CYANOBACTERIA AND HUMAN HEALTH CONCERNS ON LAKE CHAMPLAIN

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INTRODUCTION

Cyanobacteria, common photosynthetic organisms found around the world, pose a human health risk because of the possibility that they may produce toxins. The proliferation of cyanobacteria directly impacts drinking water usage and recreational activities in surface waters. Over the last decade, a strong relationship among academia, state agencies, a local environmental organization, and the regional Champlain management organization has increased local knowledge and capacity to respond to the presence of these organisms in the lake. Reducing the number, extent and intensity of cyanobacteria blooms is a priority of state water quality management activities, outlined in detail by the Champlain Total Maximum Daily Load ("TMDL"), the Phase I Implementation Plan, and the Vermont Clean Water Act.

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Cyanobacteria are important components of ecosystems. Previously called blue-green algae, these highly adaptable bacteria are found in all environments, aquatic and terrestrial, from the equator to the poles.[2] One of the oldest organisms on Earth, geologic and genetic evidence has shown that cyanobacteria were the first organisms to evolve the ability to photosynthesize, a process which dramatically reshaped life on Earth and eventually resulted in the oxygen-dominated atmosphere now present.[3] Cyanobacteria also have an important role in nitrogen cycling, particularly in extreme environments such as deserts and polar regions where this nutrient is in short supply.[4] There is increasing interest in using cyanobacteria to naturally enhance agricultural productivity.[5]

In aquatic environments, cyanobacteria can grow profusely, producing masses of floating scum and discoloring the water.[6] These masses, commonly known as blooms, deter recreational activities, disrupt water supplies, and impact other aquatic organisms when oxygen levels drop in response to the large quantity of biomass.[7] Fish kills are a common occurrence during intense cyanobacteria blooms when oxygen levels can drop significantly.[8] Some species of cyanobacteria can also produce potent toxins and it is this aspect of cyanobacteria ecology which has raised awareness of these organisms in recent years. Blooms have moved beyond being an unsightly nuisance to become potential health risks. There are no federal regulations outlining response to cyanobacteria blooms and jurisdictions across the country have developed individual approaches, ranging from no response to closing entire lakes to public recreation and drinking water use.

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[2] Hans W. Paerl et al., *Cyanobacterial—Bacterial Mat Consortia: Examining the Functional Unit of Microbial Survival and Growth in Extreme Environments*, 2 ENVTL. MICROBIOLOGY 11, 11–12 (2000).

[3] Armen Y. Mulkidjanian et al., *The Cyanobacterial Genome Core and the Origin of Photosynthesis*, 103 PROC. NAT'L ACAD. SCI. 13,126, 13,129 (2006).

[4] *See generally* Thulani P. Makhalanyane et al., *Ecology and Biogeochemistry of Cyanobacteria in Soils, Permafrost, Aquatic and Cryptic Polar Habitats*, 24 BIODIVERSITY & CONSERVATION 819 (2015) (describing the role cyanobacteria play in extreme environments).

[5] *See generally* Jay Shankar Singh, *Efficient Soil Microorganisms: A New Dimension for Sustainable Agriculture and Environmental Development*, 140 ARGIC., ECOSYSTEMS & ENV'T 339 (2011) (describing how sustainable agriculture can keep up with agricultural needs while remaining environmentally friendly and safe).

[6] Hans W. Paerl et al., *Harmful Freshwater Algal Blooms, with an Emphasis on Cyanobacteria*, 1 SCI. WORLD 76, 78 (2001).

[7] *Id.* at 76.

[8] *Id.* at 102.

On Lake Champlain, cyanobacteria have been observed in the plankton community since the 1930s.[9] Pigment markers in sediment cores from St. Albans and Missisquoi Bay document their presence in pre-colonial times and earlier.[10] These organisms are natural and native components of the Lake Champlain ecosystem. Blooms have been documented in some locations on Lake Champlain for many years. Saint Albans Bay, in particular, has experienced blooms since at least the late 1960s.[11] Cyanobacteria have been abundant in Missisquoi Bay since the early 1990s.[12] The Main Lake has also experienced blooms periodically since that time.[13]

Cyanobacteria proliferate in nutrient-rich waters and it is in these areas of Lake Champlain—Missisquoi and St. Albans Bays—where extensive intense blooms regularly occur and persist.[14] Here, waters become increasingly discolored and turbid as the cyanobacteria population grows over the summer. Under low wind conditions, or in protected areas, thick layers of cyanobacteria form at the water surface. The result is a carpet of green, blue, and occasionally, white scum at the water's surface, which may extend for miles on a calm sunny day.[15] Though they vary in magnitude each year, blooms on Champlain's nutrient-rich bays are present during much of August and into September.[16] While other areas of the lake may occasionally experience dense scums, it is the northern bays where cyanotoxins periodically exceed recreational guidelines.[17]

I. CYANOBACTERIA TOXINS

Cyanobacteria are known to produce a variety of potent toxins. There is currently no clear understanding of the role these have in the life cycle of

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[9] *See* Suzanne N. Levine et. al., *The Eutrophication of Lake Champlain's Northeastern Arm: Insights From Paleolimnological Analyses*, J. GREAT LAKES RES. 35, 42 (2012) (explaining algal abundance from 1600 in Missisquoi Bay).

[10] *Id.*

[11] *Id.* at 36.

[12] *See* Angela Shambaugh, *Historical Phytoplankton Densities At Missisquoi Bay, Station 50* 1 (Vt. Dep't Envtl. Conservation, Draft, 2008) (stating that long-term monitoring of Missisquoi Bay began in 1992).

[13] *Id.*

[14] ANGELA SHAMBAUGH ET AL., CYANOBACTERIA MONITORING ON LAKE CHAMPLAIN SUMMER 2014 5 (2015), http://dec.vermont.gov/sites/dec/files/wsm/lakes/docs/lp_Cyanobacteria2014.pdf.

[15] *Cyanobacteria: Blue-Green Algae*, VT. DEP'T OF HEALTH, http://www.healthvermont.gov/enviro/bg_algae/bgalgae.aspx (last visited Apr. 7, 2016).

[16] LAKE CHAMPLAIN BASIN PROGRAM, 2015 STATE OF THE LAKE AND ECOSYSTEM INDICATORS REPORT 13 (2015).

[17] *Id.*

cyanobacteria.[18] Not all are capable of toxin production and the ability is not shared by all taxa within a genus. Toxin production can also be turned on and off by the cells.[19] There is no visible indication that toxins are present and blooms may contain a mixture of toxic and non-toxic cells.[20] As a result, all blooms must be considered potentially toxic.[21]

Cyanotoxins affect vital organs throughout the body.[22] The hepatotoxins (microcystin, cylindrospermopsin, and nodularin) may damage the liver.[23] The neurotoxins (anatoxin, neosaxitoxin, saxitoxin) affect the nervous system.[24] Beta-Methylamino-L-alanine ("BMAA") has been linked to neurological disease such as Lou Gehrig's Disease (also know as "ALS") and Parkinson's disease.[25] Dermatoxins (lyngbyatoxin, aplysiatoxins, and lipopolysaccharides) may cause severe skin rashes and gastrointestinal distress.[26] Several cyanotoxins are likely tumor-promoters and possible carcinogens.[27] Exposure to these compounds can cause illness, sometimes severe, in mammals. Dogs are especially susceptible, with numerous deaths attributed to cyanotoxins each year in the U.S.[28] Livestock and wildlife deaths are reported periodically.[29]

People are also susceptible to cyanobacterial toxins, though attributing illness to cyanobacteria exposure can be difficult. Symptoms experienced

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[18] Timothy G. Otten & Hans W. Paerl, *Health Effects of Toxic Cyanobacteria in U.S. Drinking and Recreational Waters: Our Current Understanding and Proposed Direction*, WATER AND HEALTH 75, 75 (2015).

[19] *Id.* at 76.

[20] *Id.* at 80–81.

[21] *Id.* (explaining that it is difficult to consider an organism safe for consumption "when we know so little about it"); TOXIC CYANOBACTERIA IN WATER: A GUIDE TO THEIR PUBLIC HEALTH CONSEQUENCES, MONITORING AND MANAGEMENT ¶ 3.1 (Ingrid Chorus & Jamie Bartram eds., 1999).

[22] TOXIC CYANOBACTERIA IN WATER, *supra* note 22, ¶ 3.1.1; *see generally* LESLEY D'ANGLADA ET AL., ENVTL. PROT. AGENCY, HEALTH EFFECTS SUPPORT DOCUMENT FOR CYANOBACTERIAL TOXIN MICROCYSTINS (2015) [hereinafter EPA MICROCYSTINS EFFECTS]; LESLEY D'ANGLADA ET AL., ENVTL. PROT. AGENCY, HEALTH EFFECTS SUPPORT DOCUMENT FOR CYANOBACTERIAL TOXIN CYLINDROSPERMOPSIN (2015) [hereinafter EPA CYLINDROSPERMOPSIN EFFECTS]; LESLEY D'ANGLADA ET AL., ENVTL. PROT. AGENCY, HEALTH EFFECTS SUPPORT DOCUMENT FOR CYANOBACTERIAL TOXIN ANATOXIN-A (2015) [hereinafter EPA ANATOXIN-A EFFECTS] (each report provides an analysis of the effects of the specific cyanotoxin on human health); U.S. GEOLOGICAL SURVEY, GUIDELINES FOR DESIGN AND SAMPLING FOR CYANOBACTERIAL TOXIN AND TASTE-AND-ORDER STUDIES IN LAKES AND RESERVOIRS 8 (2008), http://pubs.usgs.gov/sir/2008/5038/pdf/SIR2008-5038.pdf [hereinafter USGS GUIDELINES].

[23] USGS GUIDELINES *supra,* note 22, at 8.

[24] *Id.*

[25] *Id.*

[26] *Id.*

[27] *Id.*

[28] Lorraine C. Backer et al., *Canine Cyanotoxin Poisonings in the United States (1920s-2012): Review of Suspected and Confirmed Cases from Three Data Sources*, 5 TOXINS 1,597, 1,597–98 (2013).

[29] *Id.* at 1,598.

may not be reported to a physician or may be misdiagnosed.[30] Human illness associated with cyanobacteria has been reported from around the world since the 1930s.[31] Though human deaths have occurred after exposure,[32] such cases are rare. More commonly, exposure results in skin, gastrointestinal, or respiratory symptoms. On Lake Champlain, a study conducted on Missisquoi Bay found residents experienced minor gastrointestinal and respiratory illnesses after exposure to cyanobacteria through drinking water and recreational activities.[33] No severe human illness associated with cyanobacteria exposure on Lake Champlain has been reported to date.

Analytical methods to detect cyanotoxins range in sensitivity and length of time required to complete the analysis. Liquid chromatography/mass spectrometry ("LC/MS") methods provide the most sensitive options.[34] Understanding of the complexity and variety of toxins—microcystin currently has more than 100 known variants[35]—is gained primarily through these methods. However, equipment is costly, requires highly trained staff, and typically needs at least 24 hours before results become available.[36] Methods are specific to individual toxins, requiring multiple tests to determine which toxins may be present in a bloom.

Rapid enzyme-linked immunosorbent assay ("ELISA") techniques have become the most common test used to inform recreational and drinking water response to the presence of cyanotoxins.[37] The method is comparatively inexpensive and results can be available in minutes (the dip-stick approach) or hours (the multi-well plate approach). ELISA currently are available for microcystin, cylindrospermopsin, nodularins, anatoxin, and BMAA.[38]

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[30] Lorraine C. Backer et al., *Cyanobacteria and Algae Blooms: Review of Health and Environmental Data from the Harmful Algal Bloom-Related Illness Surveillance System (HABISS) 2007-2011*, 7 TOXINS 1,048, 1,055 (2015).

[31] TOXIC CYANOBACTERIA IN WATER, supra note 22, ¶ 4.1.1.

[32] *Id.*; San M.F.O. Azevedo et al., *Human Intoxication By Microcystins During Renal Dialysis Treatment in Caruaru – Brazil*, 181 TOXICOLOGY 441, 442 (2002).

[33] Benoît Lévesque et al., *Prospective Study of Acute Health Effects in Relation to Exposure to Cyanobacteria*, 466–67 SCI. TOTAL ENV'T 397, 398, 401–02 (2014).

[34] EPA MICROCYSTINS EFFECTS, *supra* note 22, at 26.

[35] *Id.* at xii.

[36] USGS GUIDELINES, *supra* note 22, at 9.

[37] *Id.* at 8–9.

[38] *Id.* at 8.

II. FACTORS ENCOURAGING THE GROWTH OF CYANOBACTERIA

Cyanobacteria are highly successful organisms, as their presence on Earth for millennia and in some of the most extreme environments can attest. In particular, they have several ecological strategies that allow them to proliferate and dominate in aquatic ecosystems, particularly those that are highly nutrient-enriched. These include buoyancy regulation, tolerance of elevated temperature, nitrogen fixation, and protection from oxidative stress.

Many cyanobacteria can form gas vacuoles within their cells and control their position in the water column in response to environmental conditions, particularly in stable, calm waters.[39] This allows cyanobacteria to remain at the water surface or at depths that are suitable for maximum photosynthesis.[40] Buoyancy can also change in response to cell nutrient status, with some taxa such as *Microcystis* descending to the sediment surface in shallow waters to obtain nutrients that may be lacking in the surface waters,[41] then rising again for optimal photosynthesis. Dense accumulations at the surface shade out competitors, both other algae and rooted aquatic plants.[42]

Cyanobacteria grow under a wide range of temperatures. Though some taxa are capable of strong growth in winter conditions, highest densities typically occur in mid- to late summer on Lake Champlain.[43] On Missisquoi Bay, blooms are most likely to occur once water temperatures reach 68° F.[44]

Reactive compounds, such as hydrogen peroxide, form when dissolved organic carbons are broken down under the high light intensities found at the water's surface and can be readily absorbed into cells.[45] Recent studies suggest that microcystin may have a role in protecting cyanobacteria cells

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[39] Aharon Oren, *Cyanobacteria: Biology, Ecology and Evolution*, *in* CYANOBACTERIA: AN ECONOMIC PERSPECTIVE 10 (Naveen Sharma, Ashwani Rai & Lucas Stahl eds. 2014); Hans W. Paerl & Timothy G. Otten, *Harmful Cyanobacterial Blooms: Causes, Consequences, and Controls*, 65 ENVTL. MICROBIOLOGY 995, 999 (2013).

[40] Oren, *supra* note 39, at 10; *Harmful Cyanobacterial Blooms*, *supra* note 39, at 999.

[41] *See generally* Justin D. Brookes & George G. Ganf, *Variations in the Buoyancy Response of Microcystis Aeruginosa To Nitrogen, Phosphorus and Light*, 23 J. PLANKTON RES. 1399, 1407–09 (2001) (explaining responses in buoyancy of microcystis to limitations in resources).

[42] *Id.*

[43] *See* SHAMBAUGH, *supra* note 14, at 2 (documenting the highest concentration of mircosystin in August).

[44] Nathalie Fortin, *Toxic Cyanobacterial Bloom Triggers in Missisquoi Bay, Lake Champlain, as Determined by Next-Generation Sequencing and Quantitative PCR*, 5 LIFE 1,346, 1,366 (2015).

[45] *Harmful Cyanobacterial Blooms*, *supra* note 39, at 1,002.

from these stressors, enabling them to survive the harsh conditions present in prolonged surface blooms[46] and providing a competitive advantage.[47]

Nutrients play a pivotal role in determining community composition and abundance of phytoplankton.[48] Phytoplankton can only grow to the extent that vital nutrients are available, either dissolved in the water or released from organic matter as it decomposes.[49] In the aquatic environment, the concentration of phosphorus—the essential nutrient in shortest supply—and differences among phytoplankton taxa in their ability to use available forms, regulates the density and composition of the phytoplankton community.[50] As phosphorus concentrations increase, more biomass is supported and growth continues until another limitation—often of nitrogen—occurs. Many cyanobacteria, e.g. *Anabaena,* are capable of nitrogen fixation, which enables them to utilize gaseous nitrogen present in the water.[51] Others have evolved cellular processes that enable them to use different forms of nitrogen in the water more efficiently, influencing community structure.[52] Current research suggests the dominance of cyanobacteria in eutrophic systems is an outcome of the co-limitation of phosphorus and nitrogen.[53]

Finally, cyanobacteria are resistant to grazing pressure from zooplankton, mussels, and fish.[54] It may be physically difficult for zooplankton to capture and consume large gelatinous colonies and long filamentous forms.[55] Cyanobacteria may be less palatable and therefore actively avoided by zebra mussels.[56] They may also be resistant to digestion

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[46] Yvonne Zilliges et al., *The Cyanobacterial Hepatotoxin Microcystin Binds to Proteins and Increased the Fitness of Microcystis Under Oxidative Stress Conditions*, 6 PUB. LIBR. SCI. ONE 1, 8 (2011).

[47] Hans W. Paerl & Timothy G. Otten, *Blooms Bite the Hand that Feeds Them*, 342 ENVTL. SCI. 433, 434 (2013).

[48] C.S. REYNOLDS, THE ECOLOGY OF PHYTOPLANKTON 362–363 (2006).

[49] William B. Bowden, *Background Facts: Role of Phosphorus in Lake Champlain Pollution*, *supra* p. 506.

[50] *Id.* at 365.

[51] M.B. Allen & Daniel Arnon, *Studies on Nitrogen-Fixing Blue-Green Algae. I. Growth and Nitrogen Fixation by Anabaena Cylindrica Lemm*, 30 PLANT PHYSIOLOGY 366, 366 (1955).

[52] *See generally* Marie-Eve Monchamp et al., *Nitrogen Forms Influence Microcystin Concentration and Composition via Changes in Cyanobacterial Community Structure*, 9 PUB. LIBR. SCI. ONE 1 (2014) (indicating that some cyanobacteria cells have evolved to use nitrogen from waters).

[53] *Harmful Cyanobacterial Blooms*, *supra* note 39, at 1,004.

[54] Orlando Sarnelle, *Initial Conditions Mediate the Interaction Between Daphinia and Bloo-Forming Cyanobacteria*, 52 AM. SOC'Y LIMNOLOGY & OCEANOGRAPHY 2,120, 2,120 (2007).

[55] Alan E. Wilson et al., *Effects of Cyanobacterial Toxicity and Morphology on the Population Growth of Freshwater Zooplankton: Meta-Analyses of Laboratory Experiments*, 51 AM. SOC'Y LIMNOLOGY & OCEANOGRAPHY 1,915, 1,916 (2006).

[56] Henry A. Vanderploeg et al., *Zebra Mussel (Dreissena Polymorpha) Selective Filtration Promoted Toxic Microcystic Blooms in Saginaw Bay (Lake Huron) and Lake Erie*, 58 CAN. J. FISHERIES & AQUATIC SCI. 1,208, 1,218 (2001).

and may absorb nutrients as they pass through the gut.[57] Their ability to grow rapidly may also overwhelm the available consumers and limit the ability of the zooplankton to control cyanobacteria density.[58] Cyanotoxins may inhibit zooplankton growth.[59]

III. ECOSYSTEM AND HUMAN IMPACTS

Under low nutrient conditions, cyanobacteria often pass unnoticed. The annual transition from diatom-dominated communities in early spring to cyanobacteria dominance during the warmer stratified period and back to diatom domination after fall turnover[60] typically causes little change in visual appearance. As nutrient concentrations increase, blooms of cyanobacteria may become more common. Blooms of other phytoplankton, e.g., diatoms or green algae, also may occur but do not form the surface scums characteristic of many cyanobacteria.[61] Water clarity can be greatly reduced, which decreases swimming activity. Beaches may be closed. Boating activities can also be curtailed by blooms due to odors and the risk of inhaling water droplets containing cyanobacteria.[62] Fishing activity is generally not restricted during cyanobacteria blooms, but public health officials often recommend removing the skin, discarding the entrails, and washing fillets before consumption as a precaution.[63] The frequency and intensity of cyanobacteria blooms increases with rising nutrient concentrations.[64]

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[57] *Phosphorus Uptake by Microcystis During Passage Through Fish Guts*, 48 AM. SOC'Y LIMNOLOGY & OCEANOGRAPHY 2,392, 2,394 (2003).

[58] Francis Chan, *Bloom Formation in Heterocystic Nitrogen-Fixing Cyanobacteria: The Dependence on Colony Size and Zooplankton Grazing*, 49 AM. SOC'Y LIMNOLOGY & OCEANOGRAPHY 2,171, 2,176 (2004).

[59] Lars-Anders Hansson et al., *Cyanobacterial Chemical Warfare Affects Zooplankton Community Composition*, 52 FRESHWATER BIOLOGY 1,290, 1,291 (2007).

[60] Water density changes with water temperature. As water is warmed by sunlight, density changes and results in the formation of distinct layers of water which do not readily mix, a phenomenon known as stratification. As sunlight decreases in the fall, water temperatures become more similar in density and increasing winds can break down stratification. At these times, lake water from top to bottom mixes readily, even in lakes as large and deep as Champlain. The period is known as fall turnover. For further discussion of stratification and turnover, see ROBERT G. WETZEL, LIMINOLOGY: LAKE AND RIVER ECOSYSTEMS (3d ed. 2001).

[61] *Id.* at 334–35.

[62] *See* Lorraine C. Backer et al., *Recreational Exposure to Microcystins During Algal Blooms in Two California Lakes*, TOXICON 1 (2009) (concluding that recreational activities on water bodies with blooms can generate "aerosolized cyanotoxins, making inhalation a possible route of exposure").

[63] *Health and Ecological Effects*, U.S. ENVTL. PROT. AGENCY, https://www.epa.gov/nutrient-policy-data/health-and-ecological-effects (last updated Mar. 4, 2016).

[64] *Harmful Cyanobacterial Blooms*, *supra* note 39, at 1,004.

Drinking water facilities may also be impacted by the presence of cyanobacteria. Approximately 145,000 people consume water from Lake Champlain for drinking.[65] In Vermont alone, twenty-three private and public supplies draw water from Lake Champlain.[66] Intake structures and treatment train and purification activities directly influence the extent to which a facility may be impacted by the presence of cyanobacteria and cyanotoxins.[67] The Vermont Drinking Water and Groundwater Protection Division works closely with operators around Lake Champlain who proactively monitor surface conditions, change treatment processes in response to the density of cyanobacteria and algae, and test for the presence of cyanobacteria toxins when conditions warrant.[68]

Beach closures due to cyanobacteria occur each summer in parts of Lake Champlain.[69] Fish kills due to low oxygen conditions have occurred on Missisquoi Bay, as have mussel die-offs.[70] There have been no recent detections of cyanobacteria toxins in finished drinking water provided by facilities in Vermont.[71] In Quebec, drinking water facilities on the northern shores of Missisquoi Bay have altered their treatment train in response to the annual presence of intense scums and detectable toxin concentrations.[72]

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[65] LAKE CHAMPLAIN BASIN PROGRAM, 2015 STATE OF THE LAKE AND ECOSYSTEM INDICATORS REPORT 16 (2015).

[66] *Id.*

[67] ENVTL. PROT. AGENCY, RECOMMENDATIONS FOR PUBLIC WATER SYSTEMS TO MANAGE CYANOTOXINS IN DRINKING WATER 5–6 (2015); GAYLE NEWCOMBE ET AL., MANAGEMENT STRATEGIES FOR CYANOBACTERIA (BLUE-GREEN ALGAE): A GUIDE FOR WATER UTILITIES iv (2010), http://www.waterra.com.au/publications/document-search/?download=106.

[68] *Cyanobacteria: Blue-Green Algae*, VT. DEP'T OF HEALTH, http://www.healthvermont.gov/enviro/bg_algae/bgalgae.aspx#monitor (last visited June 16, 2016).

[69] LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 65, at 12.

[70] Elissa Schuett, *Blue-Green Algae Kills Thousands of Fish in Missisquoi Bay*, VT. WATER RESOURCES & LAKE STUDIES CTR. (Aug. 27, 2012), https://www.uvm.edu/rsenr/vtwater/?Page=news&storyID=14222&category=vwrlsc.

[71] Kathryn Flagg, *Public Water Systems Watch for Toxic Algae in Lake Champlain*, SEVEN DAYS (Aug. 13, 2014), http://www.sevendaysvt.com/vermont/public-water-systems-watch-for-toxic-algae-in-lake-champlain/Content?oid=2416816; *see* VT. DEP'T OF ENVTL. CONSERVATION, PROCESS FOR MANAGING ANATOXIN, CYLINDROSPERMOPSIN, AND MICROCYSTIN IN RAW AND FINISHED WATER SAMPLES FOR PUBLIC WATER SYSTEMS 2 (2015), http://drinkingwater.vt.gov/wqmonitoring/pdf/FINAL_CYANOPRACTICE2015.pdf (outlining the recommended cyanotoxin testing procedures for Lake Champlain) [hereinafter PROCESS FOR MANAGING ANATOXIN] *Cyanobacteria: Blue-Green Algae*, *supra* note 68 (providing links to the results of the weekly testing done of drinking water intakes in Lake Champlain over the 2015 summer for cyanotoxins).

[72] *See generally* Arash Zamyadi et al., *Application of in Vivo Measurements for the Management of Cyanobacteria Breakthrough into Drinking Water Treatment Plants*, 16 ENVTL. SCI: PROCESSES & IMPACTS 313 (2014) (describing the recommended interventions developed by the Canadian Ministry of Environment to manage the increased presence of cyanobacteria in drinking water sources).

IV. REGULATORY RESPONSIBILITY

Prior to 2015, there were no federal or state regulations outlining response to cyanobacteria blooms or cyanotoxins. Before the early 2000s, most public health officials in the Northeast were not aware of the health risks associated with blooms, though blooms did occur. With the development of ELISA in the late 1990s, testing of recreational and drinking water sources increased, documenting the frequent occurrence of some cyanotoxins, particularly microcystin, in surface waters around the country.[73] Without a common standard response, jurisdictions developed their own approach to the protection of public health during cyanobacteria blooms, often in crisis mode when they realized that the bloom on their shoreline might be highly toxic. Guidance from the Centers for Disease Control ("CDC") and the World Health Organization[74] provided valuable information, but was used inconsistently in developing response protocols around the country. The general public, who could not recognize cyanobacteria blooms, were confused and highly concerned when cyanobacteria were confirmed in surface waters close to home.

At the time of the 1999 bloom in the Burlington area, there were no cyanobacteria response plans for Lake Champlain. State officials in Vermont and New York provided guidance, but responsibility to put closures and drinking water bans in place belonged to the towns. Early on, many towns in Vermont and New York did not to respond to cyanobacteria blooms in their recreational waters. In Quebec, however, closures occurred more frequently.[75] The result was a piecemeal approach to cyanobacteria response where closures occurred on the Canadian side of the border but guidance was infrequently publicized on the U.S. side.

With the development of the Lake Champlain Cyanobacteria Monitoring Program (discussed below), a uniform and regular source of data supported state and provincial officials as they developed response protocols for public beach managers. Communication between the states

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[73] Jennifer L. Graham, *Environmental Factors Influencing Microcystin Distribution and Concentration in the Midwestern United States*, 38 WATER RES. 4,395, 4,397 (2004); *see generally* John R. Beaver et al., *Land Use Patterns, Ecoregion, and Microcystin Relationships in U.S. Lakes and Reservoirs: A Preliminary Evaluation*, 36 HARMFUL ALGAE 57 (2014) (showing the patterns of microcystins now after testing has increased).

[74] *See generally* WORLD HEALTH ORG., GUIDELINES FOR SAFE RECREATIONAL WATER ENVIRONMENTS, VOLUME 1: COASTAL AND FRESH WATERS ix, xix (2003), http://apps.who.int/iris/bitstream/10665/42591/1/9241545801.pdf (providing guidelines "intended to be used as the basis for the development of international and national approaches" to deal with health risks from cyanobacteria and other dangerous aquatic organisms).

[75] *See Cyanobacteria (Blue-Green Algae)*, LAKE CHAMPLAIN BASIN PROGRAM, http://www.lcbp.org/water-environment/human-health/cyanobacteria/ (last visited Apr. 20, 2016).

and Quebec improved as a result of the monitoring program. Though guidance protocols have commonalities, the three major jurisdictions each maintain their own thresholds triggering public health response.[76] While authority to close beaches still remains with towns in most cases, when blooms are suspected, state and provincial officials contact town health officials and local beach managers directly with information and materials to guide a consistent response.[77]

Drinking water response also varies among the jurisdictions. In Vermont, the Department of Health ("VDH") and the Department of Environmental Conservation ("DEC") worked with Champlain drinking water operators to establish a voluntary cyanobacteria response practice in 2007, one of the first in the country.[78] Operators receive weekly email updates and guidance about using this information in daily operations. In 2015, VDH and DEC facilitated the weekly testing of both raw and finish water at all twenty-three Vermont facilities on Champlain.[79] They also assisted smaller facilities with development of cyanobacteria response plans.

In June 2015, the EPA released guidelines outlining monitoring, analysis, and response to cyanobacteria in drinking water sources[80] for two cyanobacterial toxins: microcystin and cylindrospermopsin. Mandatory testing was not required; but in December, EPA issued proposed revisions to the Unregulated Contaminant Monitoring Rule ("UCMR 4") for Public Water Systems, which includes a monitoring design to gather more information on ten cyanobacteria toxins.[81] All water systems serving more than 10,000 people will be required to participate in short-term monitoring

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[76] *Blue-Green Algae and Health*, N.Y. DEP'T OF HEALTH, http://www.health.ny.gov/environmental/water/drinking/bluegreenalgae/ (last updated Feb. 2016); *see* QUEBEC DÉVELOPPEMENT DURABLE, LA GESTION DES ÉPISODES: DE FLEURS D'EAU D'ALGUES BLEU-VERT 1 (2014), http://www.mddelcc.gouv.qc.ca/eau/algues-bv/outil-gestion/gestion-episodes.pdf (indicating when Canadian province's public health response thresholds are triggered); VT. DEP'T OF ENVTL. CONSERVATION, CYANOBACTERIA (BLUE-GREEN ALGAE) GUIDANCE FOR VERMONT COMMUNITIES 13 (2015), http://www.healthvermont.gov/enviro/bg_algae/documents/BGA_guide.pdf.

[77] CYANOBACTERIA (BLUE-GREEN ALGAE) GUIDANCE FOR VERMONT COMMUNITIES 13-14, *supra* note 75.

[78] PROCESS FOR MANAGING ANATOXIN, *supra* note 71, at 1.

[79] *Cyanobacteria: Blue-Green Algae*, *supra* note 68; *see generally What's New*, VT. RURAL WATER ASS'N, http://www.vtruralwater.org (last updated Apr. 3, 2016) (explaining how the Vermont Rural Water Association combats and prevents more water pollution of drinking water in Vermont).

[80] *Guidelines and Recommendations*, U.S. ENVTL. PROT. AGENCY, https://www.epa.gov/nutrient-policy-data/guidelines-and-recommendations#what2 (last updated Mar. 15, 2016).

[81] *Monitoring Unregulated Drinking Water Contaminant: Fourth Unregulated Contaminant Monitoring Rule*, U.S. ENVTL. PROT. AGENCY, https://www.epa.gov/dwucmr/fourth-unregulated-contaminant-monitoring-rule (last updated Dec. 16, 2015).

beginning in 2018.[82] Eight hundred smaller systems will be randomly selected for participation.[83]

V. THE RECENT HISTORY OF CYANOBACTERIA AND MONITORING ON LAKE CHAMPLAIN

During a bloom on the Main Lake in 1999 and again in 2000, several dog deaths were attributed to cyanobacteria toxins on Lake Champlain.[84] The occurrence of toxins in lake water was shocking to the general public and generated apprehension about recreation on the lake. Vermont public health officials turned to scientists at the University of Vermont's School of Natural Resources ("UVM," now the Rubenstein School of Environment and Natural Resources) and the SUNY College of Environmental Science and Forestry ("SUNY-CESF") for assistance developing a response to that first bloom.

Little was known about cyanobacteria populations on Lake Champlain at that time and even less about their toxins. Resources in the Champlain Basin were, however, uniquely poised to respond. The Lake Champlain Basin Program ("LCBP") had funded a water quality monitoring program at more than a dozen sites around the lake since 1992 to support development and implementation of the Champlain TMDL.[85] UVM had the technical expertise in phytoplankton identification. With financial backing from the LCBP and support from DEC field staff, UVM developed and implemented a monitoring program within two years.[86] In 2003, a local NGO, the Lake Champlain Committee ("LCC"), joined the partnership, recruiting the first citizen volunteers to assist with monitoring.[87] UVM, LCC volunteers, and DEC field staff collected weekly samples and assessed bloom severity. Data from the program were shared with state and local health officials through weekly email summaries, individual alerts, and annual reports.

The earlier years of the program focused on developing protocols using cell counts and toxin analyses. Selected stations were monitored at weekly intervals and response actions were triggered when cell counts and/or

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[82] *Id.*

[83] *Id.*

[84] Gregory L. Boyer et al., *The Occurrence of Cyanobacterial Toxins in Lake Champlain*, *in* LAKE CHAMPLAIN: PARTNERSHIP AND RESEARCH IN THE NEW MILLENNIUM 241, 255 (T. Manley et al. eds., 2004).

[85] *Monitoring Programs*, LAKE CHAMPLAIN BASIN PROGRAM, http://www.lcbp.org/water-environment/data-monitoring/monitoring-programs/ (last visited Apr. 10, 2016).

[86] Author's personal knowledge.

[87] *Monitoring Programs*, *supra* note 85.

microcystin concentrations exceeded threshold levels.[88] Budget and time constraints limited the number of stations monitored, but the data distributed through the email list and alert notifications provided valuable information for other locations around the lake.[89] UVM also offered training and guidance materials about cyanobacteria to drinking water operators and public beach managers.

As the monitoring program matured and awareness of the health concerns associated with cyanobacteria increased around the basin, a visual protocol[90] was developed in 2012 to complement the quantitative protocols and provide a mechanism for the general public to evaluate conditions whenever they were on the water.[91] With assistance from volunteers recruited and trained by LCC, the Champlain cyanobacteria monitoring program now monitors more than eighty sites around the lake annually, using both qualitative and quantitative protocols.[92]

The monitoring data show that cyanobacteria are present throughout the lake each summer, typically appearing in mid- to late June and persisting through October in some locations. Several potentially toxic taxa are present during much of the summer, most commonly *Anabaena*, *Microcystis*, and *Aphanizomenon*. In much of the lake, these taxa rarely reach levels of concern and blooms are also rare. In the northern shallow bays and shoreline locations, however, blooms are frequent and often contain microcystin. On occasion, concentrations exceed guidelines established by the jurisdictional authority.

Monitoring also documents the rapid appearance and disappearance of blooms. Many cyanobacteria have the ability to regulate their buoyancy in response to environmental conditions, primarily light to support photosynthesis. On calm, sunny days, or in protected locations, cyanobacteria can rise to the surface and accumulate there in a matter of hours. These are small organisms, however, and no match for water currents. With a change in wind direction or wave strength, they can be mixed back into the water column in a matter of minutes. As a result,

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[88] Mary C. Watzin et al., *Application of the WHO Alert Level Framework to Cyanobacterial Monitoring of Lake Champlain, Vermont*, 21 ENVTL. TOXICOLOGY 278, 279 (2006).

[89] *Id.* at 280.

[90] The Lake Champlain Committee's current volunteer materials can be viewed at *Blue-Green Algae Monitor*, LAKE CHAMPLAIN COMM., http://www.lakechamplaincommittee.org/get-involved/volunteers/bgamonitors/ (last visited Mar. 30, 2016).

[91] ANGELA SHAMBAUGH ET AL., CYANOBACTERIA MONITORING ON LAKE CHAMPLAIN, SUMMER 2012: FINAL REPORT FOR THE LAKE CHAMPLAIN BASIN PROGRAM (2013), https://anrweb.vt.gov/PubDocs/DEC/WSMD/lakes/docs/lp_Cyanobacteria2012.pdf.

[92] SHAMBAUGH, *supra* note 14, at 2.

conditions at monitored locations frequently change, making communication about the location and extent of blooms difficult.

The intensity, composition, and location of blooms vary annually.[93] Cyanobacteria proliferate each summer in nutrient-rich St. Albans and Missisquoi Bays, but annual median cell density range widely at long-term monitoring sites.[94] The worst conditions are typically observed in late summer and blooms in these bays can persist for weeks.[95] Cyanobacteria are also common in the nutrient-rich South Lake, but blooms are rarely reported from that area.[96] Blooms do occur periodically on the Main Lake and can affect large areas under the right environmental conditions.[97] In contrast to the northern bays, blooms on the Main Lake occur primarily in early summer and typically disappear within a few days.[98] Consistently around the lake, the most intense blooms and highest cell densities occur along shorelines and in protected downwind bays.[99]

Toxin analyses detect the presence of microcystin at multiple locations in Missisquoi Bay each summer.[100] Microcystin is documented less frequently on St. Albans Bay and rarely in the Main Lake.[101] Concentrations vary greatly between locations and among years. Highest concentrations of microcystin are typically on Missisquoi Bay.[102] Anatoxin is detected infrequently.[103] Periodic testing has not detected the presence of any other cyanotoxins to date.

Data from stations that have been monitored consistently since 2003, when the program began, indicate that overall cyanobacteria conditions were worse prior to 2007 on Missisquoi and St. Albans Bays.[104] Median cell densities since 2007 have decreased and some locations have also experienced a decrease in the number of blooms observed during the summer.[105] Changes in the monitoring program and the influence of local

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[93] *See id.* at 39–40 (depicting the mean density of cyanobacteria in Missisquoi and St. Albans Bay from 2003 to 2014).

[94] *Id.* at 41.

[95] *Cyanobacteria in Vermont: What Causes Blooms and Scums?*, VT. DEP'T OF ENVTL. CONSERVATION, http://www.watershedmanagement.vt.gov/lakes/htm/lp_cyano_what_causes_blooms.htm (last visited Apr. 8, 2016).

[96] *Id.* at 19.

[97] LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 65, at 2.

[98] *Cyanobacteria in Vermont: What Causes Blooms and Scums?*, *supra* note 95.

[99] LAKE CHAMPLAIN BASIN PROGRAM, *supra* note 65, at 13.

[100] SHAMBAUGH, *supra* note 14, at 18–19.

[101] *Id.* at 14.

[102] *Id.* at 13.

[103] *Id.* at 2.

[104] *Id.* at 41.

[105] *Id.*

environmental conditions on bloom formation make it difficult to identify trends in more recent years.

Since 2012, when the visual protocol was developed, more than ninety percent of the reports submitted each summer document good conditions on Lake Champlain (Figure 1). Blooms continue to be reported each year from locations around the lake, however, and public outreach remains a key component of the monitoring effort. In addition to the weekly updates to public health officials and drinking water suppliers, a tracking map has been developed by the Vermont Department of Health which provides updates to the general public in near real-time.[106] Though water conditions can change rapidly at a given location, the qualitative observations and quantitative data collected by the monitoring program provide a common and consistent source of information to support public health officials and inform the general public about lake conditions.

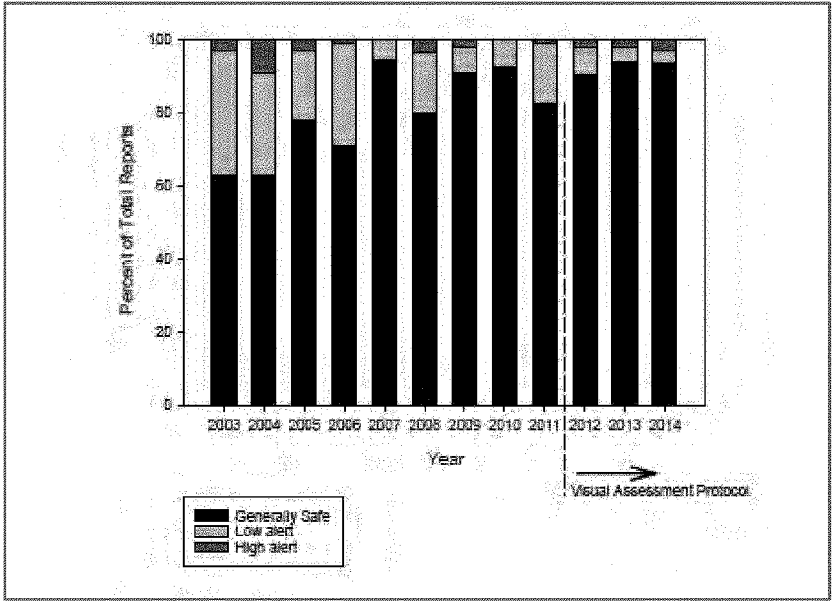

Figure 1. Cyanobacteria status reports Lake Champlain by category, percent of total reports received. Records prior to 2012 were determined using historical cell count and toxin data. Beginning in 2012, summaries include records obtained using the visual assessment protocol. The status generated by the visual assessment protocol is used at locations where both types of assessment were employed. Supplemental reports are included. From Shambaugh et al. *supra* note 14.

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[106] *Vermont Blue Green Algae Tracker*, VT. OF DEP'T HEALTH, https://apps.health.vermont.gov/gis/vttracking/bluegreenalgae/d/ (last visited Apr. 6, 2016).

The use of a qualitative visual system in conjunction with a traditional quantitative monitoring program has enabled the Lake Champlain cyanobacteria monitoring program to cover a much larger geographic area than was possible for the qualitative program alone. In 2015, the program received more than one hundred reports each week during July.[107] With support from the VDH, volunteer monitoring expanded to two additional Vermont lakes and more than ninety percent of the reports during the summer were provided by LCC volunteers.[108] This very successful partnership between state agencies, local NGOs, and citizen volunteers has increased awareness of the potential health concerns associated with cyanobacteria and understanding of the environmental conditions that support their growth.

VI. REDUCING THE OCCURRENCE OF BLOOMS ON LAKE CHAMPLAIN AND OTHER VERMONT WATERS

Phytoplankton are integral to aquatic ecosystems from Lake Champlain to small ponds. Human activities on the land have increased the rate at which nutrients are deposited in lakes, thereby increasing the growth potential of phytoplankton. Blooms—rapid and dense growth by a single class of phytoplankton—are a natural response to abundant nutrients and a specific set of environmental conditions. Lake Champlain and other Vermont waters experience annual blooms of diatoms, green algae, and cyanobacteria. Blooms of cyanobacteria, however, pose a human health risk and may have direct impacts on drinking water production and recreational activities.

Reduction of blooms is accomplished by eliminating the environmental conditions allowing a particular group of phytoplankton to outcompete other groups for common resources. Cyanobacteria gain competitive advantage through their ability to regulate buoyancy, tolerate the high light intensity and conditions present at the water surface, and circumvent nitrogen limitation in phosphorus-rich environments. Management options to eliminate the competitive advantage conferred by buoyancy and adaptation to life at the water surface are limited for a waterbody the size of Lake Champlain. Such options also do not address the underlying causes of cyanobacteria dominance—the essentially unlimited availability of the key

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[107] *See Vermont Blue-Green Algae (Cyanobacteria) Tracker*, VT. DEP'T OF HEALTH (June-Oct. 2015), https://apps.health.vermont.gov/gis/vttracking/BlueGreenAlgae/2015Summary/ (download the 2015 summary data to see each individual report).

[108] *Id.*

growth-limiting nutrient phosphorus and the increasing availability of nitrogen.

Decreasing the amount of phosphorus reaching Lake Champlain and other surface waters in the basin will limit the amount of overall biomass that can be produced by cyanobacteria and other phytoplankton. Increasing recognition of the role of nitrogen in promoting cyanobacteria growth and toxicity suggests that adoption of a dual-nutrient strategy may be necessary.[109] Elimination of cyanobacteria from Vermont's water is not possible, nor is it prudent given the important ecological roles these organisms have in the environment. Reducing the flow of nutrients into surface waters through the management approaches outlined in the Lake Champlain TMDL and the Vermont Clean Water Act will reduce the competitive edge cyanobacteria have, increase the diversity of phytoplankton communities, and reduce the risk of exposure to cyanobacterial toxins.

Future lake management will need to consider the impacts of climate change on cyanobacteria growth.[110] Under current climate change scenarios, increased water temperatures and longer growing seasons are expected, conditions which are likely to enhance cyanobacteria growth in Lake Champlain.[111] Stormwater inputs to surface water, with their high nutrient load, are expected to increase with more intensive rainfall events. Longer dry periods may lead to increased evaporation, resulting in concentration of nutrients within waterbodies. Reduction of nutrients is a key strategy to increase resiliency and protect Vermont's surface waters for changes, which may lie ahead.

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[109] EPA ANATOXIN-A EFFECTS, *supra* note 22, at 6–7.

[110] C. Gombault, *Impacts of Climate Change on Nutrient Losses from the Pike River Watershed of Southern Quebec*, 95 CAN. J. SOIL SCI. 337, 339 (2015); *see generally* Hans W. Paerl & Valerie J. Paul, *Climate Change: Links To Global Expansion of Harmful Cyanobacteria*, 47 WATER RES. 1,349 (explaining how the global expansion of harmful bacteria is linked to climate change).

[111] *See* J. CURT STAGER & MARY THILL, CLIMATE CHANGE IN THE CHAMPLAIN BASIN: WHAT NATURAL RESOURCE MANAGERS CAN EXPECT AND DO 17, 19 (2010), http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/vermont/what-we-do/champlain-climate-report-5-2010-2.pdf.