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

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Introduction

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

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

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

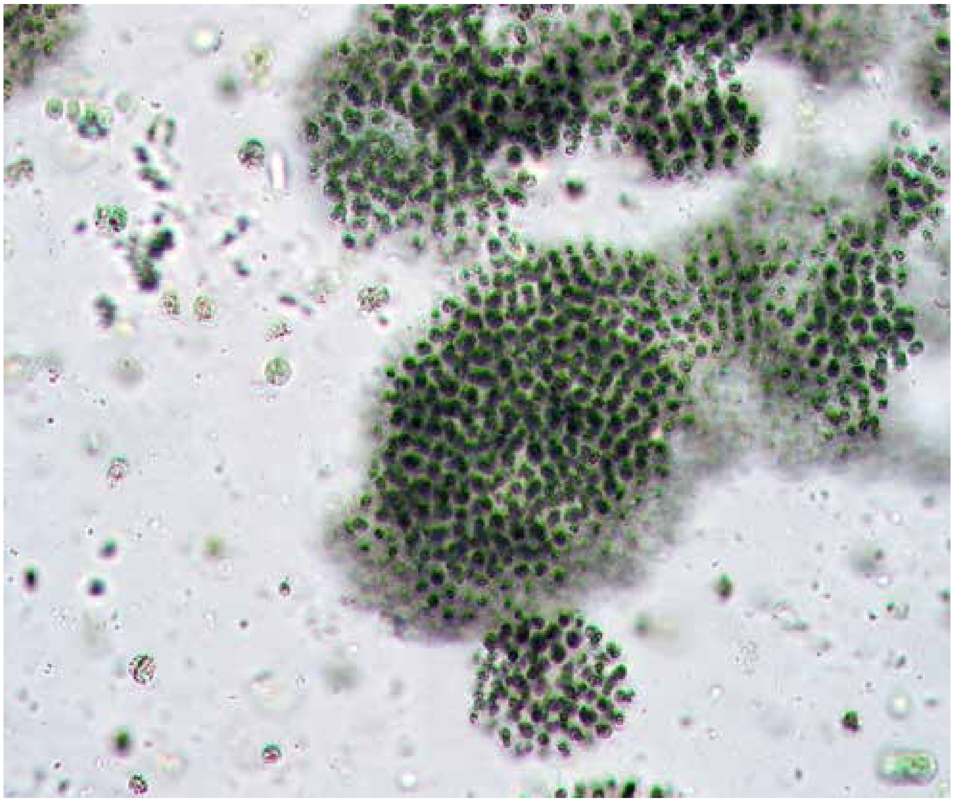

Figure 1. A colony of single-celled Microcystis sp.

Causes of cyanobacteria blooms

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

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

Mitigation of cyanobacteria blooms

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

Algaecides and peroxides

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

Figure 2. Dense cyanobacteria blooms on an inland lake.

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

Nutrient inactivation

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

Aeration/oxygenation

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

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

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

Concluding remarks

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

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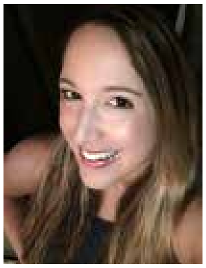

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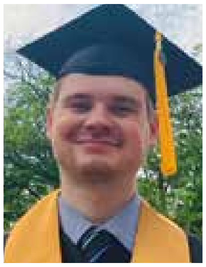

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