooms are important to understand, control, and are not well understood by the public. Thus, the need for yet another sign.

It seems to me that harmful algal blooms are topical news fillers during the heat of the summer and are then quickly forgotten. This needs to change. Algae awareness is important and needs to be in the forefront continuously. Cyanobacteria can grow year-round, and cultural eutrophication is an everyday topic for lake professionals everywhere.

An algae-awareness sign can educate the public all year long and become a part of the outdoor culture. If you want to camp during a drought, you should know if you can have a campfire before you leave. Same thing for lakes. If you want to go boating during the peak harmful algal bloom season, you should know if you can wakeboard before you pack up. Some kind of permanent sign that shows current and/or projected algae conditions will help keep the public safe and informed.

It was 1972 when the NFDRS became operational nationwide. Coincidentally, that same year the Clean Water Act started. Canada also has their own uniform, consistent rating system that keeps the public informed. It is time for lakes to have a similar program for harmful algal blooms. We have the water quality data, models, and often the historical algal patterns. The public understands scales, meters, and colored tiers. It is time for the Algalmeter.

Figure 1.Algae awareness rating sign at Barr Lake State Park (Brighton, Colorado).

Public awareness and education are key to any lake management program. This prevents the summertime panic when there are reports of sick dogs, closed beaches, and "DANGER" signs going up. Strategically placed algae rating signs can keep people informed and prepared. Along with a permanent sign, you can include postcards to park visitors explaining the various types of algae. You can create mascots to help spread the message. Just think what Smokey Bear has done for the forest fire awareness program. Now imagine a cute fish pointing a pectoral fin at you saying, "only you … can prevent harmful algal blooms."

"... blockin' out the scenery, breakin' my mind..."

The Algalmeter can break down how people think about lakes and increase their knowledge about harmful algal blooms and algae in general. Do it consistently but do not block the scenery. Be algae-aware and enjoy Lakes Appreciation Month.

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.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