ERDC WQTN-23-1
September 2023

Microseira wollei (M. wollei) Blooms in Freshwater Ecosystems in Lake St. Clair (Michigan, USA)–Impacts and Possible Management Approaches

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PURPOSE: The proliferation and shoreline accumulation of the filamentous biphasic cyanobacterium, *Microseira wollei* (*M. wollei*) (previously classified as *Lyngbya wollei*), have become an increasing problem in the Great Lakes, both for aesthetic reasons and its potential to harbor harmful bacteria and pathogens (Vijayavel et al. 2013). Occurrences have been reported and studies have also been conducted in the southeastern US where *M. wollei* has become a nuisance in recent years and is known to produce toxins (Hudon et al. 2014). Reports of *M. wollei* proliferations in the eastern US have been identified in the Manitoba lakes (Macbeth 2004), in Lake Erie from Maumee Bay (Bridgeman and Penamon 2010), in Lake St. Clair near Detroit (Vijayavel et al. 2013), and throughout the St Lawrence River (Vis et al. 2008; Lévesque et al. 2012). *M. wollei* has become a serious nuisance for marinas, public beaches, and lakefront property owners. In addition, *M. wollei* appears to have the ability to produce a wide range of toxins, but the conditions promoting their production, type, and concentration are poorly known (Hudon et al. 2014). Occurrences of large algal mats matching characteristics of *M. wollei* have been observed along the northwest shore and nearshore waters of the beach at Lake St. Clair dating back to 2010. To date, a comprehensive study detailing the potential impacts *M. wollei* has on freshwater ecosystems in the Great Lakes River, particularly Lake St. Clair is lacking. Further, management solutions are not well understood. This technical note (TN) reviews the potential causes of *M. wollei* blooms and their ecological impacts on aquatic systems and assesses the management options available to eliminate or minimize the impacts of these blooms.

BACKGROUND: *M. wollei* is the new taxonomically accepted name for *Lyngbya wollei*. This cyanobacterium was renamed because of the establishment of a new phylogenetically distinct genus, *Microseira* from *Lyngbya* (Kenins 2017). The biphasic filamentous cyanobacterium, *M. wollei,* is common worldwide and occurs in a diverse array of aquatic systems (e.g., rivers, lakes, springs) in both freshwater and brackish conditions (Metz et al. 2022.). This cyanobacterium has previously been named *Plectonema wollei*, *Lyngbya wollei*, and *Microseiria wollei* (Hudon et al. 2014; Metz et al. 2022). *M. wollei* is historically known within the southeastern US, but its occurrence is becoming increasingly widespread across the eastern US and southern Canada (Putman et al. 2022).

M. wollei is commonly observed in the metaphyton of rivers and lakes in North America, and it is easily recognizable by the formation of large algal mats (Hudon et al. 2014). Blooms have been documented in North America for ≥100 years from early reports from ponds in Massachusetts and in New Jersey (Hudon et al. 2014). The growth of *M. wollei* in lakes in the southeastern US has become an increasing problem over the last two decades. Massive benthic blooms have occurred in the summer from North Carolina to northern Florida in shallow protected embayments and rivers, in reservoirs on the Tennessee River, and in Florida Springs (Hudon et al. 2014). *M. wollei* has been reported in an increasing abundance in two shallow Manitoba lakes in Canada (Macbeth 2004). Table 1 shows a comparison of *M. wollei* bloom intensity in different locations across the US taken from Hudon et al. (2014).

Table 1. Comparison of *M. wollei* bloom intensity in different locations taken from Hudon et al. (2014).

Location	Period	Biomass (g DM [a] /m^2)	Reference
St. Lawrence River: Lake Saint Pierre	August-September 2005	Mean: 27 ± 8 (SE)	Vis et al. 2008
St. Lawrence River: 250 km river stretch	August-September 2008	Maximum: 26.3	Levesque et al. 2012
St. Lawrence River: Lake Saint Louis	April-October 2009-2011	Maximum: 68.7	D. Levesque, CH, and AC, unpublished date
Western Lake Erie, Maumee Bay	Summer 2009	Mean 19.4 Maximum: 314.8	Bridgeman et al. 2011
Western Lake Erie, Maumee Bay	Monthly, June-August 2009-2010	Maximum 2009: 23 Maximum 2010: 0.3	Panek 2012
Betula and White Lakes, Manitoba	July 2003	Range: 52-693	Macbeth 2004
Guntersville Reservoir, Alabama	1992-1993	Mean: 575 (control)	Doyle and Smart 1995
4 lakes and ponds from South Carolina, Georgia, and Alabama	July-August 1987	Range: 120-1140	Speziale et al. 1991
Crystal River, Florida	Monthly, April 1989-March 1990	Mean: 377 Range: 1-1508	Cowell and Silver Botts 1994
5 lakes and ponds from Georgia and Florida	Various dates, July 1985-February 1986	Range: 120-1440	Beer et al. 1986

[a] DM = dry biomass

M. wollei belongs to the family of Oscillatoriaceae (simple filaments lacking heterocysts) and exhibits unusually large filaments (up to 50 µm diameter) and a thick sheath (2-10 µm) (Hudon et al. 2014) (Figure 1*A*). It has been reported that *M. wollei* initially grows as multiple loose filaments tangled at the base of aquatic vegetation and eventually forms dense mats loosely associated with soft sediments (Figure 1*B*) (Hudon et al. 2014). Those filaments gradually accumulate into a several-cm-thick tangled mat on the sediments. Mats become small-scale ecosystems that support a wide variety of other cyanobacteria, microalgae, and SO_4^{-2} reducing bacteria in association with organic debris and mineral particles (Hudon et al. 2014). Under the influence of wind-induced waves, filaments form small (1–2 cm diameter) compact balls that occasionally float to the surface and are transported ashore (Figure 1*C*, *D*) (Hudon et al. 2014).

Figure 1. Photos A-F shows *M. wollei* in different forms from Hudon et al. (2014): *A*.—*M*. wollei unbranched filament, showing thick sheath and trichomes. *B*.—Underwater view of M. wollei filaments tangled at the base of rooted macrophytes. *C*.—Field collection of M. wollei mat using a double-headed rake, showing the filamentous matrix and characteristic balls of tangled filaments produced by water motion. *D*.—*M*. wollei mat floating on the surface. *E*.—Amphipods hiding in M. wollei mats. *F*.—Shoreline accumulation of M. wollei after storm, requiring removal from beaches by municipal authorities.

Occurrences of *M. wollei* has long been documented in the Great Lakes, but reports of proliferations are becoming increasingly common, and is now considered a nuisance species. Blooms have increased occurrence over the last decade, particularly in Lake St. Clair, causing concerns over the potentially negative impacts to ecosystems and human health (Vijayavel et al. 2013). Documented blooms of *M. wollei* were reported first in St. Lawrence River (2005), then in

Lake Erie (2006) and later in Lake St. Clair (2010) (Vijayavel et al. 2013). It has been reported that agriculture, industry, and urban development within the Great Lakes basin have led to anthropogenic loading of nutrients to the connected freshwater systems. In addition, causes of algal bloom proliferation include eutrophication resulting from human activities, warming water temperatures, global warming, and qualitative and quantitative load of nutrients near watersheds and airsheds (Poirier-Larabie et al. 2020).

M. wollei proliferations can be harmful to people, animals, and the environment. Research has shown that clinical signs can occur after a single exposure to *M. wollei*. *M. wollei* blooms produce volatile organic compounds with earthy or musty odors. This cyanobacterium may also produce toxins, including neurotoxins (saxitoxin) (Hudon et al. 2014; Smith et al. 2019) and hepatotoxins (Bae et al. 2020). There are individual case reports of human exposure having direct contact with water containing *M. wollei* that caused ocular and respiratory tract irritation (Solter and Beasley 2013). Skin exposure to *M. wollei* toxins can result in acute dermatitis followed by rash and vesicle formation (Solter and Beasley 2013).

In addition to changes in the watershed, which have affected nutrient and phytoplankton dynamics in the lakes, the invasion and establishment of dreissenid mussels (i.e., zebra and quagga mussels) within the region in the early 1980s, further changed these relationships (Bakkila 2014). Successful dreissenid invasions can alter ecosystem functions within lakes at lake-wide and local spatial scales. For example, the dreissenids reduce concentrations of suspended particles, resulting in increased light penetration into the water column (Geisler et al. 2016) thereby promoting growth of toxic cyanobacteria and filamentous green algae (Armenio et al. 2016). In addition, dressenids can potentially provide macronutrients and micronutrients which may provide additional resources to benthic algae (Armenio et al. 2016). These changes in the Great Lakes waterways have likely contributed to an increased growth of benthic algal and cyanobacterial blooms in the region.

***M. wollei* Impacts to Aquatic Biota.** Cyanobacteria produce a wide range of toxins, which affect the liver, nervous system, and skin of organisms ingesting, inhaling, or directly touching them or surrounding water containing toxin. It has been reported that freshwater cyanobacteria are known to produce both hepatotoxic and neurotoxic cyanotoxins that have negative impacts on human health and other mammals (Kaur 2019). *M. wollei* is known to produce hepatotoxins, neurotoxins, and dermal toxins, although toxin production varies among regions strains of the cyanobacteria (Bakkila 2014). *M. wollei* in the St. Lawrence River is recorded to produce an analog of saxitotoxin, commonly known as paralytic shellfish toxin (Bakkila 2014; Gélinas et al. 2012; Lajeunesse et al. 2012), while *M. wollei* in Lake Erie lack hepatotoxin or neurotoxin compounds (Bridgeman and Penamon 2010).

Aquatic ecosystems composed primarily of *M. wollei* are often characterized by a lower biomass of invertebrates and large fish, lower fish species richness, and slower-growing juvenile fish when compared to aquatic ecosystems composed primarily of macrophyte species (Crews 2018; Hudon et al. 2014). Cyanobacteria blooms can have cascading impacts on ecosystems. When *M. wolle*i dominates a water body it can cause a decrease in the typical diversity of the submerged aquatic vegetative community which can impact the entire food web, including decreasing species diversity and abundance of the benthic invertebrates, and thus impacting fish assemblages (Bakkila 2014; Hudon et al. 2012).

Water Quality Parameters that increase *M. wollei* Growth and Survivability. Factors that affect the growth and survivability of *M. wollei* include nutrients, water flow, and photosynthetic active radiation (PAR). *M. wollei* mats can also affect pH and bicarbonate concentrations in freshwater during photosynthesis and respiration. Optimal growth of *M. wollei* has been observed in waters between pH 7 and 8 (Cowell and Botts 1994). It is possible that a correlation between pH and Ca^{2+} assimilation by *M. wollei* may exist considering the positive growth responses observed upon addition of Ca under controlled conditions. However, more research is needed in this area to identify the metabolic mechanisms by which Ca affects growth. Cowell and Botts (1994) reported *M. wollei* growth to be only marginally influenced by nutrients (N and P) when added to test cultures alone. However, Cowell and Botts (1994) observed considerable increases in growth when Ca was added; thus, in part supporting *M. wollei*'s occurrence in spring water from limestone aquifer sources irrespective of N and P concentrations. Furthermore, studies investigating *M. wollei* under conditions of varying water flows have consistently demonstrated the similar impacts of flow rates on *M. wollei* health. Stevenson et al. (2007) suggest that higher flow rates positively impact the physiological condition of *M. wollei* by the removal of metabolic wastes and replenishing nutrients within the mat's matrix.

Like many cyanobacteria species that can grow under low light conditions due to specialized phytochrome adaptations (Rockwell and Lagarias 2017), *M. wollei* is able to carry out photobiological and metabolic activities in the presence and absence of light. PAR at low intensity is sufficient for *M. wollei* and exhibits a threshold limit for light assimilation as correlated with biomass production (Yin et al. 1997). In the presence of benthic zebra mussels, *M. wollei* can thrive due to the filtration and resultant water quality that contributes to deeper light penetration for the benthic algal mat.

MANAGEMENT APPROACHES TO PREVENT THE SPREAD OF *M. WOLLEI*

Case Study–management in Lay Lake, Alabama. To our knowledge, management of *M. wollei* in Lay Lake represents one of the most well documented long-term cyanobacteria management programs in a US freshwater resource. Numerous peer-reviewed publications on Lay Lake are available which outline the management strategy, including documenting risks to non-target species (Calomeni et al. 2015; Iwinksi et al. 2016) and evaluated algaecide efficacy (Bishop et al. 2015; Calomeni et al. 2015; Anderson et al. 2019) over the course of the 20-year management program.

Management of *M. wollei* in shallow and low flow areas of Lay Lake, Alabama, was initiated approximately 20 years ago (Alabama Power 2016; Calomeni et al. 2015; Iwinski et al. 2016). Management was needed because dense mats of *M. wollei* were interfering with the designated uses of Lay Lake, a 4,900 ha reservoir located in central Alabama (Calomeni et al. 2015). Additionally, residents and visitors of Lay Lake reported foul smelling *M. wollei* mats surrounding boat docks, shoreline properties, and marinas that would become tangled in fishing lines and boat motors making these recreation activities impossible (Alabama Power 2016).

Prior to 2004, numerous management strategies including a limited number of single use copper-based algaecides, physically raking algal mats, and mechanical harvesters had been used for the management of *M. wollei* at this site with marginal success (Alabama Power 2016; Calomeni et al. 2015). Therefore, a series of bench scale algaecide efficacy studies were conducted to evaluate a suite of US Environmental Protection Agency (USEPA) registered algaecides for efficacy in decreasing the biomass of *M. wollei* post treatment. Evaluation of algaecide treatments at the bench scale allow for comparison of the efficacy of multiple algaecide formulations and combinations of algaecides at a series of concentrations with low expense relative to testing *in situ*. The results from this bench-scale treatment were then "scaled up" and applied as field treatments. These data informed an effective management approach which included using a combination of two algaecides used at a rate of approximately five treatments per year. First, a peroxide-based algaecide was applied, then 24 hours later a copper-based algaecide and surfactant was applied which resulted in sustained control of *M. wollei* (Calomeni et al. 2015). Using this management strategy, *M. wollei* has been successfully controlled for the past decade (Calomeni et al. 2015).

Long-term management program. Throughout the 20-year *M. wollei* management program at Lay Lake, algaecide efficacy was re-evaluated to ensure treatments continued to be effective, identify new sites requiring treatment, decrease treatment costs and minimize risks (Calomeni et al. 2015; Anderson et al. 2019). Different algaecide treatments were applied in Lay Lake coves from 2013 to 2018 and efficacy was measured in terms of benthic biomass (e.g., visual assessment, benthic rake tosses).

Efficacy of the long-term management approach was observed in approximately two to three years following the algaecide treatments as anecdotally, homeowners reported decreases in *M. wollei* biomass (Alabama Power 2016). Following seven to twenty years of treatment, *M. wollei* mats were absent within treated coves and remained dense in untreated coves providing further evidence of long-term treatment success. Algaecide efficacy is also apparent in terms of a decrease in the need to treat areas that were once actively managed using algaecide applications. From 2013 to 2017, the acreage requiring treatment decreased from approximately 160 acres to 30 acres (i.e., 81% reduction in management area; Anderson et al. 2019).

Long-term risks of copper-based algaecide treatments. Because copper from an algaecide treatment will partition to the sediment phase, concerns often arise regarding the potential for "release" of bioavailable copper species present at concentrations toxic to resident benthic invertebrates. Therefore, in 2015 a study was conducted to assess the potential for these long-term risks in Lay Lake using a sediment quality triad (Iwinski et al. 2015). The sediment quality triad implements analytical detection of sediment copper concentrations, *in situ* benthic invertebrate abundance, and sediment toxicity testing with naïve organisms to provide a weight of evidence conclusion regarding potential risks. In this study, sediments from three treated coves with approximately 7, 10, and 20 years of algaecide treatment were compared to sediments from three untreated coves. Sediment copper concentrations from a cove that had been treated for approximately 20 years had elevated copper concentrations relative to the other coves evaluated. Importantly, none of the treated coves (including the cove with elevated copper concentrations) had bioavailable species of copper present in sediments that were causing toxicity to naïve organisms in toxicity experiments nor resulted in altered benthic invertebrate abundances *in situ*. Based on the weight of evidence, long-term treatments using copper-based algaecides were not causing adverse impacts to benthic invertebrates in Lay Lake.

Implication to other M. wollei impacted sites. Information can be gained from this long-term *M. wollei* management program and applied to other locations experiencing similar issues with this problematic species. Laboratory scale algaecide experiments were useful for the identification of effective formulations for treatment *in situ.* Following *in situ* treatments, monitoring was used to determine treatment success. Effective algaecide treatments were reassessed multiple times throughout the management program. Following diligent adaptive management and monitoring, the acreage requiring treatment could be decreased due to apparent *M. wollei* control.

Overall, these data indicate a few key points for *M. wollei* management of infested lakes:

- A combination of algaecides was effective at decreasing biomasses of *M. wollei* with long-term treatment.

- Following effective long-term treatment, sites that were once treated annually could be removed from the treatment schedule due to lack of *M. wollei* mats.

- In Lay Lake, no long-term risks to benthic invertebrates were apparent following 7 to 20 years of applications using copper-based algaecides.

Algaecide Efficacy. There is a substantial body of data documenting the successful application of algaecides for mitigating HABs (ITRC 2021; Kibuye et al. 2021). Specifically, both copper- and peroxide-based USEPA-registered algaecides have shown efficacy for the management of the cyanobacterium, *M. wollei* (Alabama Power 2016; Calomeni et al. 2015; Iwinski et al. 2016; Anderson et al. 2019). Therefore, a general overview of both copper- and peroxide-algaecides are outlined below, with a comparison of effectiveness, advantages, and limitations of each algaecide presented in Table 2.

Copper algaecides. Copper algaecides are one of the most commonly used chemical products to control HABs (Kibuye et al. 2021). Copper algaecides impact respiration and photosynthesis of algal cells leading to decreases in cell density or can directly compromise cell integrity leading to cell lysis in higher copper doses (Calomeni et al. 2014). There are several forms of copper used in registered algaecides, including copper sulfate, acidified copper products, and chelated copper (e.g., copper ethanolamine, copper citrate, copper gluconate) and have a range of uses and efficacies based on the HAB species of concern and water conditions (i.e., water hardness, pH, alkalinity; ITRC 2021). Overall, the efficacy of copper-based algaecides is supported by a substantial body of research that provide improved predictions of cyanobacterial responses in field-scale applications. Non-target species impacts and copper residuals from long-term use should be considered.

Peroxide algaecides. Peroxide-based algaecides are oxidants (i.e., hydrogen peroxide [H_2O_2]) that can affect algae by impairing cellular photosynthesis and cellular integrity leading to cell lysis (Geer et al. 2017; Kibuye et al. 2021; ITRC 2021). Peroxide algaecides are available in both solid compounds (sodium carbonate peroxyhydrate [SCP]) or as a liquid mixture, and both have advantages and disadvantages based on the targeted treatment parameters and site conditions (ITRC 2021). For example, solid peroxide products can be applied to (1) control benthic algal mats by allowing the product to sink through the water column, or (2) floating algal mats for treatment of surface blooms. Overall, peroxide-based algaecides offer effective treatment of a wide variety of HABs, with minimal adverse impacts to the environment due to its rapid dissipation and dissociation to O_2 and H_20.

Table 2. Overview of considerations for use of copper and peroxide algaecides (based on ITRC 2021).

Parameter	Copper Algaecides	Peroxide Algaecides
Body of Research	Substantial	Substantial
Relevance	Known to be effective for control of Microseira wollei (formerly L. wollei)	Known to be effective for control of Microseira wollei (formerly L. wollei)
Site Use Considerations	Algaecide labels will specify applicable uses; generally available for a wide range of water body types, depth, surface areas, trophic states, and mixing regime	Algaecide labels will specify applicable uses; generally available for a wide range of water body types, depth, surface areas, trophic states, and mixing regime
Cost	$	$$
Nature of HABs	HAB sensitivities to copper algaecides vary, but cyanobacteria often more sensitive than green algae	HAB sensitivities to peroxide algaecides vary, but cyanobacteria often more sensitive than green algae
Advantages	• Scalable	• Scalable
	• Can be used to target specific problematic algal or cyanobacterial species	• Can be used to target specific problematic algal or cyanobacterial species
	• Known to be effective against a wide variety of cyanobacteria	• Rapidly dissociates to 02 and H20
		• Oxidizes cyanobacteria cells and toxins
Limitations	• National Pollutant Discharge Elimination System (NPDES) permits, or state/territory/tribe-specific equivalent permits are required for treatment in Waters of the United States. There also may be location-specific requirements on use or nonuse.	• National Pollutant Discharge Elimination System (NPDES) permits, or state/territory/tribe-specific equivalent permits are required for treatment in Waters of the United States. • Peroxide compounds need special handling and possible state-required training, and application permits
	• Care is required when treating algae or cyanobacteria in soft waters due to the sensitivities of off-target species	• May be less effective in highly turbid systems or systems with high algal densities
	• Frequent application can lead to copper accumulation in sediments and potential adverse effects.	

CONCLUSIONS: As *M. wollei* continues to proliferate in regions around the Great Lakes, there is a concomitant need to better understand and quantify the potential impact and identify prevention or management opportunities. *M. wollei* is a filamentous cyanobacterium that can (1) form dense biphasic mats, (2) impact aesthetics, (3) produce unpleasant taste and odor compounds, (4) produce potent toxins, and (5) harbor potentially harmful bacteria and pathogens. *M. wollei* proliferations are present within Lake St. Clair, however, limited site-specific information is known about environmental triggers for their growth, potential for toxin production and ecological risks. Management of *M. wollei* has been successfully achieved in locations within the southeast US where adaptive management approaches were used. Therefore, past management successes that mitigated impacts of *M. wollei* can be used to inform future goals within the Great Lakes.

REFERENCES

Alabama Power. 2016. *End is Near for 'Water Kudzu' M. Wollei on Alabama Power Lakes*. https://apcshorelines.com/2016/10/22/end-is-near-for-water-kudzu-M. Wollei-on-alabama-power-lakes/.

Anderson, W. T., J. N. Yerby, J. Carlee, W. M. Bishop, B. E. Willis, and C. T. Horton. 2019. "Controlling M. Wollei in Three Alabama, USA Reservoirs: Summary of a Long-Term Management Program." *Applied Water Science* 9(8): 1–12.

Armenio, Patricia M., Christine M. Mayer, Scott A. Heckathorn, Thomas B. Bridgeman, and Sarah E. Panek. 2016. "Resource Contributions from Dreissenid Mussels to the Benthic Algae Lyngbya Wollei (Cyanobacteria) and Cladophora Glomerata (Chlorophyta)." *Hydrobiologia* 763(1): 35–51. https://doi.org/10.1007/s10750-015-2357-3.

Bae, E. H., J. S. Kang, and C. S. Park. 2020. "New Report on Cyanophyte in Korea, Microseira Wollei (Farlow Ex Gomont) G.B. McGregor and Sendall Ex Kennis (Oscillatoriaceae)." *Journal of Species Research* 9(3): 210–17.

Bakkila, 2014. *The Movement of Escherichia Coli snd Enterococci Among Beach Sand, Lyngbya wollei, and The Water Column: Implications for Human Health*. MS Thesis. Detroit, MI: Wayne State University.

Bishop, West M., Ben E. Willis, and C. Todd Horton. 2015. "Affinity and Efficacy of Copper Following an Algicide Exposure: Application of the Critical Burden Concept for Lyngbya Wollei Control in Lay Lake, AL." *Environmental Management* 55(4): 983–90. https://doi.org/10.1007/s00267-014-0433-5.

Bridgeman, Thomas B., and Wanda A. Penamon. 2010. "Lyngbya Wollei in Western Lake Erie." *Journal of Great Lakes Research* 36(1): 167–71. https://doi.org/10.1016/j.jglr.2009.12.003.

Calomeni, A. J., K. J. Iwinski, C. M. Kinley, A. Mcqueen, and J. H. Rodgers. 2015. "Responses of M. Wollei to Algaecide Exposures and a Risk Characterization Associated with Their Use." *Ecotoxicology and Environmental Safety* 116: 90–98.

Cowell, Bruce C., and Pamela Silver Botts. 1994. "Factors Influencing the Distribution, Abundance and Growth of Lyngbya Wollei in Central Florida." *Aquatic Botany* 49(1): 1–17. https://doi.org/10.1016/0304-3770(94)90002-7.

Crews, B. G. 2021. *Ecotoxicological effects of lithium chloride on Lyngbya wollei*. MSc Thesis. Valdosta, GA: Valdosta State University.

Farlow, W. G. 1877. "Remarks on Some Algae Found in the Water Supplies of the City of Boston." *Bulletin of the Bussey Institute* 2: 75–80.

Geer, T. D., A. J. Calomeni, C. M. Kinley, K. J. Iwinski, and J. H. Rodgers. 2017. "Predicting in Situ Responses of Taste-and Odor-Producing Algae in a Southeastern US Reservoir to a Sodium Carbonate Peroxyhydrate Algaecide Using a Laboratory Exposure-Response Model." *Water, Air, & Soil Pollution* 228(2): 1–14.

Geisler, Marianne E., Michael D. Rennie, Darren M. Gillis, and Scott N. Higgins. 2016. "A Predictive Model for Water Clarity Following Dreissenid Invasion." *Biological Invasions* 18(7): 1989–2006. https://doi.org/10.1007/s10530-016-1146-x.

Gélinas, M., A. Lajeunesse, C. Gagnon, and F. Gagné. 2013. "Temporal and Seasonal Variation in Acetylcholinesterase Activity and Glutathione-S-Transferase in Amphipods Collected in Mats of Lyngbya Wollei in the St Lawrence River (Canada)." *Ecotoxicology and Environmental Safety* 94: 54–59.

Higgins, Scott N., Sairah Y. Malkin, E. Todd Howell, Stephanie J. Guildford, Linda Campbell, Veronique Hiriart-Baer, and Robert E. Hecky. 2008. "An Ecological Review of Cladophora Glomerata (Chlorophyta) in the Laurentian Great Lakes(1)." *Journal of Phycology* 44(4): 839–54. https://doi.org/10.1111/j.1529-8817.2008.00538.x.

Hudon, C., M. De Sève, and A. Cattaneo. 2014. "Increasing Occurrence of the Benthic Filamentous Cyanobacterium Lyngbya Wollei: A Symptom of Freshwater Ecosystem Degradation." *Freshwater Science* 33(2): 606–18.

ITRC (Interstate Technology Regulatory Council). 2021. *Strategies for Preventing and Managing Harmful Cyanobacterial Blooms (HCBs)*. Management and Control Strategies for HCBs. https://hcb-1.itrcweb.org/management-and-control-strategies-for-hcbs/.

Iwinski, Kyla J., Andrew D. McQueen, Ciera M. Kinley, Alyssa J. Calomeni, Tyler D. Geer, and John H. Rodgers Jr. 2016. "Sediment Copper Concentrations, in Situ Benthic Invertebrate Abundance, and Sediment Toxicity: Comparison of Treated and Untreated Coves in a Southern Reservoir." *Water, Air, and Soil Pollution* 227(3). https://doi.org/10.1007/s11270-016-2778-2.

Kaur, Gurjot. 2019. "Freshwater Cyanotoxins." In *Biomarkers in Toxicology*, 601–13. https://doi.org/10.1016/b978-0-12-814655-2.00035-9.

Kenins, A. 2017. "Validation of the Noxious Cyanophyte Microseira Wollei (Farlow Ex Gomont) G.B.McGregor & Sendall (Oscillatoriaceae)." *Notulae Algarum* 43: 1–3.

Kibuye, Faith A., Arash Zamyadi, and Eric C. Wert. 2021. "A Critical Review on Operation and Performance of Source Water Control Strategies for Cyanobacterial Blooms: Part I-Chemical Control Methods." *Harmful Algae* 109(102099): 102099. https://doi.org/10.1016/j.hal.2021.102099.

Lajeunesse, André, Pedro A. Segura, Malorie Gélinas, Christiane Hudon, Krista Thomas, Michael A. Quilliam, and Christian Gagnon. 2012. "Detection and Confirmation of Saxitoxin Analogues in Freshwater Benthic Lyngbya Wollei Algae Collected in the St. Lawrence River (Canada) by Liquid Chromatography-Tandem Mass Spectrometry." *Journal of Chromatography A* 1219: 93–103. https://doi.org/10.1016/j.chroma.2011.10.092.

Lévesque, D., A. Cattaneo, C. Hudon, and P. Gagnon. 2012. "Predicting the Risk of Proliferation of the Benthic Cyanobacterium Lyngbya Wollei in the St. Lawrence River." *Canadian Journal of Fisheries and Aquatic Sciences* 69: 1585–95.

Macbeth, A. J. 2004. *Investigation of an introduced subtropical alga (Lyngbya wollei) in Whiteshell Provincial Park, Manitoba*. MSc Thesis. Winnipeg, Manitoba: University of Manitoba.

Metz, Tryston T., Samuel P. Putnam, Geoffrey I. Scott, and John L. Ferry. 2022. "Shoreline Drying of Microseira (Lyngbya) Wollei Biomass Can Lead to the Release and Formation of Toxic Saxitoxin Analogues to the Water Column." *Environmental Science & Technology* 56(23): 16866–72. https://doi.org/10.1021/acs.est.2c05579.

Michigan Department of Environmental Quality. 2010. *Lake St. Clair – H.C.M.A. – Lake St. Clair Metropark Beach*. Retrieved from http://www.deq.state.mi.us/beach/BeachDetail.aspx?BeachID=545.

Putnam, Samuel P., Meagan L. Smith, Tryston T. Metz, Ashley M. Womer, Emily J. Sellers, Samantha J. McClain, Cassidy A. Crandell, Geoffrey I. Scott, Timothy J. Shaw, and John L. Ferry. 2022. "Growth of the Harmful Benthic Cyanobacterium Microseira Wollei Is Driven by Legacy Sedimentary Phosphorous." *Harmful Algae* 117(102263): 102263. https://doi.org/10.1016/j.hal.2022.102263.

Rockwell, Nathan C., and J. Clark Lagarias. 2017. "Phytochrome Diversification in Cyanobacteria and Eukaryotic Algae." *Current Opinion in Plant Biology* 37: 87–93. https://doi.org/10.1016/j.pbi.2017.04.003.

Smith, Zacharias J., Robbie M. Martin, Bofan Wei, Steven W. Wilhelm, and Gregory L. Boyer. 2019. "Spatial and Temporal Variation in Paralytic Shellfish Toxin Production by Benthic Microseira (Lyngbya) Wollei in a Freshwater New York Lake." *Toxins* 11(1): 44. https://doi.org/10.3390/toxins11010044.

Soulter, P. F., and V. R. Beasley. 2013. "Phycotoxins. Haschek and Rousseaux's Handbook of Toxicologic Pathology," 2013, 1155–86. https://doi.org/10.1016/B978-0-12-415759-0.00038-8.

Speziale, B. J., and L. C. Dyck. 1992. "Lyngbya Infestations: Comparative Taxonomy of M. Wollei Comb. Nov." *Cyanobacteria). Journal of Phycology* 28: 693–706.

Stevenson, R., A. Pinowska, A. Albertin, and J. Sickman. 2007. *Ecological Condition of Algae and Nutrients in Florida Springs: The Synthesis Report*.

Vijayavel, Kannappan, Michael J. Sadowsky, John A. Ferguson, and Donna R. Kashian. 2013. "The Establishment of the Nuisance Cyanobacteria Lyngbya Wollei in Lake St. Clair and Its Potential to Harbor Fecal Indicator Bacteria." *Journal of Great Lakes Research* 39(4): 560–68. https://doi.org/10.1016/j.jglr.2013.09.018.

Vis, Chantal, Antonella Cattaneo, and Christiane Hudon. 2008. "Shift from Chlorophytes to Cyanobacteria in Benthic Macroalgae along a Gradient of Nitrate Depletion(1)." *Journal of Phycology* 44(1): 38–44. https://doi.org/10.1111/j.1529-8817.2007.00429.x.

Wolle, F. 1887. *Freshwater Algae of the United States*. Bethlehem, Pennsylvania: Comenius Press.

Yin, Q., W. Carmichael, and W. R. Evans. 1997. "Factors Influencing Growth and Toxin Production by Cultures of the Freshwater Cyanobacterium Lyngbya Wollei Farlow Ex Gomont." *Journal of Applied Phycology* 9: 55–63.