CYANOBACTERIA (BLUE-GREEN ALGAE) IN THE FINGER LAKES, CENTRAL NY.

John D. Halfman
Department of Geoscience, Environmental Studies Program, Finger Lakes Institute
Hobart and William Smith Colleges
Geneva, NY 14456
Halfman@hws.edu

INTRODUCTION

The recent onset of cyanobacteria (blue-green algae) and their associated toxins (HABs) has heightened awareness about water quality issues in the Finger Lakes of central and western New York. Blooms were detected as early as 2012, and by 2017, all of the Finger Lakes reported HABs events, even the three ultraoligotrophic (very low productivity) lakes, Skaneateles, Canandaigua and Keuka. The largest cyanobacteria blooms are typically at shoreline locations, and occur during August and September, where and when lakeshore residents and tourists want to use the lake. Cyanobacteria have also been detected in the municipal raw water supplies for Auburn, Syracuse and Rushville that draw water from the Finger Lakes. Thus, cyanobacteria could stimulate an economic disaster for the predominantly rural region surround the Finger Lakes. Harmful algal blooms are not unique to the Finger Lakes. A few hundred lakes in New York State experienced cyanobacteria blooms each year, e.g., 184 lakes in 2020, out of the 7,849 lakes in the state (2020 Compilation by NYS-DEC). Cyanobacteria have infested many other lakes throughout the country including the Laurentian Great Lakes.

BACKGROUND

Cyanobacteria were some of the earliest forms of recognizable life, and the first photosynthesizing organisms, on the planet. They were responsible for adding oxygen (O_2) to the Earth's oxygen-free atmosphere approximately 3 billion years ago. Unlike algae, cyanobacteria contain gas vacuoles in their cellular tissues that enable them to regulate water column buoyancy. They occasionally float to gain superior access to sunlight in productive aquatic environments. Thus, cyanobacteria typically form unsightly surface scums that can accumulate along shorelines into rotten, smelly, goos of organic matter. They may also produce a variety of toxins that are health threats to humans and other warm-blooded animals (e.g., dogs). The toxin story is complicated. Not all cyanobacteria taxa synthesize toxins. Cyanobacteria taxa that synthesize toxins do not do it all the time. The environmental triggers that induce toxin production are poorly understood. To complicate the situation, different toxins are synthesized by different cyanobacteria taxa, and each toxin, in sufficient concentrations, can impact different parts of the body, e.g., the skin, liver, gastrointestinal and/or nervous systems.

This article focuses on the data from my ongoing, multi-decade, water quality (WQ) monitoring program of the eight eastern Finger Lakes and other research projects that are pertinent to the development, occurrence, and proliferation of cyanobacteria in the Finger Lakes (Halfman, 2017, Halfman et al., 2021). The monitoring program collected water quality / limnological data from at least two deep water sites in each lake on a monthly basis from May through September, since 2005. Monitoring in Seneca Lake started in 1994, and occurs on a weekly monitoring surveying 4 sites. At each site, a Secchi disk depth, plankton tow, CTD profile (temperature, conductivity, dissolved oxygen, pH, fluorescence, and turbidity), and surface and bottom water samples were collected, and the water analyzed for nutrients (TP, SRP, NO_x, SiO_2), chlorophyll, and total suspended solid concentrations in the lab. More recently, weather stations, WQ sondes, and automated cameras collected nearshore meteorological, water quality and bloom occurrence data at a number of shoreline sites around Seneca and Owasco Lakes.

Plankton enumerations indicated that cyanobacteria have always been in the planktonic community in the Finger Lakes. The mean annual percentage of cyanobacteria compared to diatoms, green algae, dinoflagellates, and other taxa, enumerated from plankton tow samples have ranged from a few to just over 40% (Halfman, 2017). They were even in the plankton community in the earliest limnological surveys of some Finger Lakes by Birde and Juday in the mid-1900's. Yet, something recently changed in these lakes so that they could proliferate in nearshore regions in the past decade.

The long-term monitoring program revealed the occasional excursion in total phosphorus, soluble reactive phosphate and total suspended sediment concentrations by an orders of magnitude above mean annual concentrations in the open lake (Halfman, 2017, Halfman et al., 2021). These excursions typically followed a very brief but very intense, super-cell, thunderstorm that drop over 5 inches of rain within a day onto a small localized portion of a watershed, super-storms associated with global warming. When these events happened, they typically coincided with, provided a slug of nutrients for, and individual lakes perhaps surpassed the tipping point for the initial blooms in the lake. These events are too infrequent to support every bloom, however. What does? The following focuses on the preferred conditions for cyanobacteria.

CYANOBACTERIA PREFERENCES

Cyanobacteria prefer the following water quality conditions:

- warm water, temperatures between 15 to 30°C (60 and 80°F);
- light levels that are sufficient for photosynthesis and growth;
- lake stratification, as cyanobacteria buoyancy regulation provides a competitive edge in a warm, stratified water column;
- calm or near-calm conditions as turbulence disrupts cyanobacteria buoyancy;
- rainfall, as rain events deliver nutrients to the lake; and,
- elevated (eutrophic) concentrations of nutrients, especially waters rich in phosphorus, the limiting nutrient for many cyanobacteria;

Warm Water: Surface water temperatures measured since 1995 in Seneca Lake indicate a warming trend over the past two$^+$ decades (Fig. 1). Maximum water temperatures detected in 2020 were the warmest in this dataset. The linear, best-fit line to the data suggests that the lake has warmed approximately 0.2°C/year, a result of Global Warming. The warming was not uniform but instead occurred in a step function with a few years occasionally deviating above and below the linear warming trend. Of interest here, water temperatures over the past five years were some of the warmest detected over the past two$^+$ decades, a timing coincident with cyanobacteria blooms. A similar warming trend that parallels bloom events was detected in Owasco and neighboring Finger Lakes. See my most recent annual HABs research report for more information (Halfman et al., 2021). Additional papers, reports and data are available on my web site (http://people.hws.edu/halfman/).

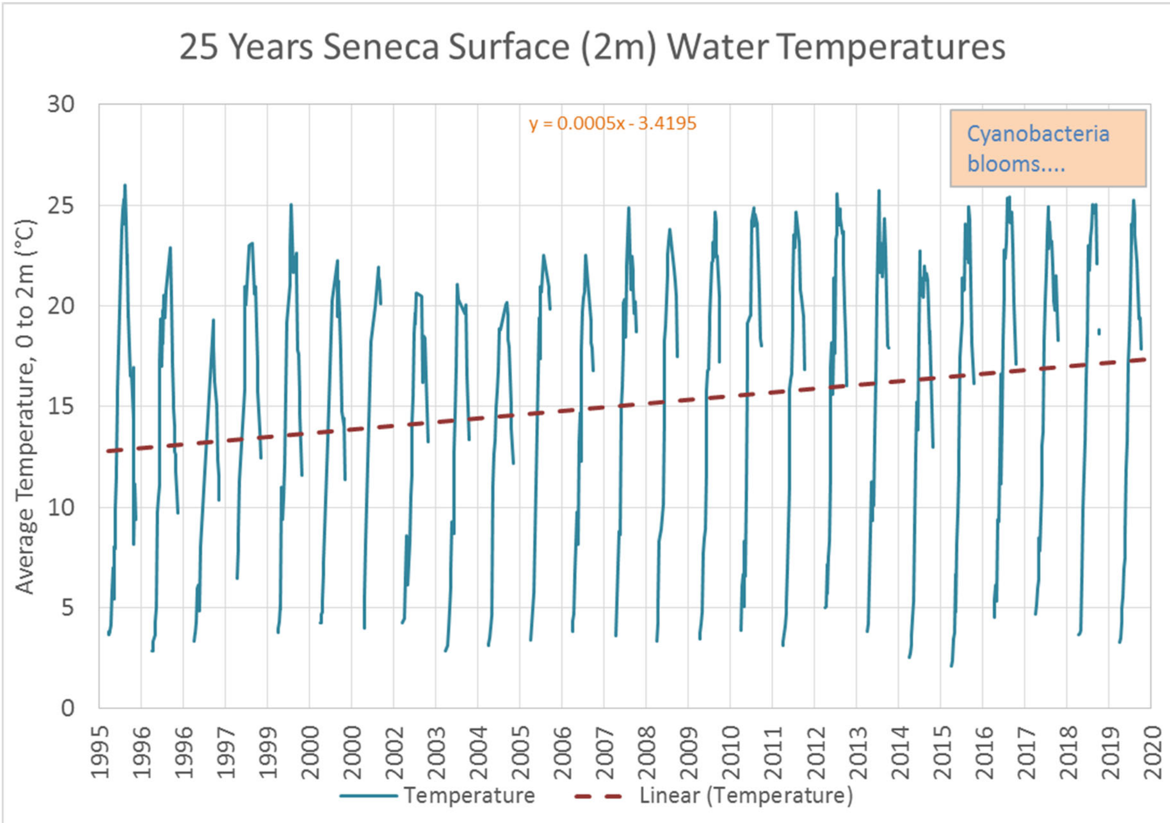

Fig. 1. Surface water (< 2-m) temperatures from Seneca Lake and years with reported cyanobacteria blooms.

However, detailed surface-water temperatures recorded by loggers at shoreline locations and a mid-lake WQ monitoring buoy revealed that blooms occurred after the warmest temperatures of the summer and into the early fall (Fig. 2). In fact, they typically occurred after a multi-day, few °C, dip in water temperature. It suggests that warmer temperatures by themselves were not the sole reason for cyanobacterial blooms. Warmer temperatures do promote increased biological respiration of dead organic matter, and increased nutrient recycling. Perhaps HABs events must wait for the accumulation and subsequent release of sufficient nutrients, and thus blooms are delayed until after the warmest part of the summer season. The dip in water temperature is probably due to mixing of colder hypolimnetic (bottom) water into the warmer epilimnetic (surface) water by strong winds and their associated waves and/or an occasional rain event. Perhaps the wave-induced turbulence released nutrients from the nearshore sediments to help stimulate bloom development.

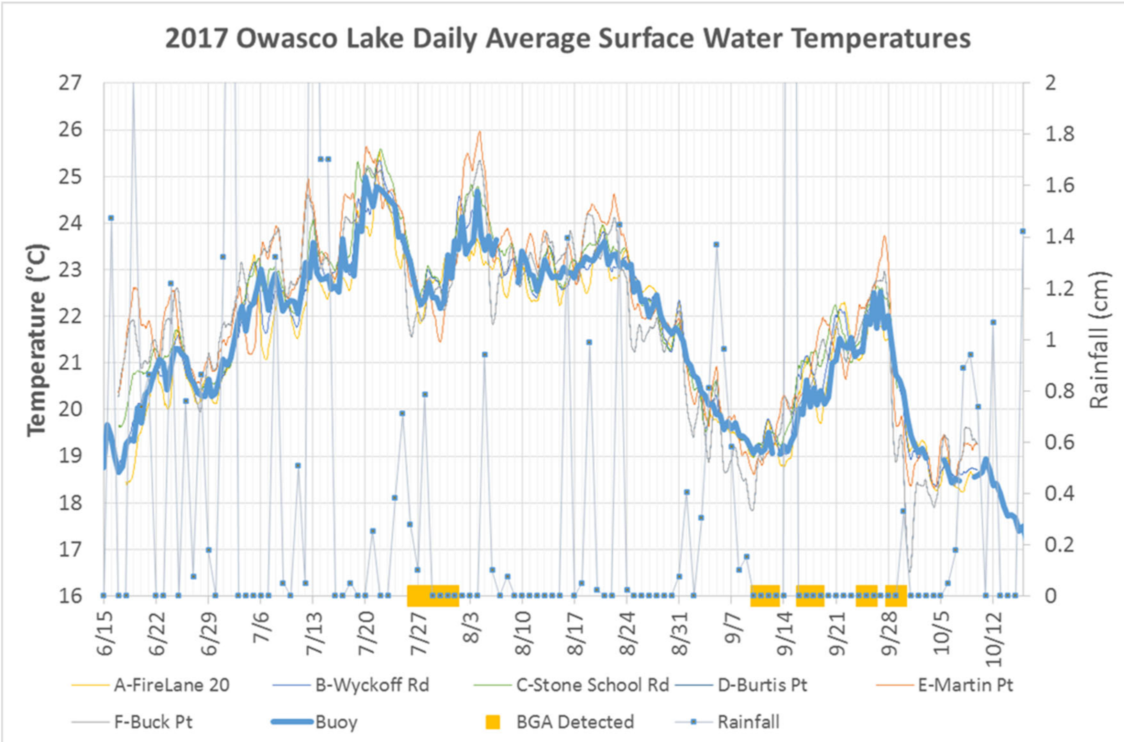

Fig. 2. 2017 Surface water (< 2-m) temperatures from six nearshore sites and an offshore WQ buoy at Owasco Lake. Dates with reported cyanobacteria blooms (orange squares) appear to follow decreases in surface water temperatures.

Sunny Skies and Calm Conditions: Sunny skies and calm weather frequent the Finger Lakes in the summer, even during the late summer (Fig. 3). However, blooms were not detected on every sunny and calm day, and when blooms were detected at one shoreline, they were not detected everywhere else. Wind speed and direction provide some control over the bloom temporal and spatial variability. For example, the 2019 and 2020 meteorological data from Owasco Lake indicate that average wind speed over the bloom season decreased from 9 mph at the offshore buoy to 1.9 to 4.3 mph at the shoreline sites in 2019 and 2020. The shoreline configuration is key as it only allows winds to impact downwind (exposed) shorelines. The result, the shoreline sites experienced significantly calmer (<1.5 mph) conditions, from 3 to 4% of the time at the offshore buoy compared to 40 to 60% of the time along the shoreline. Wind rose diagrams revealed radically different dominate wind directions at the shoreline sites as well, ranging from northerly, westerly to southerly directions, compared to southerly winds at the offshore buoy site. Thus, one shoreline might experience onshore winds, waves and turbulence and no surface blooms, whereas wind-free shorelines experienced favorable conditions. But even with sunny and calm conditions, these suitable shorelines may not experience a bloom.

Automated cameras photographed the lake surface every 10-minutes during the daylight hours and indicated that cyanobacteria are indeed fickle, and do not bloom every day when the shoreline experienced favorable conditions. The photo logs also indicate that number of days with bloom events were not consistent from one site to the next, ranging from no blooms to 17 days with blooms. Blooms lasted from 20 minutes to 9 hours, averaged 2 to 3 hours, and were detected anytime during the daylight hours, peaking during the early afternoon. Finally, blooms, once formed, can be transported by longshore currents.

Fig. 3. An aerial photo of Owasco Lake looking south, September, 2019, taken by a sUAV. It looks sunny and calm to me.

Nutrients: The availability of nutrients must play an important role in the bloom equation. Cyanobacteria blooms typically occur in lakes with elevated (eutrophic) concentrations of nutrients, especially waters rich in phosphorus, the limiting nutrient for most lakes. However, Skaneateles, Canandaigua and Keuka Lakes are ultraoligotrophic, i.e., very nutrient poor systems, and all three lakes have experienced cyanobacteria blooms. Cayuga, Seneca, Owasco, & Otisco are oligotrophic to borderline oligotrophic/mesotrophic systems. Only Honeoye Lake is eutrophic in the eight-lake survey. Owasco Lake provides an ideal example. Total phosphorus (TP) concentrations rarely exceed 20 ppm in the water column, the minimum concentration for eutrophic systems. TP in nearshore waters were also below 20 ppm, even shoreline locations where blooms were frequent. More importantly, these phosphorus concentrations are two or more orders of magnitude smaller that the amount of phosphorus within the biomass of an average cyanobacteria bloom. The water column lacks sufficient nutrients.

Sediment organic matter and macrophytes (rooted plants) are the next obvious nutrient sources to support cyanobacteria blooms. To test this, mud samples were collected from different water depths and placed in a flask with filtered lake water. The mud/water mixture was swirled simulating a mixing event by waves, and then placed on a sunlit window sill in the lab. All eight flasks experienced blooms within the next week or so. Thus, the sediments must contain sufficient nutrients and cyanobacteria resting stage cells to support bloom development. The zebra and quagga mussels provide an effective pathway to increase "nutrients" in the nearshore sediments through their "nearshore shunt". Biomass is transported from the open water to the nearshore zone as mussels filter feed on algae (open water nutrients) and deposit (poop) organic-rich debris in the nearshore muds. Finally, the locations that typically experience the most blooms have the most extensive shallow-water shelves, and by extrapolation, the most nearshore biomass.

Macrophytes utilize the nutrients in shallow-water sediments. Once the macrophytes die, waves typically concentrate the rotting plant matter along the downwind shoreline. The rotting biomass could be the source of nutrients for blooms. It is consistent with the delay in the bloom season to the end of the summer and their location, because the cyanobacteria were waiting on the decay of nearshore organics, and also the dominance of blooms along the downwind shoreline. In support, macrophytes were unfortunately (fortunately?) trapped inside the PVC deployment tube for a WQ sonde, and blocked the flow of water. In a few days, the dissolved oxygen concentration declined to anoxia inside the pipe, indicating extensive and isolated respiration of the plant matter. Cyanobacteria concentrations rapidly increased inside the pipe as well over the subsequent week or so, suggesting the blooms utilized the nutrients released by the respiration of the plant matter. Photos of blooms along the shoreline taken by bloom watch volunteers frequently revealed rotting macrophytes along the beach. Finally, once each cyanobacteria bloom dies, the biomass provides the resting cells and a source of nutrients for the next bloom. Thus, once a shoreline experiences a bloom, it will probably experience more blooms. Research in the coming years will instigate the nearshore abundance of macrophytes, mussels and the organics in the sediments.

A Final Unsettling Thought

Cyanobacteria concentrations in offshore, surface water samples have increased over time (Fig. 4). Have cyanobacteria learned to outcompete other algae in the nutrient poor surface waters away from the shoreline? Will these high concentrations persist across the entire lake's surface in the years to come? Alternatively, did stronger winds in 2020, compared to earlier years, transport more cyanobacteria from the shoreline to the open water? Hopefully the data from 2021 will shed more light on this issue.

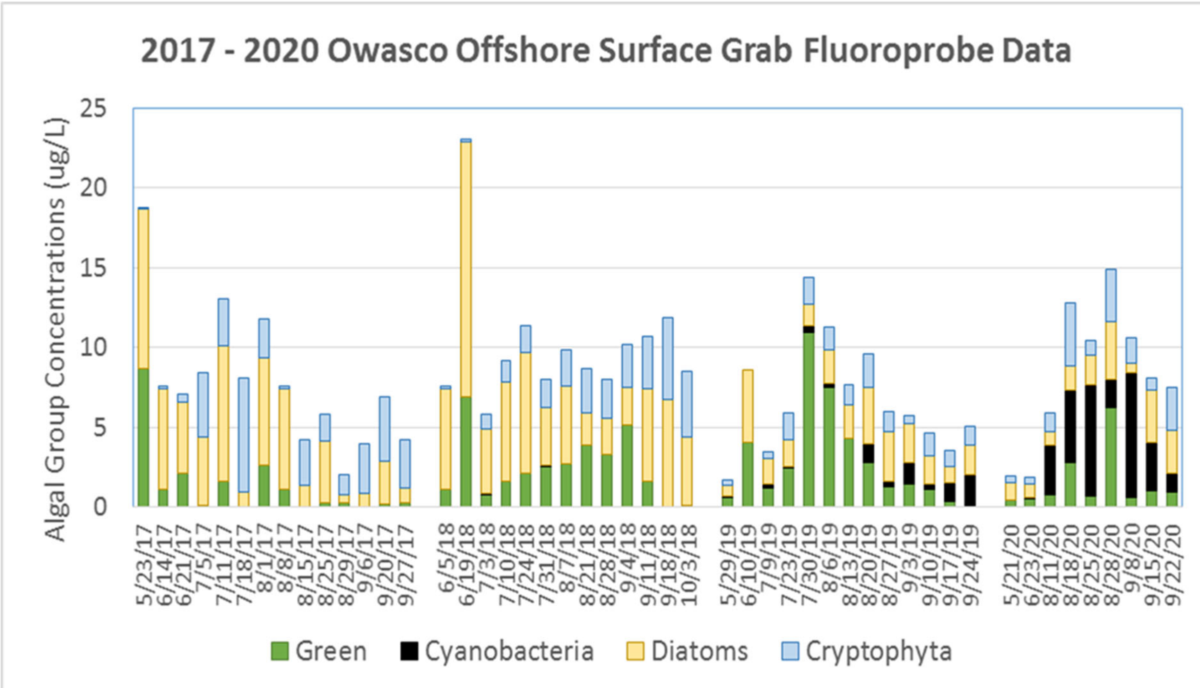

Fig. 4. Mean concentrations of the three major algal groups (diatoms in orange, greens in green, and crypotophytes in blue) and cyanobacteria (in black) in surface grab samples by survey date in Owasco Lake as detected by bbe FluoroProbe.

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REFERENCES

2020 HABs Archives Summary for 2020, (2020). Compiled by New York State Department of Environmental Conservation.

Halfman, J. D., 2017. Decade-scale water quality variability in the eastern Finger Lakes, New York. Clear Waters. Fall 2017, v. 47, No. 3, pg. 20-32.

Halfman, J. D., A. Shaw, I. Dumitriu & L.B. Cleckner, 2021. The 2021 Water Quality Monitoring Report, Owasco Lake, NY. Finger Lakes Institute, Hobart and William Smith Colleges. 48 pg.

Halfman, J. D., S. Stone, I. Dumitriu & L.B. Cleckner, 2021. 2020 Nearshore monitoring of Cyanobacteria (Blue-Green Algae) in Seneca and Owasco Lakes. Finger Lakes Institute, Hobart and William Smith Colleges. 62 pg.

For more information see: http://people.hws.edu/halfman/ or email: halfman@hws.edu