Algae, Cyanobacteria Blooms, and Climate Change

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Cyanobacteria are a normal part of most aquatic ecosystems, including lakes, rivers, and oceans. However, when toxic algae are present in an ecosystem, or when there are “algal blooms” (the rapid, uncontrolled growth of algae) they can be harmful. There are factors that contribute to algal blooms, including limiting nutrients, climate change, and pollution. Although the impact algal blooms can have on an ecosystem and on the environment are damaging, there are solutions in place which help remediate the presence of algal blooms, and policies in place to help prevent the issues which cause them.

Algae, Cyanobacteria, and Cyanobacteria Blooms

Algae are “prokaryotic organisms — cyanobacteria, also known as blue-green algae — as well as eukaryotic organisms (all other algal species)” that are photosynthetic[1]. Like plants, algae turn sunlight into food, making them primary producers. Algae play an important role in many ecosystem, providing food and shelter for many different species of aquatic animals.[2] Cyanobacteria are very diverse. They can be found in both freshwater and saltwater environments. Although these organisms’ impressive success across such varied conditions is remarkable, it can also be a cause for concern. Algae is a normal and healthy part of many aquatic ecosystems; however, in large numbers, cyanobacteria blooms can cause chaos in an aquatic ecosystem and may even threaten human health. In fact, these bloom events can be so large that in some cases the resulting cyanobacteria cover can be seen from space.

“Cyanobacteria bloom” is a term used to describe the rapid growth of cyanobacteria, also called blue-green algae. A bloom essentially takes over parts of a body of water, or a full body of water, and changes the way in which the ecosystem functions.

Although some blooms occur naturally, others are caused, in part, by human activities. Two important contributing factors are climate change, which creates an environment in which cyanobacteria can thrive, and nutrient loading, which provides the cyanobacteria with and excess of limiting nutrients (nutrients necessary to the the growth of cyanobacteria).

Figure 1:. Image captured of an algal bloom in Lake Eerie. Source: NOAA

Causes and Results

The underlying cause of an individual cyanobacteria bloom can vary, but a major cause of cyanobacteria blooms is nutrient pollution. “Nutrient over enrichment of waters by urban, agricultural, and industrial development has promoted the growth of cyanobacteria as harmful algal blooms.”[3] As Paerl points out, nutrient over-enrichment can come from multiple sources, including urban, agricultural, or industrial activities.

Limiting Nutrients

Limiting nutrients refers to nutrients that are essential for an organisms growth and survival. For cyanobacteria, these limiting nutrients include phosphorus and nitrogen. In normal quantities, these nutrients are healthy for many environments. However, when there is an excess of these limiting nutrients, it causes an excess of growth—in the case of cyanobacteria, a “bloom.” Excessive limiting nutrients in lakes can cause eutrophication. Eutrophication is when bodies of water are overloaded with limiting nutrients. “As bodies of freshwater become enriched in nutrients, especially Phosphorus (P), there is often a shift in the phytoplankton community towards dominance by cyanobacteria. Examples of these changes are the dense blooms often found in newly euthrophied lakes, reservoirs, and rivers previously devoid of these events.”[4]

There are several causes for eutrophication. Each one has its own challenges, but ultimately each one also has its own solution.

Agriculture

Agriculture is one of the main contributors to nutrient pollution. Farmers often use chemical fertilizers and pesticides to increase crop yields. These can contain limiting nutrients for cyanobacteria such as nitrogen and phosphorus. Since farmers usually have irrigated land, excess of rainwater is diverted away from the farm in order to keep crops from being flooded. Runoff from farms is often contaminated with chemicals picked up from the crops and soil. This nutrient rich water usually finds its way to another water source, such as a river or lake, where the excess nutrients can produce a cyanobacteria bloom.

Climate Change

Climate change contributes to excess cyanobacteria blooms by creating ideal conditions for cyanobacteria to grow. Cyanobacteria thrive in warm waters: as global temperatures rise, so too does global water temperatures. Cyanobacteria not only grow more rapidly in warm water from increased temperatures, but warmer waters also make it more difficult for water to mix, meaning the surface of the water remains much warmer than the rest of the body of water—and cyanobacteria grow more successfully on the surface.[5] This is also disadvantageous because growing a thick cover on the surface of the water means that this photosynthetic organism can absorb sunlight easily, and grow even more rapidly.

Furthermore, increasing concentrations of atmospheric carbon dioxide are also favorable to the growth of cyanobacteria.[6] The combination of warmer water temperatures and carbon dioxide absorption further creates perfect conditions for cyanobacteria growth and blooms.

A change in climate also affects precipitation rates and patterns. According to NASA, "Rising temperatures will intensify the Earth's water cycle, increasing evaporation. Increased evaporation will result in more storms, but also contribute to drying over some land areas."[7] This poses a problem when increased rainfall and storms causes more frequent nutrient pollution, "Thus, fertilization of arable land, sewage discharging, industrial effluents, use of detergents, extensive livestock farming are some of the activities that are responsible for the anthropogenic input of nutrients."[8]

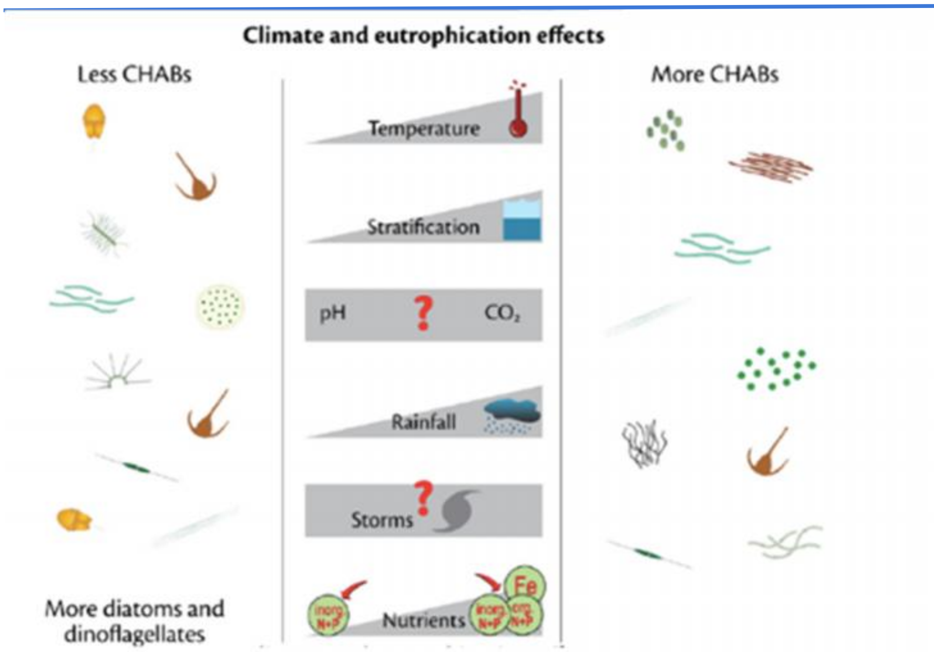

Fig. 2. Eutrophication and potenital effects of climate change on Cyanobacterial Harmful Algal bloom (CHAB) abundance.

Figure 2: Infographic depicting the relationship between Cyanobacteria Harmful Algal Blooms and the factors that contribute to them. Source: Harmful Algae. 2012.O'Neil, J.M., T.W. Davis, M.A. Burford, and C.J. Gobler

What are the Consequences?

<u>Ecology</u>

Cyanobacteria blooms have various negative impacts. Hypoxia, and anoxia are two of the most harmful consequences that can result from a cyanobacteria bloom. Hypoxia is when the dissolved oxygen levels in water drop, and anoxia is when dissolved oxygen levels in water become extremely low or reach zero. When this happens, it is more common to occur in pockets of bodies of water, called "dead zones," but in some serious cases can affect whole bodies of water. During a cyanobacteria bloom, an excess of dead and decaying cyanobacteria can result in hypoxia or anoxia. "When these blooms decay in enclosed coastal environments, they can leach nutrients, organic matter, and water soluble toxins, consequently causing localized anoxia, fish kills and mortality in marine organisms"[9]

As the vast amounts of cyanobacteria begin to die, the process of decay uses up oxygen. "When the cyanobacteria blooms decay, they will cause oxygen depletion owing to the microbial decomposition of cyanobacterial cells."[10]

This causes issues because it depletes or lessens the dissolved oxygen levels in the water, which puts aquatic flora and fauna at risk.

Aquatic Flora and Fauna

When dissolved oxygen levels in aquatic environments plummet, it means that in extreme circumstances, aquatic flora and fauna can suffocate.

Table 1. Effects of eutrophication

- Anoxia (no oxygen present) which kills fish and invertebrates and also leads to release of unpleasant and injurious gases.
- Algal blooms and uncontrolled growth of other aquatic plants.
- Production of toxic substances by some species of blue-green algae.
- High concentrations of organic matter which if treated with chlorine can create carcinogenic compounds.
- Deterioration of recreational value of a lake or reservoir due to decreased water transparency.
- Restricted access for fishing, angling and recreational activities due to plant accumulation.
- Decreased number of species and diversity of plants and animals (biodiversity).
- Shifts in fish species composition from more to less desirable species (in economic terms and protein intake).
- Oxygen depletion particularly in the deeper layers during the autumn in temperate lakes and reservoirs.
- Decreased fish yields caused by significant oxygen depletion in the water column and bottom water layers of lakes and reservoirs.

Figure 3: Chart listing several effects of nutrient-rich waters. Source: United Nations Environmental Programme

"High biomass blooms, whether of toxic or nontoxic species, can lead to very low oxygen levels in the water column (hypoxia), resulting in higher mortality rates in local fish, shellfish, invertebrate, and plant populations." With low oxygen levels, fish and plants have less oxygen than they need to survive. Furthermore, "the blooms may also affect benthic flora and fauna due to decreased light penetration. Toxic blooms from some cyanobacteria genera may lead to inhibition of other phytoplankton and suppression of zooplankton grazing, leading to reduced growth and reproductive rates and changes in community structure and composition."[11]

Fishing & Economy and Recreation

Cyanobacteria blooms not only cause issue with the organisms in a body of water, but also impact the way in which lakes themselves are used.

Many people make a living from fishing. Cyanobacteria blooms can greatly affect the fishermen's ability to catching fish. According to the EPA, "fishing and shellfish industries are hurt by harmful algal blooms that kill fish and contaminate shell fish. Annual losses to these industries from nutrient pollution are estimated to be in the tens of millions of dollars."[12] The loss of marine life (or healthy marine life) directly impacts the economic success of fishermen. This can cause issues especially in coastal cities and towns where fishing make up a large part of the local economy. According to the National Wildlife Federation, "In fish, toxins (e.g. microcystins) are taken up by the liver, and at sufficient exposures, can affect the liver function and cause liver damage. In some cases, fish kills have been associated with HABs."[13] HABS, or Harmful Algal Blooms, have the ability to not only kill aquatic wildlife, but also make living wildlife unsafe for human consumption. NOAA states that, "at present, HABs cause about $82 million in economic losses to the seafood, restaurant, and tourism industries each year. HABs reduce tourism, close beaches and shellfish beds, and decrease the catch from both recreational and commercial fisheries."[15]

Furthermore, the absence of aquatic wildlife also impacts some aboriginal communities, where fishing is not only a profession, but an important cultural tradition.

Recreation is also affected by cyanobacteria blooms. According to the EPA, "The tourism industry loses close to $1 billion each year, mostly through losses in fishing and boating activities, as a result of water bodies that have been affected by nutrient pollution and harmful algal blooms."[16] When cyanobacterial harmful algal blooms are present (CHABS), also known as harmful algal blooms (HABS), the ability of patrons to enjoy recreational activity is inhibited. Recreational water activities during CHABS are also the most common way in which harmful toxins from CHABS are ingested.

Why are CHABS Harmful?

There are several strains of cyanobacteria that contain harmful toxins that can negatively affect the not only the health of aquatic flora and fauna ecology, as discussed above, but that can also be potentially harmful to humans. In fact, there are many reported instances of cyanobacteria toxins in Australia, dating back to 1878. "To a lesser extent, toxins produced by some types of cyanobacteria can also be dangerous to health." There are well-documented reports of animal and human poisonings from drinking water contaminated with cyanobacteria"[17] There are, in fact, reported cases of CHABS negatively impacting not only animal health outside of the organisms that live in the lake, but also human health, "In humans, the toxins can cause nerve and liver damage, gastroenteritis, or skin and eye irritation. Long-term exposure to microcystin—the most common toxin in cyanobacterial blooms—may possibly promote tumour growth."[18] Below is a chart that depicts the most common types of toxins that are associated with different strains of cyanobacteria, and what they can do when introduced to the human body.

Cyanotoxins	Acute Health Effects in Humans	Most common cyanobacteria producing toxin
Microcystin-LR	Abdominal pain, Headache, Sore throat, Vomiting and nausea, Dry cough, Diarrhea, Blistering around the mouth, and Pneumonia	*Microcystis*, *Anabaena*, *Nodularia*, *Planktothrix*, *Fischerella*, *Nostoc*, *Oscillatoria*, and *Gloeotrichia*
Cylindrospermopsin	Fever, Headache, Vomiting, Bloody diarrhea	*Cylindrospermopsis raciborskii*, *Aphanizomenon flos-aquae*, *Aphanizomenon gracile*, *Aphanizomenon ovalisporum*, *Umezakia natans*, *Anabaena bergii*, *Anabaena lapponica*, *Anabaena planctonica*, *Lyngbya wollei*, *Rhaphidiopsis curvata*, and *Rhaphidiopsis mediterranea*
Anatoxin-a group	Tingling, burning, numbness, drowsiness, incoherent speech, salivation, respiratory paralysis leading to death*	*Chrysosporum (Aphanizomenon) ovalisporum*, *Cuspidothrix*, *Cylindrospermopsis*, *Cylindrospermum*, *Dolichospermum*, *Microcystis*, *Oscillatoria*, *Planktothrix*, *Phormidium*, *Anabaena flos-aquae*, *A. lemmermannii Raphidiopsis mediterranea* (strain of *Cylindrospermopsis raciborskii*), *Tychonema* and *Woronichinia*

* Symptoms observed in animals.

Figure 4: Potential health effects upon exposure to cyanotoxins. Source: Environmental Protection Agency

There are several different cyanotoxin exposure routes that can affect people. Inhalation or ingestion of water is one way, but people can also inhale certain types of cyanotoxins through the air: "Wind-driven currents may cause buoyant cyanobacterial blooms to amass on shorelines. These accumulations of cyanobacteria cells are much larger than blooms in open waters, thus presenting a greater risk to human and animal health."[19] Furthermore, people can also be exposed to cyanotoxins by eating seafood which has been exposed to cyanotoxins during bloom events, "People often get sick by eating shellfish containing toxins produced by these algae. Airborne HAB toxins may also cause breathing problems and, in some cases, trigger asthma attacks in susceptible individuals."[20]

Where is this Happening?

CHABS are happening all over the world, however we will focus here on the occurrences of CHABS in the United States. According to the National Wildlife Federation HABS have been seen across the United States, listing some examples;

Where Have Harmful Algal Blooms Happened?

- A major bloom of harmful algae in western **Lake Erie** in early August 2014 led to contamination of Toledo's water by a microcystin toxin, and the cutoff of drinking water supplies to nearly 500,000 people for two days.
- Numerous blooms in the **Chesapeake Bay region**, including nearly annual blooms in Maryland (with the first beach closure issued there in 2000).
- Large blooms in the **Lower St. John's River in Florida** (including in 2005 and 2013), leading to recreational water advisories.
- A harmful algal bloom in **Lake Pontchartrain, north of New Orleans,** leading to a recreational use advisory, following diversion of Mississippi River water in 1997.
- Blooms of Prymnesium parvum (or the "golden algae") responsible for numerous fish kills in **Texas waters** over the past 15 years.
- Blooms transported downstream to **Monterey Bay, California,** leading to sea otter deaths.

Figure 5: A list of locations that some harmful algal blooms have taken place in the United States. Source: National Wildlife Federation

<u>Case Study</u>

Harmful algal blooms are not a new phenomenon in Chesapeake Bay, "Cyanobacteria blooms have been causing problems in the Potomac River and other waterways at least since the 1930s"[21]

There have been many reported cases of HABS over the years, and their numbers only continue to grow. According to the University of Maryland's Center for Environmental Science,

> "The frequency of blooms of cyanobacteria in the tidal waters of the Chesapeake estuary has increased from about 13 per year in the 1990s to 23 in the 2000s. Cyanobacteria are the major causes of HABs in freshwater environments, a rapidly expanding global problem that threatens human and ecosystem health. It was cyanobacteria blooms in Lake Erie that last year required shutting down the water supply in Toledo, Ohio."[22]

The rate of HABs in the Chesapeake Bay have been growing, and are projected to continue growing as the population grows, and as more land is used for agriculture and other non-point sources of nutrient pollution grow exponentially.

Around the Chesapeake Bay, agriculture is a major contributing factor to the amount of nutrient pollution, which causes eutrophic waters and cyanobacteria blooms. Other causes include increased recreational activity, pollution, increases in agricultural and individual fertilizer use, and increased population density.[23]

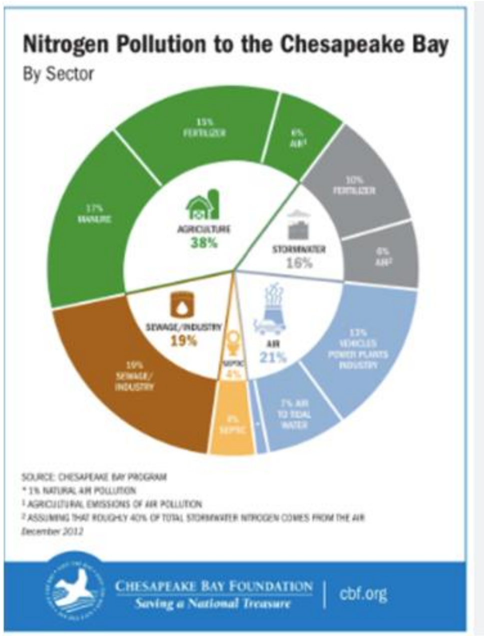

Figure 6: An infographic of sectors that contribute to Nitrogen pollution and their percentages. Source: Chesapeake Bay Foundation

There is a serious threat that harmful cyanobacteria may begin to affect the health of the Chesapeake Bay. In fact, the same strain of cyanobacteria that was found in Lake Eerie that caused Teledo's water supply to be shut off for two days is also found in Chesapeake Bay.[24]
Eutrophic waters rich with nutrients can also cause HABS that deplete dissolved oxygen levels. The Chesapeake Bay faced one of the lowest dissolved oxygen years in 2009, where hypoxic and anoxic areas of water, including dead zones, could be seen along the Bay.

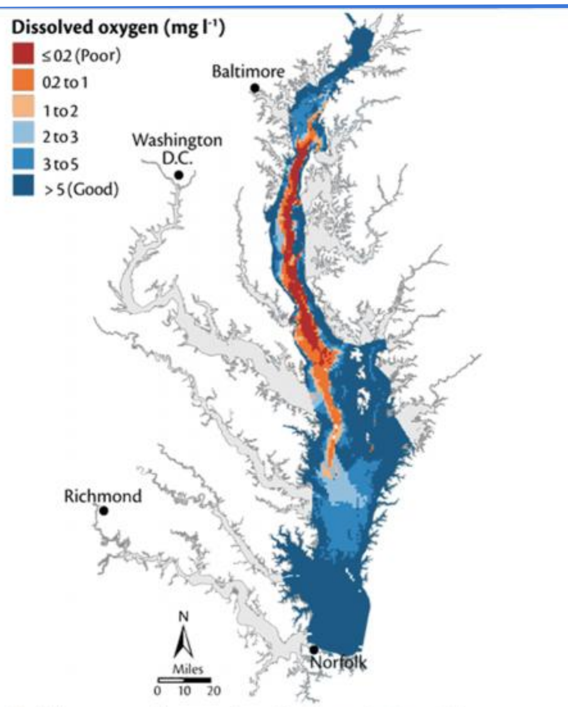

Figure 7: A map of the Chesapeake Bay depicting dissolved oxygen levels. Source: Integration and Application Network

In fact, in a recent study conducted between 2000 and 2006, it was found that 30% of waters with cyanobacteria blooms along Chesapeake were unsafe for children to swim in due to the amount of toxins found in the water.[25]

It is clear that cyanobacteria blooms are an issue worldwide; however, there are also those who are working to ensure that there are practical and accessible mitigation strategies in place to keep people, and the environment, safe.

Mitigation: Issues and Success

In the United States, there are already several mitigation strategies in place in the hopes of preventing or better understanding the cause and effect relationship of anthropogenic activity and HABS.

One such group is called the Harmful Algal Bloom and Hypoxia Research and Control Amendments Act (HABHRCA.) This groups purpose is to work with the United States Environmental Protection Agency and the National Oceanic and Atmospheric Administration to deepen their understanding of causes of HABS, create prevention and mitigation strategies, and conduct research on HABs and compile reports of their findings.[26]

One document that has been created by the National Science and Technology Council in the United States is the Harmful Algal Blooms and Hypoxia Comprehensive Research Plan and Action Strategy: An Interagency Report. In this report, several prevention strategies are discussed, which include better management strategies of nitrogen in order to prevent nutrient pollution.[27] They also discuss mitigation strategies, stating that the "EPA has developed models that predict chlorophyll *a*, or 'trophic state,' for nearly all lakes in the United States in order to determine pollution levels and the likelihood of cyanobacteria presence in inland waters" in order to better predict when a cyanobacteria bloom may occur before it happens.[28]

Another imitative includes Waters of the U.S Rule, which ensures the "adequate protection of additional wetlands to help reduce nutrient runoff into our rivers and lakes."[29] as well as the Great Lakes Restoration Initiative and U.S Farm Bill.[30]

Some other idea about mitigation include finding a way for excess nutrients to be removed from the water before it gives cyanobacteria a chance to grow rapidly enough to cause a bloom event. For example, "[i[f submersed plant beds were restored to historical levels of areal coverage (i.e. most areas <2 m mean depth, Kemp et al. 2004), they would remove almost 45% of the current N inputs to the upper Bay from watershed and atmospheric sources, with most of this attributable to particle trapping and direct assimilation. Even partial restoration of these plant beds would, thus, substantially help to mitigate effects of nutrient loading."[31]

There has also been some research put into the potential benefits of man-made wetlands in order to absorb excess nutrients, as well as vegetative buffers placed along farm boarders to stop and catch nutrient runoff.

There are many challenges to face when considering the prevention and mitigation of cyanobacteria blooms, however, the importance of clean and safe water is a cause worth fighting for.

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