2020 NEARSHORE MONITORING OF CYANOBACTERIA (BLUE-GREEN ALGAE) IN SENECA & OWASCO LAKES.

THE 2020 FLI REPORT TO THE SENECA LAKE PURE WATERS ASSOCIATION, FRED L. EMERSON FOUNDATION AND CAYUGA COUNTY

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INTRODUCTION

The recent onset of cyanobacteria (aka blue-green algae, BGA) blooms and their associated toxins (HABs) has heightened awareness about water quality issues in Seneca, Owasco and neighboring Finger Lakes. In 2016, cyanobacteria toxins were detected in the Auburn and Owasco municipal drinking water supplies that draw water from Owasco Lake. Since then, toxins were also detected in the City of Syracuse's municipal water intake that draws water from Skaneateles Lake in 2017, and in Rushville's municipal drinking water that draws water from Canandaigua Lake in 2018. The largest measured cyanobacteria concentrations in the Finger Lakes are typically at shoreline locations, where lakeshore residents want to use the lake. By 2017, all of the Finger Lakes reported HABs events, even the three oligotrophic (low productivity) lakes, Skaneateles, Canandaigua and Keuka. Seneca & Owasco Lakes are no exception and both have been listed on the New York State Department of Environmental Conservation's (DEC) HABs website with documented BGA blooms, most with high toxin concentrations. Blooms were first reported in Owasco Lake in 2012 and in Seneca Lake in 2015 with the majority of these events localized along the shoreline. These events stimulated concerned citizens in each watershed to form HABs volunteer monitoring groups under the guidance and training of DEC staff.

Seneca Lake Pure Waters Association (SLPWA) and Owasco Watershed Lake Association (OWLA) have spearheaded volunteer HABs monitoring efforts in the Finger Lakes region. They have also advanced methods to report HABs events to the local community. With exceptional leadership, SLPWA's program has grown quickly, and now over 100 HABs volunteers surveying approximately 100 km of the 130 km long shoreline, and enter HABs detection reports and photos electronically using cell phones or tablets. HABs locations and photos are pinpointed on a google earth map. The mapping app has been adopted by New York State DEC, and it forms the backbone of the State's NYHABs statewide monitoring/mapping system. A critical result of these and neighboring monitoring programs is that cyanobacteria blooms are concentrated along the shoreline, and are sporadic in both space and time during the late August through early October HABs season.

This report details our 2020 findings from the Seneca and Owasco Lake dockside monitoring programs (Fig. 1). All of the data were combined into one report to provide an interesting comparison. It follows up on promising research by Halfman and his collaborators on both lakes[1], which documented a number of key findings:

- Cyanobacteria blooms were sporadic in both space and time.
- Sufficient nutrients were lacking in the offshore and, more importantly, the nearshore water column to support the observed bloom concentrations.
- We hypothesized that HABs form along the shoreline after an onshore wind or rain events during the subsequent calm and sunny day.
- Shoreline features influenced nearshore wind speeds and directions enough to dictate where and/or when shoreline blooms develop.

These projects were designed to investigate four questions:

- What are potential meteorological and limnological triggers for a bloom event?
- Why are bloom events variable in both space and time?
- What is the source of nutrients for the shoreline blooms?
- Most importantly, are the hypothesized cyanobacteria triggers common to both Seneca and Owasco Lakes?

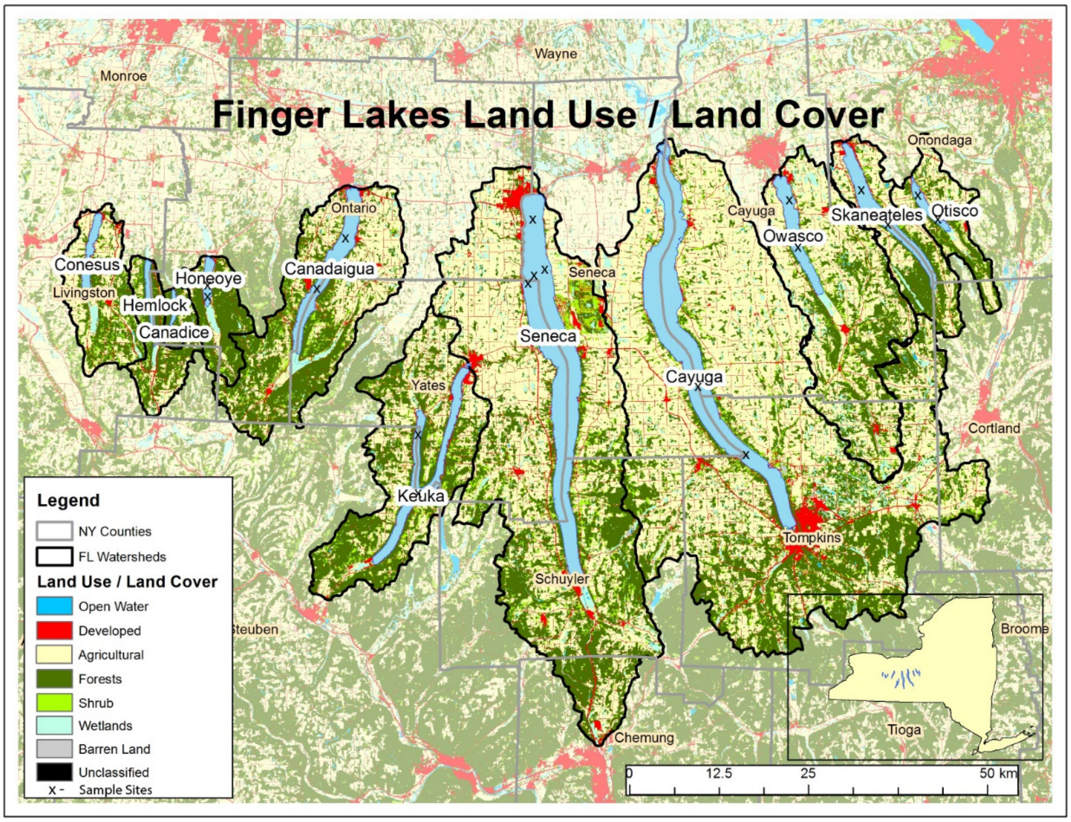

Fig. 1. Land Use / Land Cover (NDLC 2011 data) map of the Finger Lakes Watersheds. Seneca & Owasco Lakes are the focus of this report.

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[1] Halfman, J.D., et al., 2020. Dockside monitoring of Blue-Green Algae in Seneca Lake. The 2019 FLI report to the Seneca Lake Pure Waters Association. Finger Lakes Institute, Hobart and William Smith Colleges. 40 pg. Halfman, J.D., et al., 2020. Blue-Green Algae in Owasco Lake, the 2019 Update. The 2019 Annual Report to the Fred L. Emerson Foundation. Finger Lakes Institute, Hobart and William Smith Colleges. 38 pg.

EXECUTIVE SUMMARY

COVID Issues:

- We were able to collect the majority of the proposed data in 2020 including offshore water quality monitoring, deployment of WQ buoy, and deployment of the dock equipment to detected water temperatures, lake surface images and meteorological conditions at a number of docks around both Seneca and Owasco Lakes despite COVID issues.
- COVID issues hampered collection the macrophyte and mussel assays, and sediment nutrient flux studies as proposed for Owasco Lake because we were not allowed to hire students for in-person research. We plan to collect this data in the future.

2020 Research Highlights:

- Much fewer cyanobacteria blooms were detected in Seneca Lake (15) than Owasco Lake (115) in 2020. This discrepancy and differences from past years mandated a single report to compare and contrast the data collected from both lakes to discern potential reasons for the bloom count variability.
- Water quality data from both lakes revealed borderline oligotrophic-mesotrophic systems, previously thought unable to support cyanobacteria blooms. Minimal differences in the offshore limnology were detected that could explain the variance in bloom counts in these two lakes.
- The offshore plankton communities in Owasco Lake had significantly more cyanobacteria than Seneca Lake in 2020, perhaps reflecting the longer length of time cyanobacteria were in Owasco Lake and/or the slightly more productive state in Owasco Lake, sufficient winds that mixed nearshore blooms offshore, and/or sufficient nutrient sources.
- The FLI buoy on Owasco Lake and the USGS buoy on Seneca Lake (the FLI buoy was inoperative in 2020) recorded suitable water temperatures, air temperatures and light intensities for blooms development. Algal blooms in the open water were not coincident with shoreline blooms.
- Water temperatures were the warmest in 2020 than any previous year on record. Warmer water was detected almost every year when cyanobacteria were detected in each lake.
- Faster winds were detected by the buoys in 2020 than 2019 during the HABs season, especially at Seneca Lake. Persistently faster winds in Seneca Lake may have reduced the bloom count; whereas a dip in wind speeds and a smaller number of wind events during the second half of September probably promoted bloom development in Owasco Lake.
- Nearshore and offshore surface water temperature across Seneca and Owasco Lakes occasionally decreased just before cyanobacteria blooms. The declines suggest that wind and/or storm events and their associated waves, that likely caused the surface water temperature decrease, also disturbed the nearshore sediments, and released nutrients to stimulate nearshore cyanobacteria blooms. The actual bloom typically (but not always) occurred on the next sunny and calm day.
- The dock site automated cameras detected cyanobacteria blooms. The cameras detected blooms missed by local HABs volunteers; and conversely, the volunteers detected blooms missed by the cameras limited field of view. Moving the cameras closer to shore in 2020 detected the blooms within 1-m of the shoreline that were missed in 2019.

- Imaged cyanobacteria blooms were most frequent during the mid-day hours and they typically lasted a few hours. The blooms duration ranged from less than an hour up to 9 hours in a day, and variable from site to site.
- Nearshore wind speeds decreased and wind directions were different between nearshore areas, and between the nearshore areas and the mid-lake buoy. The shoreline orientation consistently impacted the regional winds, and because each shoreline orientation is unique, each site experienced unique wind fields. Variability in winds along the shoreline suggests that one shoreline can experience calm conditions and a cyanobacteria bloom, whereas neighboring shorelines with different orientations may experience sufficient winds to retard bloom development at the lake's surface, and along with nutrient availability, provides a potential reason why surface blooms are localized in time and space.
- The dry weather and associated decrease in nutrient loads from the watershed may have contributed to the 2020 low bloom counts in Seneca Lake. However, similar dry conditions around Owasco Lake did not decrease bloom counts in Owasco Lake. Perhaps the larger watershed to lake surface area stemmed the nutrient loading decline in Owasco Lake. Alternatively, nutrients delivered by streams have a smaller impact on bloom genesis than previous thought.
- Water quality (WQ) sondes deployed in Owasco Lake detected daily oscillations in dissolved oxygen (DO) concentrations. Photosynthesis increased DO during the day and respiration decreased DO at night. It highlights the importance of biological activity in the nearshore areas, even shorelines with rocky lake floors.
- The WQ sondes also revealed hour long episodes of elevated total and cyanobacteria-PC fluorescence during periods of turbid water. It suggests that waves dislodged benthic algae during onshore wind events, and highlights the importance of nearshore biological activity, even along rocky shorelines. The sondes missed surface hugging cyanobacteria blooms.
- Plants clogged the sonde's deployment PVC pipe at Martin S. As a consequence, the salinity and cyanobacteria-PC fluorescence increased, and dissolved oxygen decreased inside the pipe. It highlighted the importance of organic debris, e.g., macrophytes and *Cladophora*, to provide nutrients through bacterial respiration for subsequent nearshore cyanobacteria blooms.
- Compared to other Finger Lakes tested in 2020 including Cayuga, Seneca, Canandaigua, and Honeoye, mesocosm experiments revealed that Owasco Lake was the only lake to show serial phosphorus limitation. We plan to continue our mesocosm experiments in 2021 and hope to analyze the phytoplankton community for DNA using 16S community analysis to further understand the phytoplankton community composition and associated bacteria.

ACKNOWLEDGEMENTS

The 2020 research was supported by the Fred L. Emerson Foundation, Cayuga County Legislature, Finger Lakes – Lake Ontario Watershed Protection Alliance for the work on Owasco Lake, and Seneca Lake Pure Watershed Association for the work on Seneca Lake. Initial support to purchase the dock equipment deployed at Seneca Lake originated from the Tripp Foundation. We thank members of the Owasco Watershed Lake Association and Seneca Lake Pure Waters Association, specifically the homeowners for access to their docks: Brian, Barbara, Ed, and Jim on Owasco Lake, and Grant, Frank, Mary, Rick, Dick, Maura, Terri, and especially Bill on Seneca Lake. We're very grateful to Bill for pushing this project from an idea to a reality. Thanks are also extended to members of the Cayuga County Planning Department, Cayuga County Water Quality Management Agency, Owasco Watershed Lake Management Council, Cayuga County Health Department, Owasco Watershed Lake Association, the Cayuga County Soil and Water District, the Institute for the Application of Geospatial Data and NYS Department of Environmental Conservation for their help over the past few decades of effort.

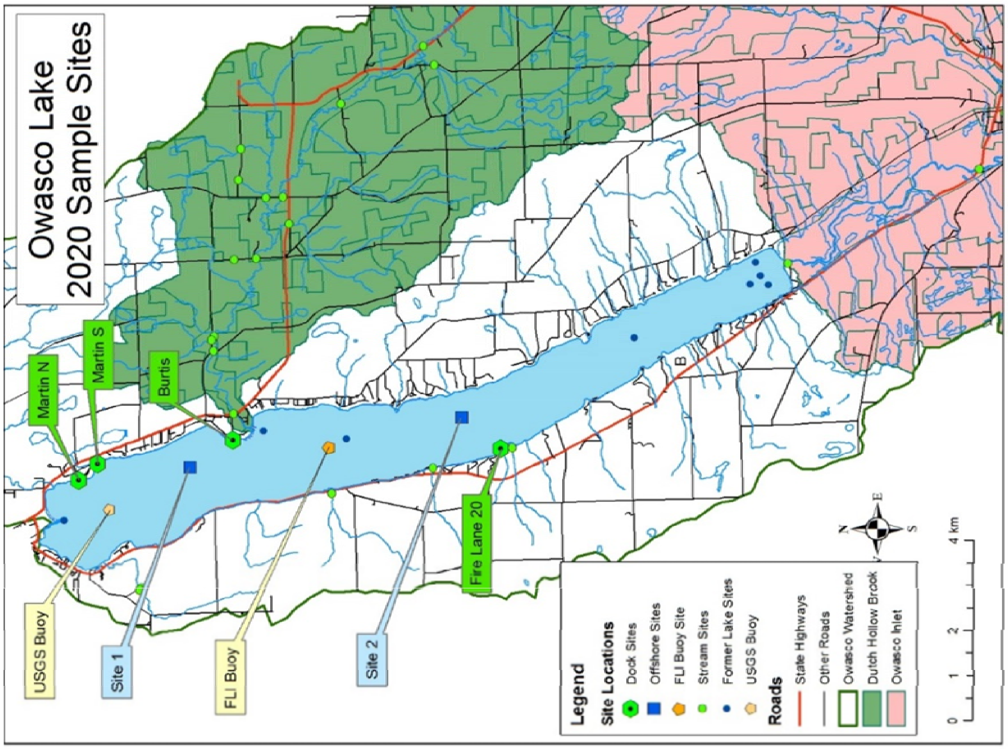
METHODS

Nearshore Data: This project monitored the meteorological and limnological conditions at eight dock sites distributed around Seneca Lake and four docks around Owasco Lake. The sites utilized homeowners who already were SLPWA and OWLA HABs volunteers and were willing to host the dockside instrumentation (Fig. 2). The Seneca sites duplicated six of the eight sites surveyed in 2019 (NE Adams, SEC Toole, NW Roege, NWC Downs, SWC DiOrio, and SW Rose), moved the NEC site slightly farther south (NES Bloss), and moved the SE site to the northern side of Kashong Point (NNW Allen). The Owasco sites duplicated the two used in 2019, Martin and Burtis Points, and added two more sites, the south side of Martin Point and the end of Fire Lane 20 on the west side of the lake.

At each site, a weather station, an automated camera, and two water temperature loggers were deployed to detect and elucidate occurrences of nearshore cyanobacteria blooms, and precursor water quality and weather information for each bloom (Fig. 3). A water quality sonde was also deployed at the four Owasco locations. The weather station (Ambient 1002-WS or WS-2000 Osprey, the discontinued 1002-WS replacement) recorded air temperature, rainfall, barometric pressure, humidity, light intensity, wind speed and direction every 30 minutes to an SD card. A Brinno TLC-200 automated camera, deployed on the weather station pole approximately 3 m above the lake's surface, recorded daily images of the lake's surface every 10 minutes from dawn to dusk (7 am to 6 pm) on an SD card in a movie format (*.avi). Each day was saved in a separate file, and used to log clear vs turbid water conditions, and the presence of obvious cyanobacteria blooms. The camera's 60° field of view imaged a 2x3 to 3.5x5 meter area of the lake's surface depending on the exact deployment height. A *HOBO* TidBit MX or *HOBO* U20L-04 data logger was placed inside a 2" PVC pipe and the assembly was strapped to a dock post at each site in ~1-m of water to record water temperature every 30 minutes. PVC pipes protected the loggers from wave action. Another TidBit was attached to a surface float to record surface water temperatures every 30 minutes. An *In-Situ* Aqua Troll 600 water quality sondes with temperature, conductivity, total chlorophyll and cyanobacteria phycocyanin sensors was deployed at each dock on Owasco Lake except one (Fire Lane -20 Site) where a *YSI/Xylem* EXO2 water quality sonde with temperature, conductivity, dissolved oxygen, turbidity, and total chlorophyll and cyanobacteria phycocyanin fluorescence was deployed instead. The sondes were deployed inside 4" diameter PVC pipes for their protection. Each deployment pipe had numerous holes for continuous water flow.

The instrumentation was deployed around Seneca Lake on 7/8 and recovered on 10/10, and deployed around Owasco Lake on 7/7 and recovered on 10/14, timeframes anticipated to span the HABs season. The equipment was deployed slightly later, on 7/22, at the Allen (NNW) site on Seneca Lake while we determined the best location to deploy the equipment. The Fire Lane 20 site on Owasco Lake had a slightly earlier recovery, 9/19, to interface with the local homeowner's wishes. Its water quality sonde was deployed slightly later, on 8/14, as well.

In addition, each site was visited every two to three weeks to replace the camera batteries (if necessary), and swap the camera's SD memory card for image analysis in the laboratory.



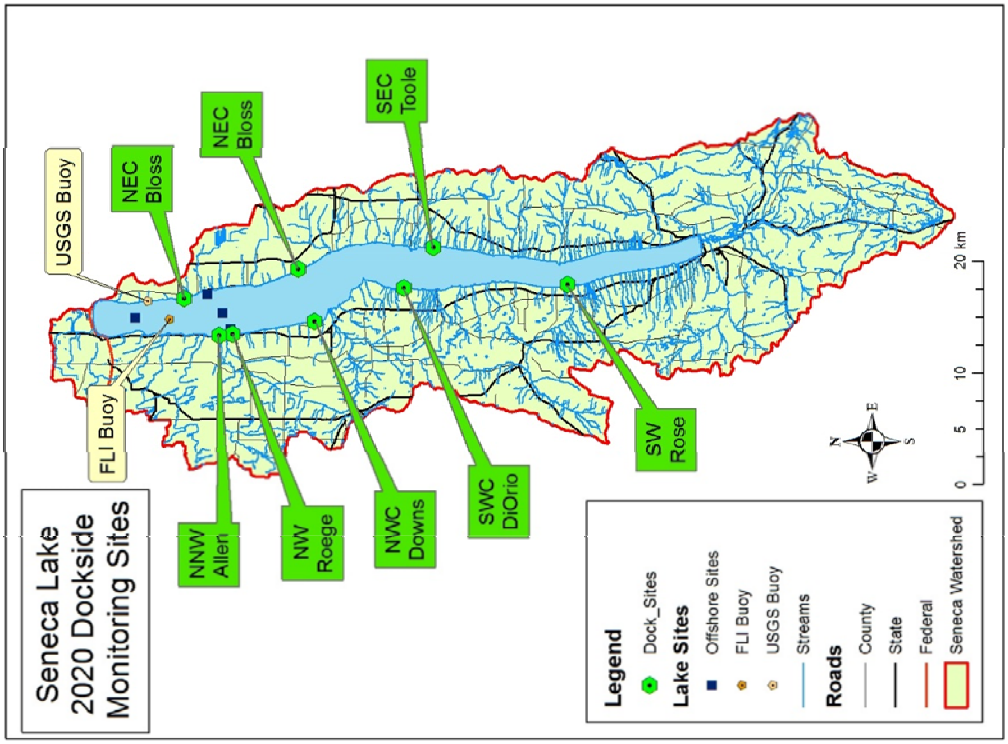


Fig. 2. The 2020 dock and offshore site locations in Owasco (above) and Seneca (below) Lakes.

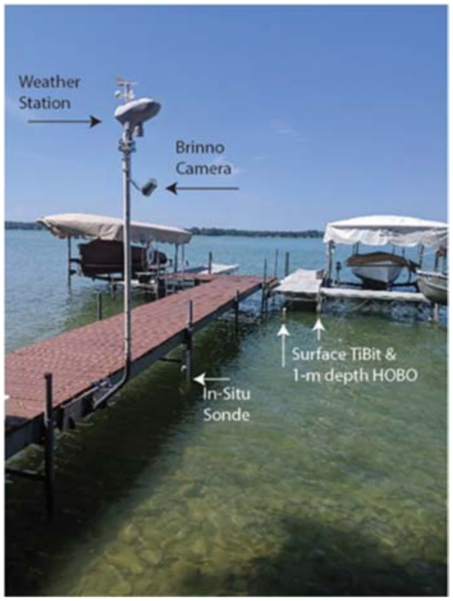


Fig. 3. Weather station, Brinno camera and logger/sonde deployments at a dock (right). The *In-Situ sondes* and a temperature logger (*HOBOs*) were placed inside separate PVC pipes and strapped to a dock leg. A second temperature sensor (*HOBOs*) was attached to a surface float. The pipes protected the instrumentation from waves.

Offshore Data: Weekly offshore water quality monitoring data from Seneca and Owasco Lakes and daily data from the FLI monitoring buoy were used to place the nearshore data in perspective. The offshore monitoring sampled four sites in the northern portion of Seneca Lake and two sites in Owasco Lake (Fig. 2). At each site, a CTD water quality profile, Secchi disk depth, vertical plankton tow (80-μm mesh), and surface and bottom water samples were collected. The CTD electronically measures water column profiles of temperature (°C), conductivity (reported as specific conductance, μS/cm, a measurement proportional to salinity), dissolved oxygen (mg/L), pH, turbidity (NTUs), photosynthetic active radiation intensities (PAR, μE/cm^2-s), and fluorescence (a measure of chlorophyll-a, μg/L) using a SeaBird SBE-25 CTD. The CTD was lowered from the surface to the lake floor, collecting data every 0.5 second (~0.1 meters) along the downcast. Phytoplankton was collected using an 80 µm mesh net integrating the algae through a depth of ~20 m. The net contents were preserved in a 6-3-1 water-alcohol-formalin solution and enumerated to species when possible otherwise to genus level back in the laboratory under a microscope.

Water samples were analyzed onsite for temperature (°C), conductivity (specific conductance, μS/cm) and alkalinity (mg/L, CaCO$_3$) using hand-held probes and field titration kits, and analyzed back in the laboratory for total phosphate (TP, μg/L, P), soluble reactive phosphate (SRP, μg/L, P), nitrate (NOx, mg/L, N), chlorophyll-a (μg/L) and total suspended solid (TSS, mg/L) concentrations using standard limnological spectrophotometric techniques. Rather than collecting bbe FluoroProbe profiles in the field as performed in earlier years, surface and bottom water grab samples were analyzed by FluoroProbe in the lab to determine the relative concentrations of: 'green' algae (Chlorophyta and Euglenophyta), 'brown' algae (diatoms: Baccillariophyta, Chyrsophyta, and Dinophyta), 'blue-green' algae (Cyanophyta), and 'red' algae (Cryptophyta).

FLI Monitoring Buoy: The FLI meteorological and water quality monitoring buoy manufactured by YSI/Xylem was redeployed at its mid-lake site in Owasco Lake from 5/22 through 10/24 (Fig. 2). COVID issues delayed its normal April deployment. The buoy was again programmed to collect water column profiles with an *YSI/Xylem* EXO2 water quality sonde every 12 hours (noon and midnight). The sonde detected temperature, conductivity, dissolved oxygen (by optical sensor), turbidity (by backscattering), and fluorescence. The fluorescence sensor measured both total chlorophyll and cyanobacteria phycocyanin concentrations (after specific pigment excitation by different wavelengths of light). Data were collected every 1.5 meters down the water column starting at 1-m below the surface. The buoy also contained a standard suite of meteorological sensors recording five-minute mean, air temperature, barometric pressure, relative humidity, light intensity, wind speed and wind direction data every 30 minutes. Raw data were periodically transferred to HWS by cellular phone ~1 hour after collection and archived in a database on a user accessible website (http://fli-data.hws.edu/buoy/owasco/). The buoy's EXO2 sonde was calibrated before and after the deployment and minimal instrument drift was noted. The raw buoy data were then calibrated against *in situ* CTD and laboratory data collected over the entire field season from the offshore sites, and the calibrated data are presented in this report. The cyanobacteria concentrations were normalized to a constant temperature due to the sensor's temperature sensitivity.

Electronic issues prevented deployment of the FLI Seneca Lake WQ buoy in 2020. The data from the USGS Buoy (Site: 425027076564401) deployed on Seneca Lake was used instead (unfortunately the USGS buoy lacked wind direction data).

Fig. 4. Mesocosm racks floating in a pond at Hanley Preserve. Incubations were conducted in a small pond at the HWS Hanley Preserve to reduce the likelihood of losing or breaking a rack due to waves and winds in Owasco Lake. Temperature and solar radiation measurements were made at the site every five minutes during the seven day incubation.

Limiting Nutrient, Mussel and Macrophyte Assays: Mesocosm experiments investigated the limiting nutrient (phosphorus, SRP, nitrate/nitrate, NO_x, and/or ammonium, NH_4) for algal growth for Seneca, Owasco and neighboring Finger Lakes (Fig. 4)[2]. Multiple filtered water samples using a 153 μm mesh to remove medium to large zooplankton were collected from each lake, placed in 12 separate 500 mL Britran baggies, to analyze triplicates of four treatments – control (no amendments), phosphorus (addition of 31 μg/L of soluble reactive phosphorus), nitrogen (addition of 168 μg/L each of nitrate and ammonium), and a combination of the phosphorus and nitrogen treatments. The treatments were then randomly placed into a PVC rack with mesh that allowed for incubation at the water surface, which was a small pond on the HWS Hanley Preserve property (Fig. 4). A screen was placed over the top of the rack to decrease the amount of solar radiation to each chamber. Solar radiation and temperature were measured throughout the incubation period. At the conclusion of the incubation period, individual samples were poured off for chlorophyll analysis and were analyzed using the bbe FluoroProbe in the FLI laboratory. Statistical comparisons (ANOVA)

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[2] Jacobsen, A., Egge, J. K. and Meimdal, B. R. (1995) Effects of increased concentration of nitrate and phosphate during a spring bloom experiment in mesocosm. J. Exp. Mar. Biol. Ecol., 187, 239–251.

were completed to test whether chlorophyll concentrations were different within and across treatments.

We proposed to undertake sediment derived nutrient flux studies, and lake-floor zebra and quagga mussel density and macrophyte (attached plants) density assays in 2020 to investigate the likely source of nutrients to stimulate cyanobacteria blooms. However, COVID restrictions on student hires prevented this effort in 2020. Even though these tasks were not performed in 2020, the methods are outlined below. We plan to resume this effort in 2021 and 2022.

Mussel and macrophyte population assays were to collect all plants and mussels within 6-replicate, randomly tossed, quadrats using SCUBA divers adjacent to the dock sites in Owasco Lake. The proposed sites represent the range in substrates and historical bloom frequency. Mussels will be separated from any rocks to avoid crushing during transit to the lab. Once in the lab, mussels will be separated by species and size classes, counted, and weighed wet and dry. In addition, macrophyte communities will be sampled once each month (July – September) using the rake toss method to identify the species and relative biomass of different plant species. The proposed timing spans the life cycle for most macrophytes in the lake. The plant specimens collected from the August collection will be separated, sized, identified to species level, and weighed wet and dry. Phosphorus content will determined on the dry plant matter. The mussel and macrophyte data will enable assessment of the relative contribution of these fractions to the sediment nutrient pool, and their potential impact on the nutrient supply for the cyanobacteria blooms.

Nutrient flux studies were to collect intact sediment cores and overlying water by hand in 6.75 cm diameter tubes from nearshore areas adjacent to the dock sites in Owasco Lake[3]. Approximately 20-L of water for the incubations is also collected in pre-rinsed, ~20-L cubitainers® from each core site. In the laboratory, continuous-flow incubations of intact sediment cores are started within ~ 2 hrs of field collection. For each site, cores are incubated with just sediment or with sediments and aquatic macrophytes (~15 g wet weight) that were present at each site. Core tubes are wrapped in heavy duty aluminum foil to replicate light levels in the sediment and fitted with a gas-tight plunger using an O-ring seal. Each core receives aerated site water from the cubitainer through polyetheretherketone (PEEK) tubing connected to the inflow and outflow ports of a peristaltic pump at a flow rate of ~1.15 mL of site water per minute[4]. Inflow and outflow water is sampled at 24 hour intervals for three days. The daily water samples are immediately filtered for nutrient analysis measured with an automated, colorimetric flow-injection analysis system (QuikChem 8500 Lachat Instruments) according to manufacturer methods and standard EPA protocols.

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[3] Gardner WS, McCarthy MJ, Carini SA, Souza A., Lijun H., McNeal KS, et al. 2009. Collection of intact sediment cores with overlying water to study nitrogen- and oxygen-dynamics in regions with seasonal hypoxia. *Continental Shelf Research* 29:2207-2213.

[4] McCarthy, M.J., W.S. Gardner, M.F. Lehmann, A. Guindon, & D.F. Bird. 2016. Benthic nitrogen regeneration, fixation, and denitrification in a temperate, eutrophic lake: effects on the nitrogen budget and cyanobacteria blooms. Limnology and Oceanography 61: 1406-1423.

SENECA AND OWASCO LAKES

Seneca and Owasco Lakes are two of the eleven Finger Lakes in central New York State. Both are elongated, north-south orientated lakes, and larger than the western lakes (Fig. 1). Both are borderline oligotrophic (low productivity) – mesotrophic (medium productivity) lakes, i.e., experience moderate algal productivity and oxygenated bottom waters, and have experienced cyanobacteria blooms. However, important differences exist. For example, Seneca Lake is much larger, deeper, and has a much longer water retention time than Owasco Lake (Table 1). These physical characteristics influence factors like fetch, which impacts the maximum size of wind driven waves, i.e., waves are much larger in Seneca than Owasco Lake given the same wind speed and direction. A smaller watershed to lake surface area ratio in Seneca Lake makes it less susceptible to activities within the watershed like nutrient and sediment loading than Owasco Lake. Both lakes are critical to the local, agro-tourism economy with internationally known wineries. They also supply municipal water to nearby communities.

Table 1. Physical & Other Characteristics of Seneca and Owasco Watersheds[5].

Characteristic	Seneca Lake	Owasco Lake
Maximum Length & Width (km)	57 & 5.2	18 & 2.1
Shoreline Length (km)	123.6	41.3
Surface Area (km^2)	175	27
Watershed Area (km^2)	1,181	470
Watershed/Lake Surface Area Ratio	6.7	17.4
Volume (km^3)	15.5	0.78
Max Depth (m)	198	54
Water Retention Time (yr)	18 (13 to 23)	2 (1.5 to 4)
Land Use (% Forest / Agriculture / Urban / Lake)	38 / 40 / 6 / 15	35 / 49 / 5 /11
Drinking Water Withdrawals (MGD)	9	16

CYANOBACTERIA AND HARMFUL ALGAL BLOOMS BACKGROUND

Many species of cyanobacteria exist, each trying to gain an ecological advantage over the others. For example, some species of *Dolichospermum* (formerly *Anabaena)* can “fix” atmosphere nitrogen (N_2) for their source of nitrogen to synthesize organic matter. Most other forms of cyanobacteria including *Microcystis* cannot “fix” N_2, and are instead dependent on the dissolved forms of nitrogen like nitrate (NO_3^-), nitrite (NO_2^-), and preferably ammonium (NH_4^+). Nitrogen fixing cyanobacteria have an ecological edge in nitrogen-limited lakes like Honeoye. Nitrogen limitation should not be a concern in Seneca or Owasco and the other phosphorus-limited Finger Lakes, especially in the open water. However, the details of the phosphorous and nitrogen dynamics, especially the different types of nitrogen, is not very well understood. Both *Dolichospermum* and *Microcystis* were most often detected in Seneca and Owasco Lakes. Typically *Dolichospermum* appearances typically precede *Microcystis* blooms in a given field season.

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[5] Callinan, C., 2001. Water Quality of the Finger Lakes. New York State Department of Environmental Conservation Report. 152 pg.

Cyanobacteria blooms are not only unsightly surface scums, but 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 can 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, most notably, the skin, liver, gastrointestinal and/or nervous systems. Liver cyanotoxins like microcystins are most commonly found in HAB blooms, and can cause organ damage, heart failure and death at high doses in lab animals. Microcystins are a class of related toxin compounds (heptapeptides) that can be synthesized by various species of *Microcystis* and *Dolichospermum*. Because both are common in NY lakes, total microcystin is commonly measured in New York State to assess cyanobacteria toxin status. Another common toxin group, anatoxins, impact the nervous system, and can be synthesized by *Dolichospermum* and other cyanobacteria genera but not *Microcystis* species.

The impact of these toxins on humans at low concentrations still remains unclear. The World Health Organization (WHO) has issued a provisional finished drinking water guideline of 1 μg/L for chronic exposure to microcystin, and recreational exposure limit of 20 μg/L[6]. The EPA's drinking water guideline for microcystin is 0.3 μg/L for infants and 1.6 μg/L for school-age children and adults; their recreational contact limit is 4 μg/L. No thresholds are set for anatoxins yet, although 0.5 μg/L is used by Vermont in their drinking water guidelines[7]. The anatoxin half-life, the time interval for decomposition, is very short, less than 24 hours, which makes detection in the water column difficult. The DEC defines a cyanobacteria bloom when the blue-green chlorophyll (phycocyanin) concentration exceeds 25 μg/L, and a bloom is reclassified as a harmful algal bloom (HABs) or a bloom with high toxins when microcystin concentrations exceed 20 μg/L in nearshore areas and 10 μg/L in offshore areas.

Harmful algal blooms are not unique to Seneca and Owasco Lakes. Major cyanobacteria blooms were confirmed in all of the Finger Lakes in the recent past (Fig. 5). A few hundred lakes in New York State experienced cyanobacteria blooms each year out of the 7,849 lakes in the state (all identified lakes and ponds with or without monitoring programs, Rebecca Gorney, DEC, pers. comm.).

Lakeshore residents with private water systems should use bottled water during cyanobacteria outbreaks along their shoreline because their private water supply systems are challenged to remove cyanobacteria from the water without bursting cell walls[8]. Cell wall integrity is critical because once it is compromised, the toxins can be released to the water, and more easily impact human health. The watershed should seriously consider extending municipal water around the lake to decrease the potential health risks from drinking lake water.

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[6] WHO, 2011. Guidelines for Drinking Water Quality. 4th Edition. World Health Organization. Switzerland.

[7] https://www.epa.gov/nutrient-policy-data/guidelines-and-recommendations

[8] A Water Utility Manger's Guide to Cyanotoxins. 2015. Water Research Foundation, American Water Works Association, 18 pgs. www.waterrf.org

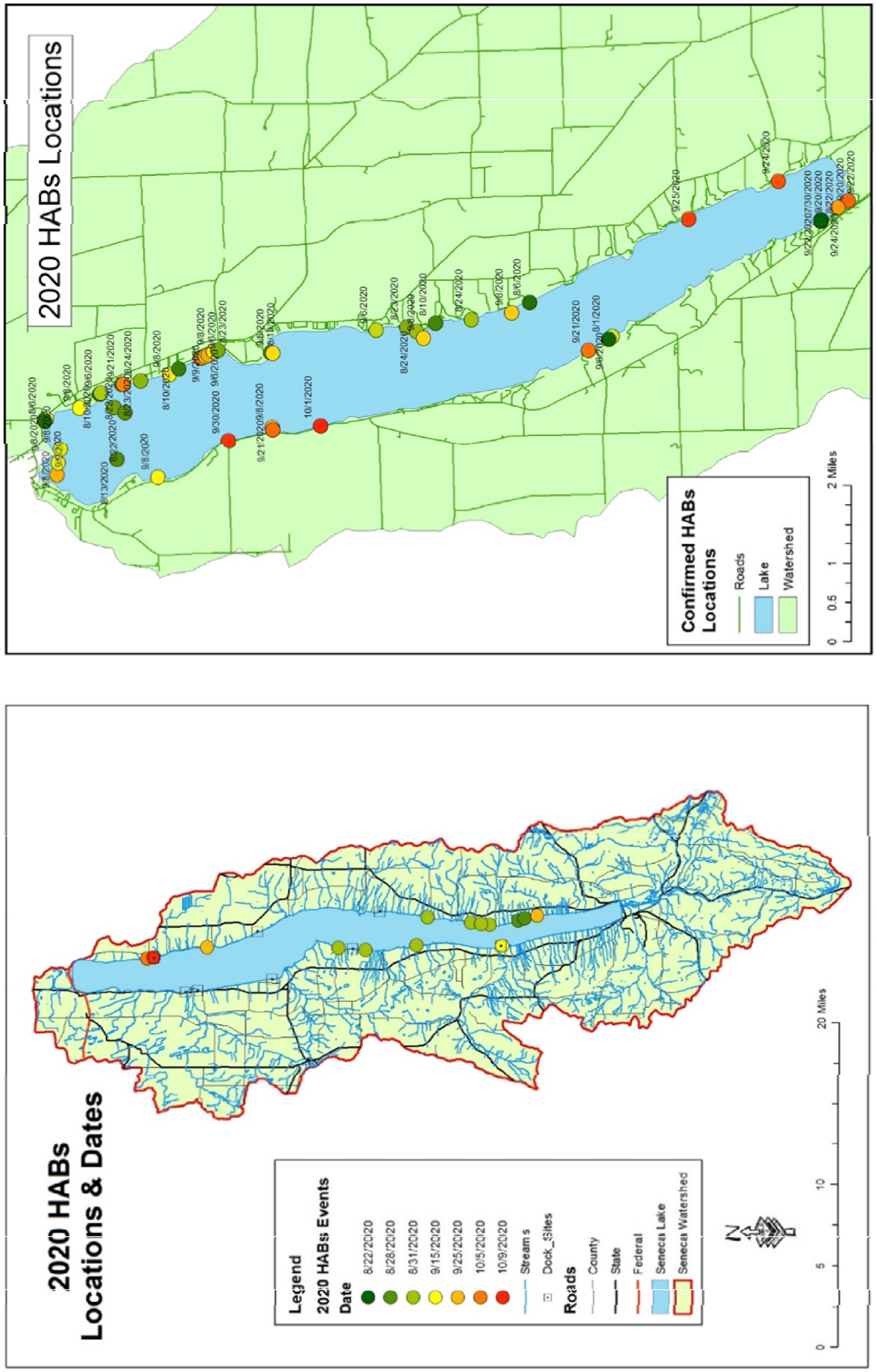
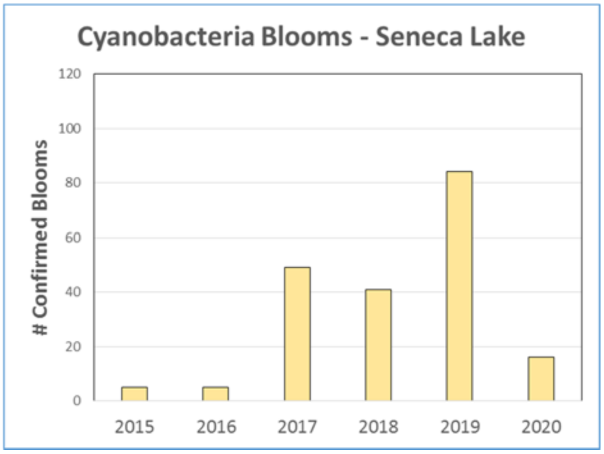


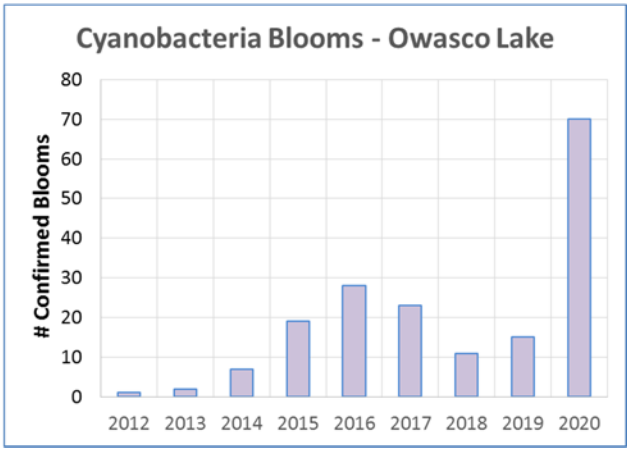
Fig. 5. DEC confirmed cyanobacteria bloom locations in Seneca and Owasco Lake during 2020.

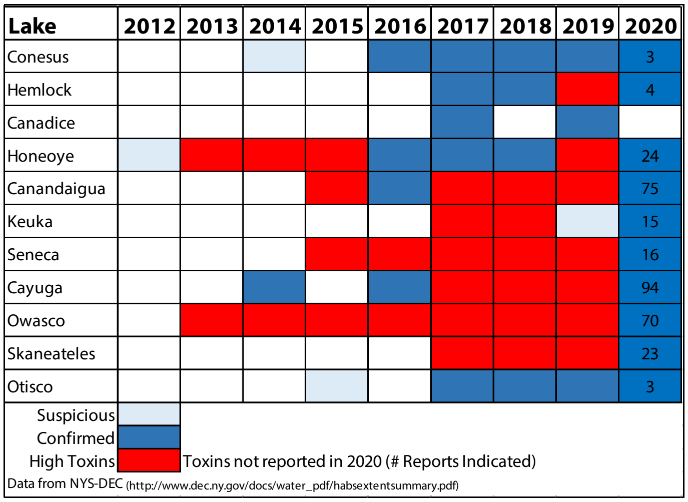
Seneca and Owasco Lakes have experienced significant surface-water, nearshore, cyanobacteria (cyanobacteria) blooms, some with toxic levels of microcystin and other toxins (Fig. 6). In Seneca Lake, blooms were first detected in 2015. Since then, annual mean cyanobacteria concentrations ranged from 3,600 to 6,700 µg/L (Max: 59,000 to 118,000 µg/L) and mycrocystin toxin concentration ranged from 47 to 290 µg/L (Max: 670 to 2,100 µg/L). In Owasco Lake, blooms were first detected in 2012 with annual mean cyanobacteria concentrations ranged from 140 to 4,960 µg/L (Max: 1,100 to 45,500 µg/L) and mycrocystin toxin concentration ranged from 240 to 750 µg/L (Max: 1,100 to 45,500 µg/L; see Table within Fig. 6). DEC confirmed bloom in 2020 were tallied from the NY HABS website.

Most importantly, the number of DEC confirmed blooms were significantly different between the two lakes (Fig. 6). This tally excluded cyanobacteria detected by the dock cameras. From 2017 through 2019, more blooms were detected in Seneca Lake (40 to 85 each year) than Owasco Lake (15 to 23). Lake size may explain these differences. Normalizing the bloom counts to length of shoreline, the Seneca Lake volunteers detected 0.4 to 0.68 blooms/km of shoreline compared to 0.17 to 0.68 blooms/km of shoreline in Owasco Lake.

In Seneca and Owasco Lakes, the number of blooms changed drastically in 2020. It decreased to 16 confirmed blooms in Seneca (0.12 blooms/km) compared to a record high 115 blooms in Owasco (1.7 blooms/km). The change is probably real despite other potential factors that can influence bloom counts in any one year like, e.g., the number of volunteers, the fraction of shoreline surveyed, the day and time of the weekly survey, and number of days in the survey. This difference is the primary reason why the Seneca and Owasco reports were combined this year to determine potential water quality and/or meteorological variables that influenced this change. As a comparison, Canandaigua reported 75 confirmed blooms in 2020, whereas Cayuga 94, or 1.3 blooms/km and 0.5 blooms/km, respectively. Less than 50% of the Cayuga shoreline was surveyed in 2020, thus its bloom/km value should be proportionally larger.







Lake	2012	2013	2014	2015	2016	2017	2018	2019	2020
Conesus			▨		🟦	🟦	🟦	🟦	🟦 3
Hemlock						🟦	🟦	🟥	🟦 4
Canadice						🟦		🟦	
Honeoye	▨	🟥	🟥	🟥	🟦	🟦	🟦	🟥	🟦 24
Canandaigua				🟥	🟦	🟥	🟥	🟥	🟦 75
Keuka						🟥	🟥	▨	🟦 15
Seneca				🟥	🟥	🟥	🟥	🟥	🟦 16
Cayuga			🟦		🟦	🟥	🟥	🟥	🟦 94
Owasco		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟦 70
Skaneateles						🟥	🟥	🟥	🟦 23
Otisco				▨		🟦	🟦	🟦	🟦 3

Suspicious ▨
Confirmed 🟦
High Toxins 🟥 Toxins not reported in 2020 (# Reports Indicated)
Data from NYS-DEC (http://www.dec.ny.gov/docs/water_pdf/habsextentsummary.pdf)

Cyanobacteria & Mycrocystin Concentrations

Annual Means	Seneca	Owasco
Cyanobacteria (µg/L)		
2017	6,580	4,910
2018	4,280	4,960
2019	3,660	n/a
2020	n/a	n/a
Mycrocystin (µg/L)		
2017	47	400
2018	290	750
2019	n/a	n/a
2020	n/a	n/a

Fig. 6. Annual numbers of confirmed cyanobacteria blooms detected by the volunteers and compiled by DEC, Seneca (above left), Owasco (above right). The tallies excluded blooms detected by the dock cameras. The number of Finger Lakes with suspicious activity, confirmed cyanobacteria blooms and confirmed blooms with high toxins since 2012 (bottom left, by permission DEC). The DEC stopped funding cyanobacteria and toxins analyses in 2020.

OFFSHORE WATER QUALITY MONITORING AND FLI BUOY RESULTS

Cyanobacteria blooms prefer the following conditions:

- warm water, temperatures between 15 to 30°C (60 and 80° F);
- elevated (eutrophic) concentrations of nutrients, especially waters rich in phosphorus, the limiting nutrient for many cyanobacteria;
- 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,
- alkaline pH.

However, predicting their occurrence remains a challenge due to the large number of cyanobacteria species and the diversity of their habitats. Cyanobacteria blooms in the Finger Lakes are significantly more challenging because most of these lakes are oligotrophic to mesotrophic systems, and not the nutrient-rich, eutrophic lakes, where cyanobacteria blooms were more common in the past.

Algal Populations: Offshore FluoroProbe concentrations revealed low concentrations of cyanobacteria in the plankton communities of both lakes, especially in August and September (Fig. 7). Diatoms dominated the communities in both lake during the early spring and fall, green algae and cryptophytes during mid-summer, and cyanobacteria were detected at lower concentrations primarily in the late summer and early fall. Over the past few years, the relative concentration of cyanobacteria increased in Owasco Lake. This is consistent with 2020 visual observations at Owasco that noted an increased presence of cyanobacteria in the surface water throughout the lake. A similar increase in cyanobacteria was not observed in Seneca Lake.

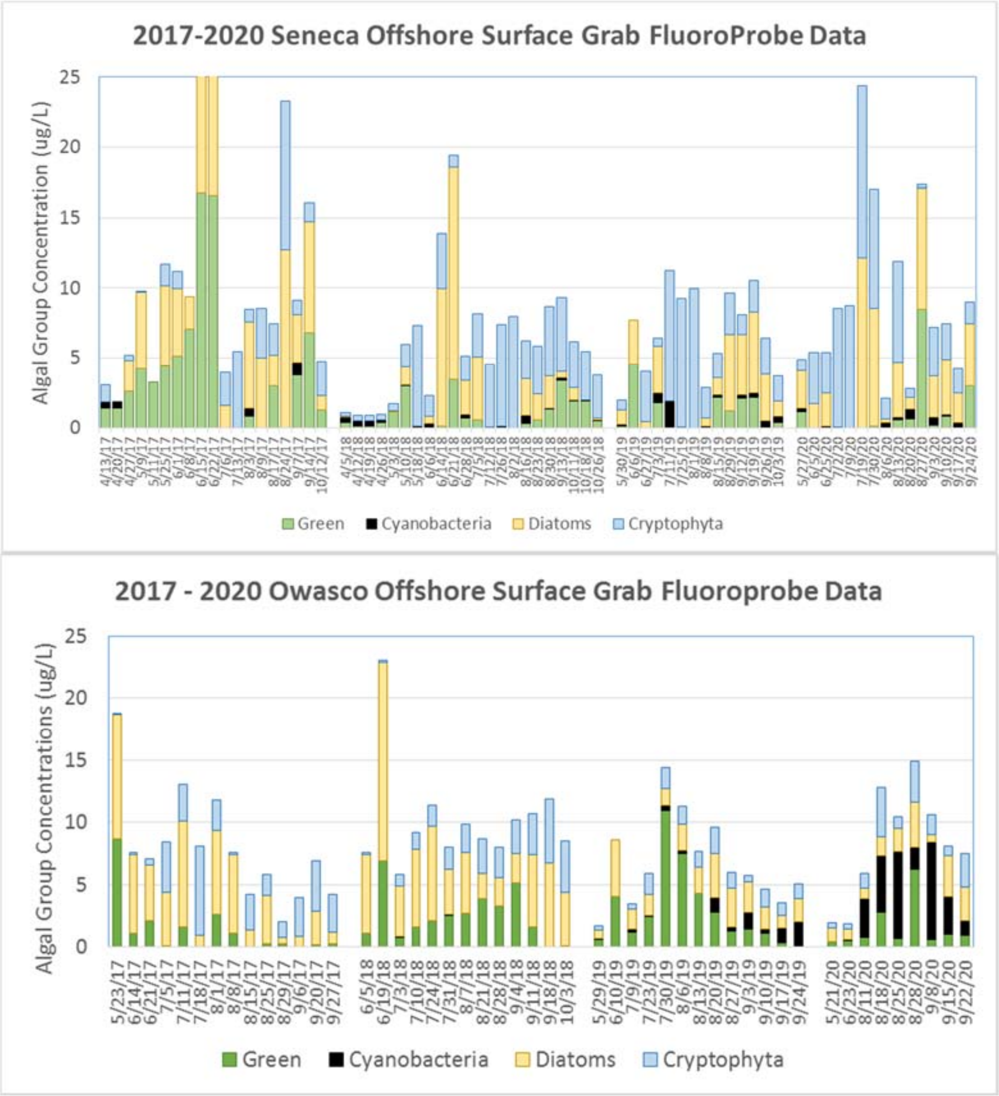


Fig. 7. Offshore, surface grab, date averaged, bbe FluoroProbe concentrations of the four algal groups from 2017 through 2020 in Seneca (above) and Owasco (below) Lakes.

Mean annual plankton enumerations paralleled the FluoroProbe results (Fig. 8). The counts revealed more cyanobacteria species in the community over time in Owasco Lake, especially in 2020, but not in Seneca Lake. *Fragillaria* (fall) and *Asterionella* (spring) were two common species of diatoms. *Dolichospermum* (formerly *Anabaena*) and *Microcystis* were the two common cyanobacteria forms, *Dolichospermum* at low counts appeared before and was followed by much more *Microcystis* later in the HABs season. Varieties of green algae and dinoflagellates make up the rest of the communities. The plankton net mesh is too coarse to collect most cryptophyte species. Cyanobacteria dominated the plankton counts (40 to 95%) in Owasco Lake during the 2020 August to September HABs season but not Seneca Lake. Perhaps HABs impacted Owasco Lake to a greater extent than Seneca Lake in 2020 because cyanobacteria had additional time to be firmly established in Owasco Lake and/or nutrient sources were more ideal for cyanobacteria proliferation in Owasco Lake. Alternatively, waves from the 2020 strong winds mixed nearshore cyanobacteria blooms into the open water column, and/or nutrient supplies were ideal in 2020.

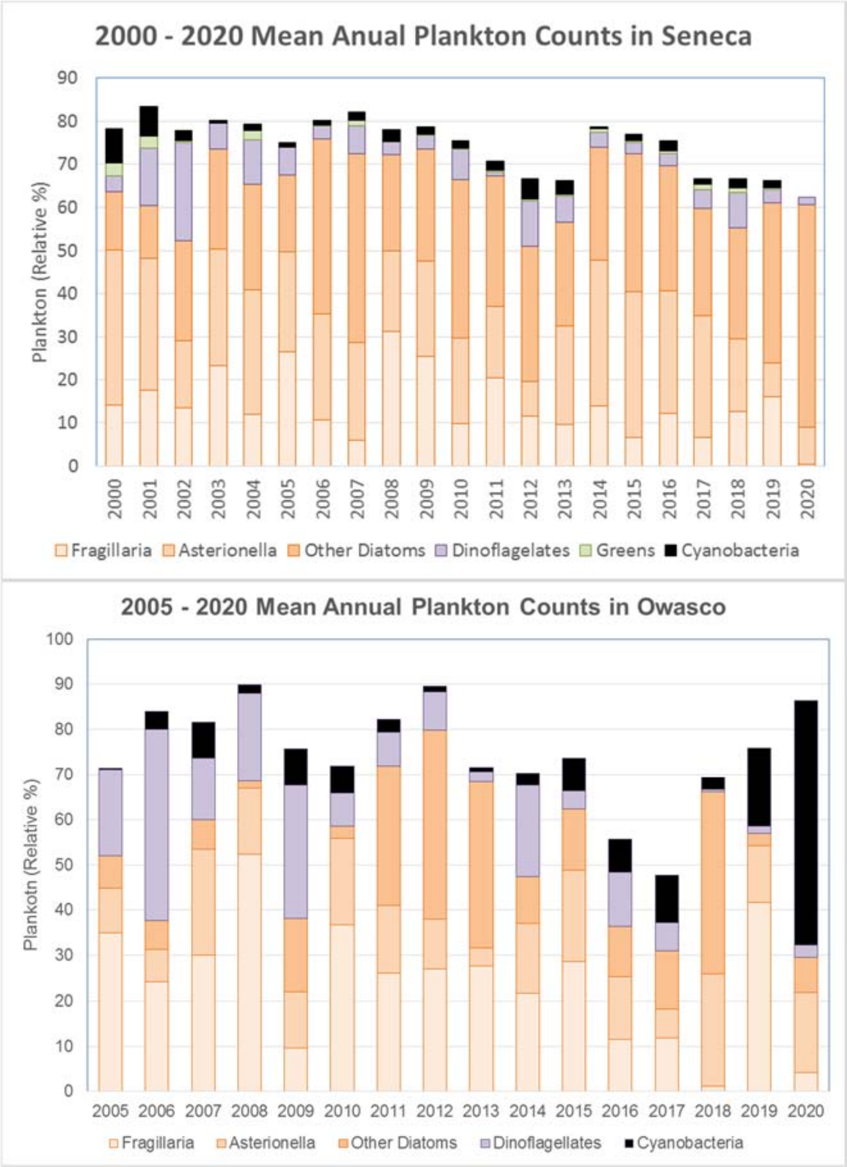


Fig. 8. Mean annual plankton counts from offshore vertically integrating (15m deep) plankton tows (80 μm mesh) in Seneca (above) and Owasco (below) Lakes.

Surface Water Temperatures by CTD: Surface water temperatures measured by CTD since 1995 in Seneca Lake indicate that surface waters have warmed over the past two decades (Fig. 9). 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 0.18°C/year, a result of Global Warming (0.0005°C/day). 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 was detected in Owasco Lake (0.21°C/year). Since 2012 the first detection of cyanobacteria in Owasco Lake, the surface water was at its warmest, especially the past 7 years. Warmer water probably stimulated blooms in these two lakes as surface water temperatures were within the preferred range for cyanobacteria blooms.

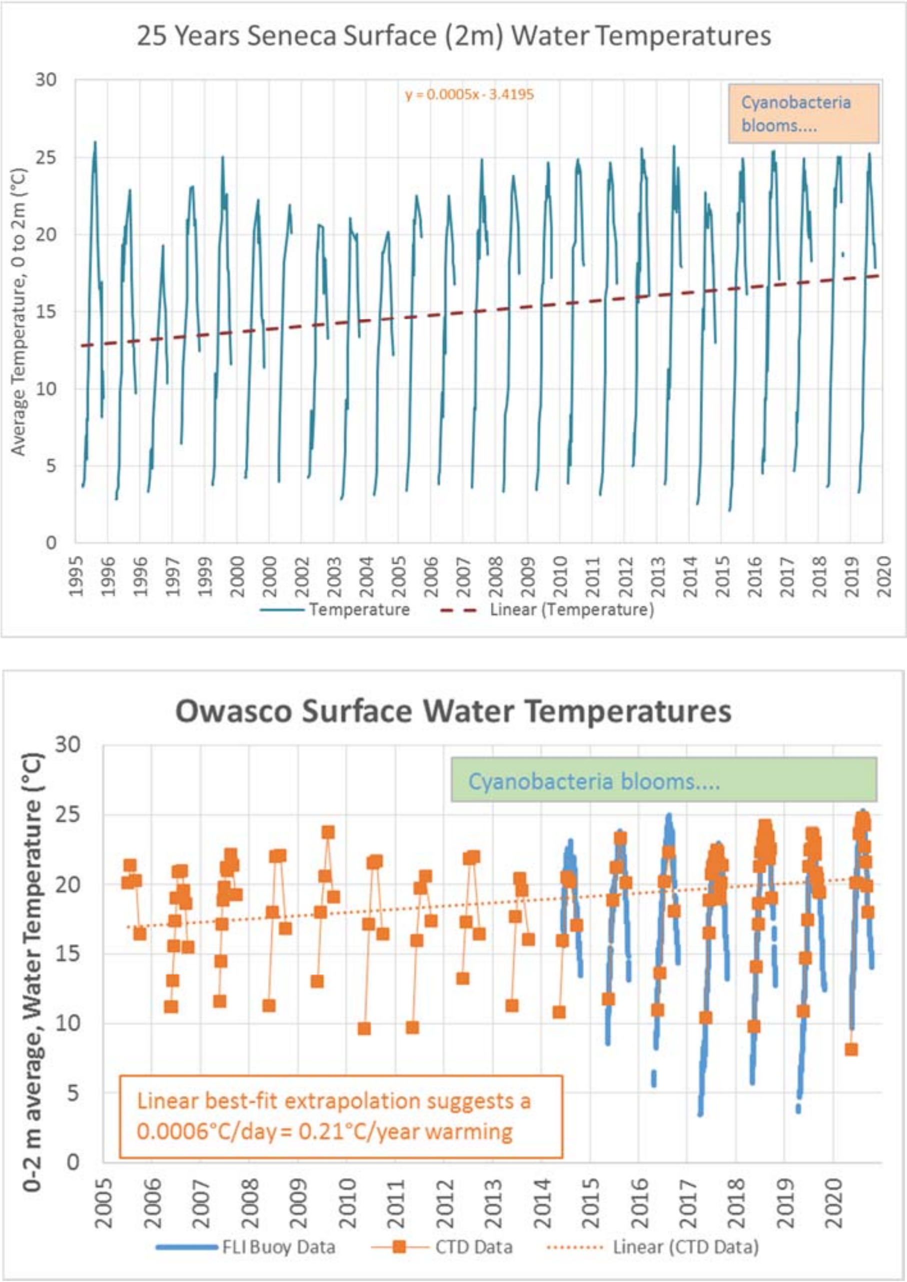


Fig. 9. Surface water (< 2-m) temperatures from Seneca (above) and Owasco (below) Lakes measured by CTD and FLI Buoy. Years with reported cyanobacteria blooms are shown.

Secchi Disk, Nutrient, Turbidity & Chlorophyll-a Concentrations: Secchi depths, total phosphorus, soluble reactive phosphate, nitrate, total suspended solids and chlorophyll-a concentrations have also changed over time (Fig. 10). In Seneca Lake, deviations in these limnological parameters during the 1990's are related to the introduction and proliferation of zebra mussels, and their impact on the ecology of the lake[9]. During the past decade and coincident with detected cyanobacteria blooms, larger concentrations and larger variability in

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[9] 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.

each year's data was observed, especially the largest values in each year, i.e., the upper whisker of the box and whisker plots. Two years, 2014 or 2015, detected larger concentrations of TP and SRP (2014), and shallower Secchi depths, and larger TSS and chlorophyll concentrations (2015) in Seneca Lake. The unusually high concentrations are interpreted to reflect significant additions of phosphorus and sediments from localized storm events and the resulting runoff (flood-like) events. The 2014 and 2015 timing also corresponds to the initial detection of cyanobacteria blooms in the lake. The historical data suggest that the addition of extra phosphorus, the limiting nutrient in the lake, and the onset of warmer water pushed Seneca Lake over a tipping point in 2015 that triggered subsequent cyanobacteria blooms. Nitrate did not significantly change, perhaps because it is not the limiting nutrient. Once additional nutrients are in the lake, nutrient recycling is typically effective enough to regenerate the nutrients required for cyanobacteria blooms in subsequent years. These limnological precursors to the onset of cyanobacteria blooms are also observed in the water quality data from neighboring Finger Lakes[10].

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[10] 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.

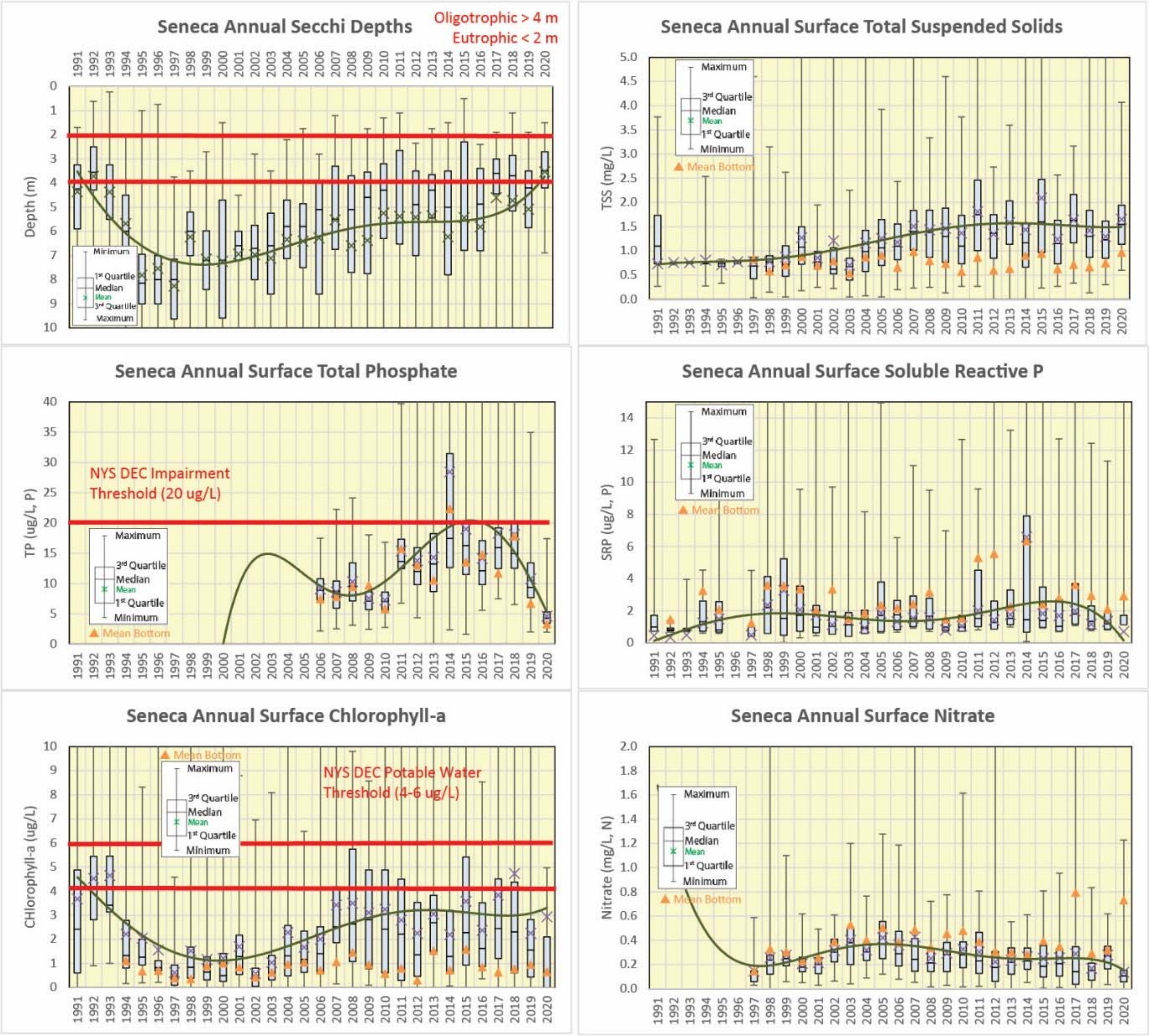

Fig. 10. Historical Secchi depths, nutrient and chlorophyll data from the Seneca Lake monitoring program. The box in the box and whisker plots contain 50% of the available annual data. The lower and upper whiskers correspond to the minimum and maximum values of the available annual data. The orange diamonds plot mean annual C-SLAP data.

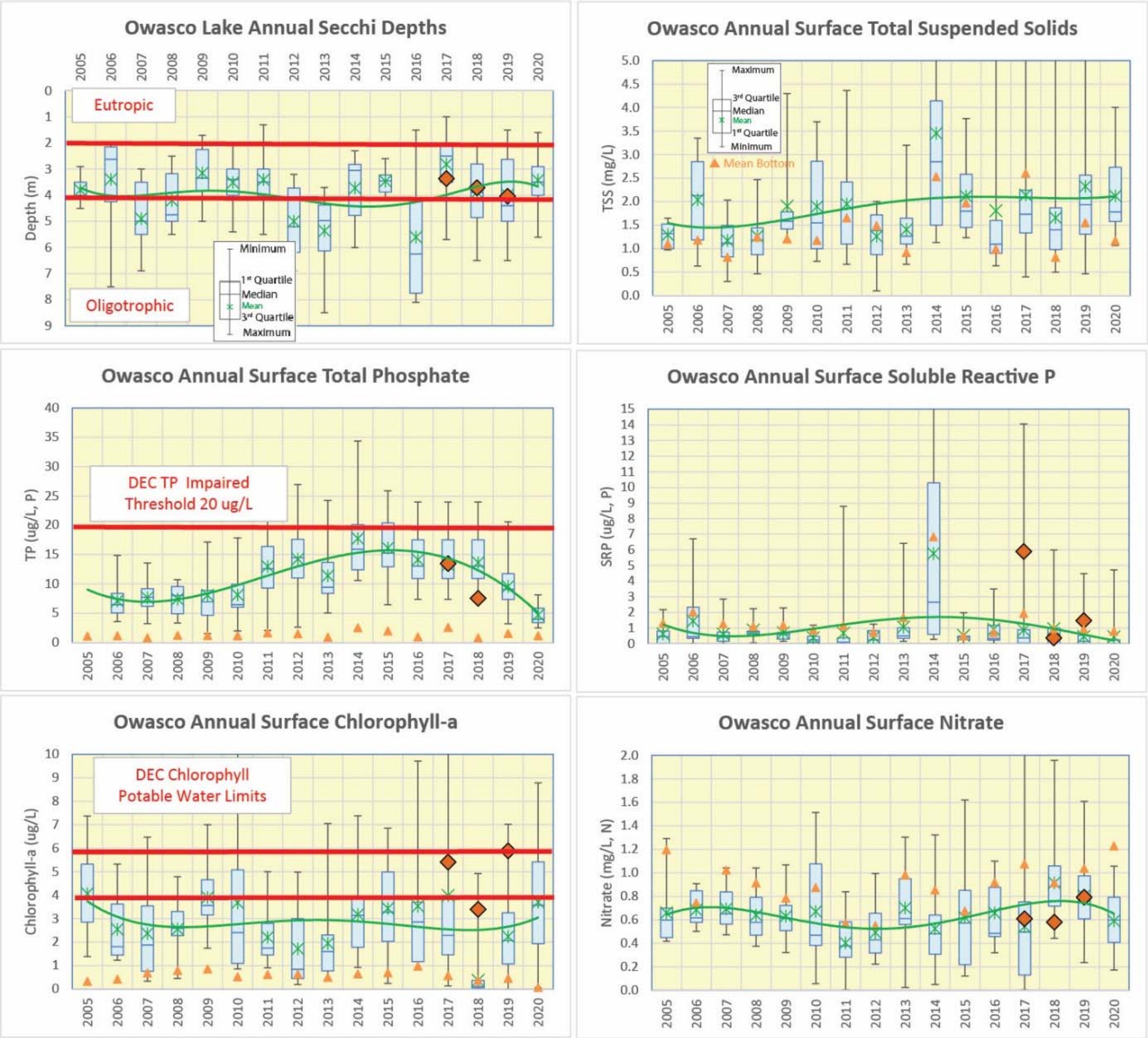

Fig. 10 continued. Historical Secchi depths, nutrient and chlorophyll data from the Owasco Lake monitoring program. The box in the box and whisker plots contain 50% of the available annual data. The lower and upper whiskers correspond to the minimum and maximum values of the available annual data. The orange diamonds plot mean annual C-SLAP data.

Similar changes in limnological parameters were detected in Owasco Lake within the overlapping time frame (Fig. 10). Owasco experienced shallower Secchi disk depths and slightly larger chlorophyll-a concentrations, especially earlier in the record. Owasco was also slightly more turbid, experienced smaller maximum total phosphate and soluble reactive phosphate concentrations, and slightly larger nitrate concentrations. These differences indicate that Owasco Lake is slightly more productive, i.e., more mesotrophic than Seneca Lake, and the differences can be attributed to its smaller size, larger watershed to lake surface area ratio, and slightly more agricultural land use / land cover in its watershed. The increase in nutrients helped the proliferation of cyanobacteria blooms, especially runoff from floods created by large summertime convective storms. However, the nutrient concentrations available in the open water and nearshore settings of Owasco Lake are, by an order or magnitude (or more), insufficient to support the amount of P and N required for typical cyanobacteria blooms[11]. Another source of nutrients is required to proliferate cyanobacteria blooms in these lakes.

In 2020, none of these limnological parameters were unique enough from themselves or from previous years to influence differences in the cyanobacteria activity in these lakes. Smaller phosphorus (TP & SRP) and nitrate concentrations were detected in both lakes in 2020, most likely due to lower rainfall and lower nutrient loadings in 2020. It suggests that smaller nutrient concentrations should decrease the number of blooms in both lakes. Bloom counts decreased in Seneca, but increased in the Owasco. This nutrient-bloom inconsistency reaffirms that open water nutrients were not the primary nutrient source for the cyanobacteria blooms. The open-water lack of nutrients stimulated the search for nutrients in the nearshore sediments and lake-floor biota (e.g., macrophytes, *Cladophora* and mussels).

Similar limnological data in both lakes indicates that open lake limnological parameters were probably not a reason for the difference in the 2020 bloom counts in these two lakes.

Lake Temperatures by Buoy: The FLI Monitoring buoys provided higher resolution water quality data than the weekly limnological surveys (Fig. 11). Unfortunately the FLI buoy on Seneca Lake was inoperative, so data from the USGS buoy was used instead[12]. The USGS buoy was deployed in shallower water north of the FLI buoy site, and the shallower site influenced the apparent warming of the bottom water temperatures in 2020, as the USGS bottom temperatures sampled the lower epilimnion / upper hypolimnion, instead of the hypolimnion at the FLI buoy site. In other respects, the USGS buoy temperature data were consistent with previous FLI buoy results[13].

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[11] Halfman, J.D., B. Kharrazi*, E. Wilber*, A. Leavitt*, J. Andrews*, W. White*, E. Moore*, P. Spacher, I. Dumitriu, M. Kastan, E. Rosser, T Massey & L.B. Cleckner, 2020. Blue-Green Algae in Owasco Lake, the 2019 Update. The 2019 Annual Report to the Fred L. Emerson Foundation. Finger Lakes Institute, Hobart and William Smith Colleges. 36 pg

[12] https://ny.water.usgs.gov/maps/habs/

[13] Halfman, J.D., et al., 2018. Blue-Green Algae in Owasco Lake: The 2018 Update. The 2018 Annual Report to the Fred L. Emerson Foundation, Finger Lakes Institute, Hobart and William Smith Colleges. 37 pg.

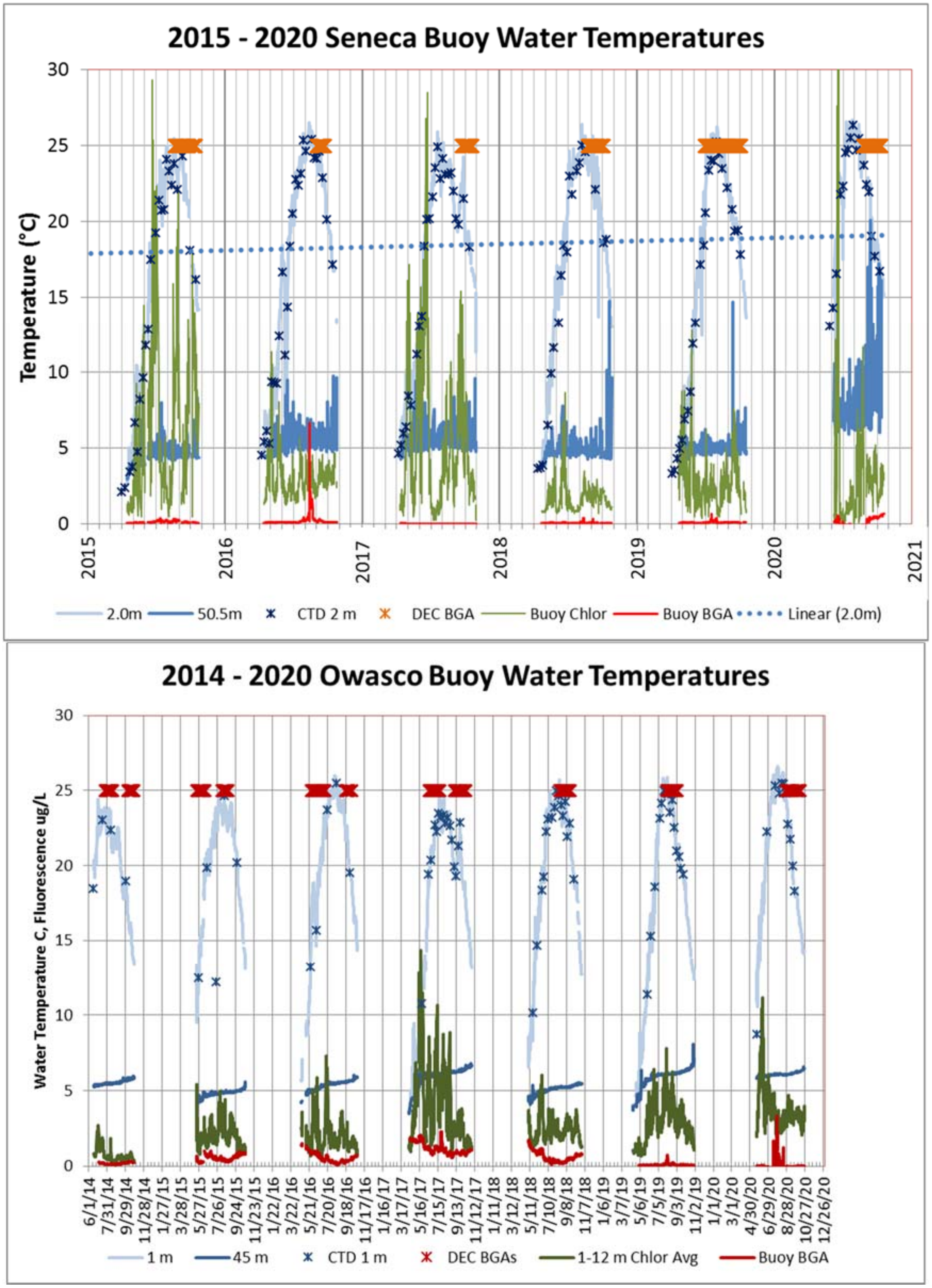


Fig. 11. Seven years of surface and bottom water temperatures at the Seneca (above) & Owasco (below) buoys. Surface water (1-m) CTD data were superimposed onto the buoy temperatures. The USGS buoy on Seneca Lake was used for the 2020 data. The weeks these lakes were on DEC's Notification Page are also shown.

Shoreline cyanobacteria blooms were detected when the surface water was warm, 20 to 26°C (70 – 80°F) since their initial detection in each lake (Fig. 11). However, in every year but 2019 in Seneca Lake, blooms did not appear until a week or two after the warmest water temperatures of the summer season. Similar delays were observed in Owasco Lake during 2014, 2018, 2019 and 2020. The delay indicates that warm water by itself does not directly trigger bloom activity. The delay may instead provide enough time for sufficient bacterial decomposition of organic matter and storage of nutrients in the environment for subsequent cyanobacteria blooms. Cyanobacteria activity may have started earlier in some years because more nutrients were available, e.g., from more rainfall or other sources, to jumpstart the cyanobacteria blooms. Alternatively, bloom watch volunteers were better at detecting blooms and/or looked for blooms earlier in the season in those years. Cyanobacteria blooms were not detected after the surface water cooled below 15°C (60°F).

Similar water temperature patterns were detected in both lakes, and were within the expected range for bloom development. It indicates that water temperatures probably not a reason for the difference in the 2020 cyanobacteria bloom counts in these two lakes.

Buoy Total Algae and Cyanobacteria-PC Fluorescence: Minimal correlations were observed between the buoy total fluorescence and buoy cyanobacteria-PC, or between the buoy total fluorescence and shoreline cyanobacteria blooms (Fig. 11-13). The lack of a correlation is not surprising because the buoy measures open water parameters, and the bulk of the cyanobacteria blooms occur at shoreline locations. The buoy detected higher algal concentrations and more frequent offshore algal blooms in 2015 and 2017 compared to 2016, 2018, 2019 and 2020. More rain fell in 2015 and 2017, and the associated increased nutrient loads from its runoff probably stimulated more algal growth during the impacted years.

Cyanobacteria-PC fluorescence rarely revelaed a cyanobacteria bloom at the buoy site. The absence may reflect the 1-m shallowest depth for the buoy measurements, a depth below the surface hugging cyanobacteria blooms. Alternatively, smaller and/or less frequent blooms occurred offshore compared to nearshore areas. Perhaps an automated camera should be deployed on the buoy to monitor the presence or absence of cyanobacteria at this offshore site.

Similar offshore fluorescence concentrations were detected in both lakes, and probably was not a reason for the difference in the 2020 cyanobacteria bloom counts in these two lakes.

Buoy Air Temperatures: Like water temperatures, the shoreline cyanobacteria blooms commonly occurred a few weeks after peak air temperatures (23 to 24°C, 70-75°F) for the summer season (Fig. 12). Colder air temperatures in the fall, i.e., 10°C (50°F), coincided with seasonal end for cyanobacteria blooms. Thus, blooms prefer warm air and water temperatures, and are terminated by cold air and water temperatures. The parallel nature for air and water temperatures is not surprising because both air and water temperatures are linked to and ultimately forced by changes in solar insolation.

Similar air temperatures at both lakes indicates that air temperatures probably were not a reason for the difference in the 2020 cyanobacteria bloom counts in these two lakes.

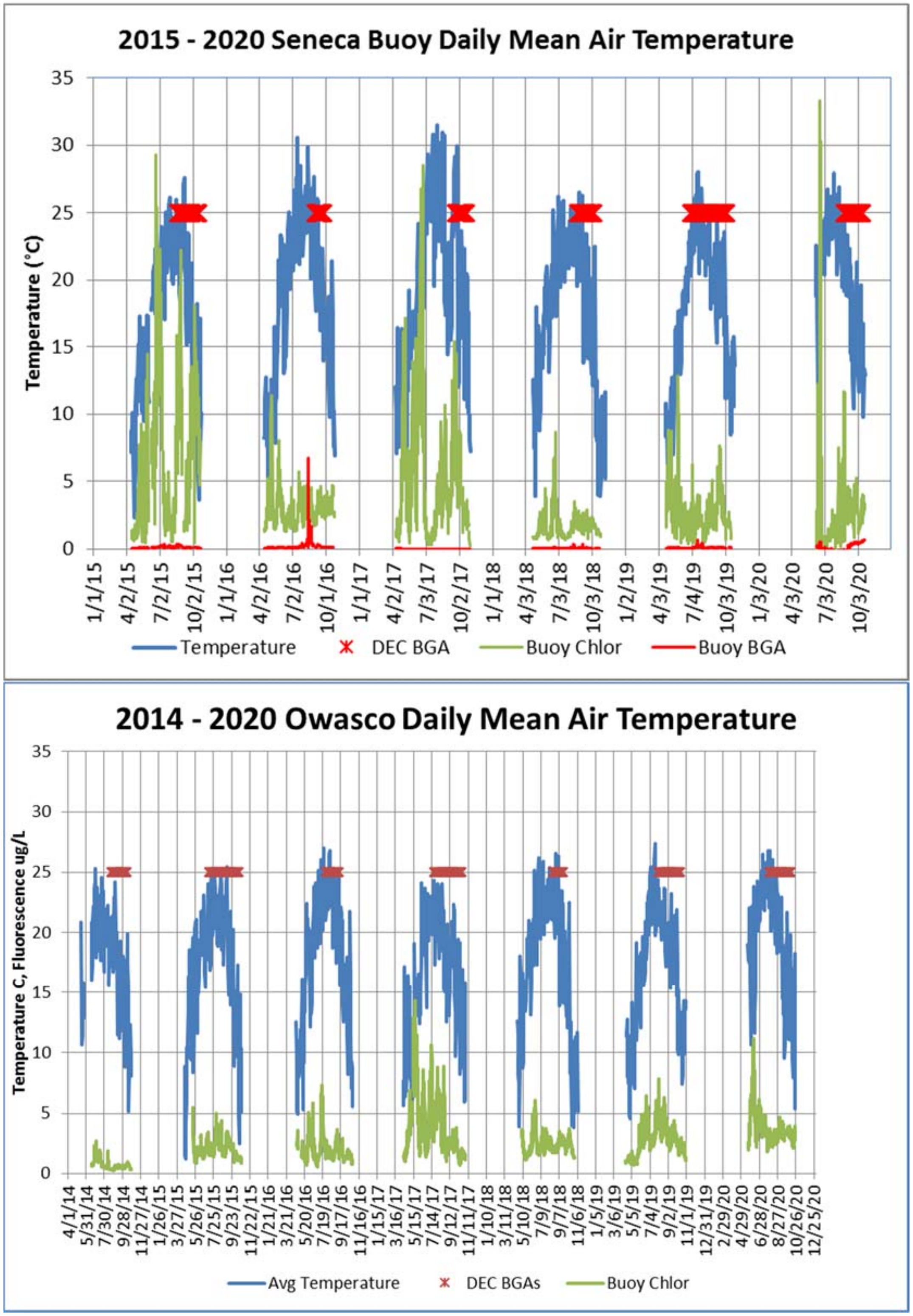
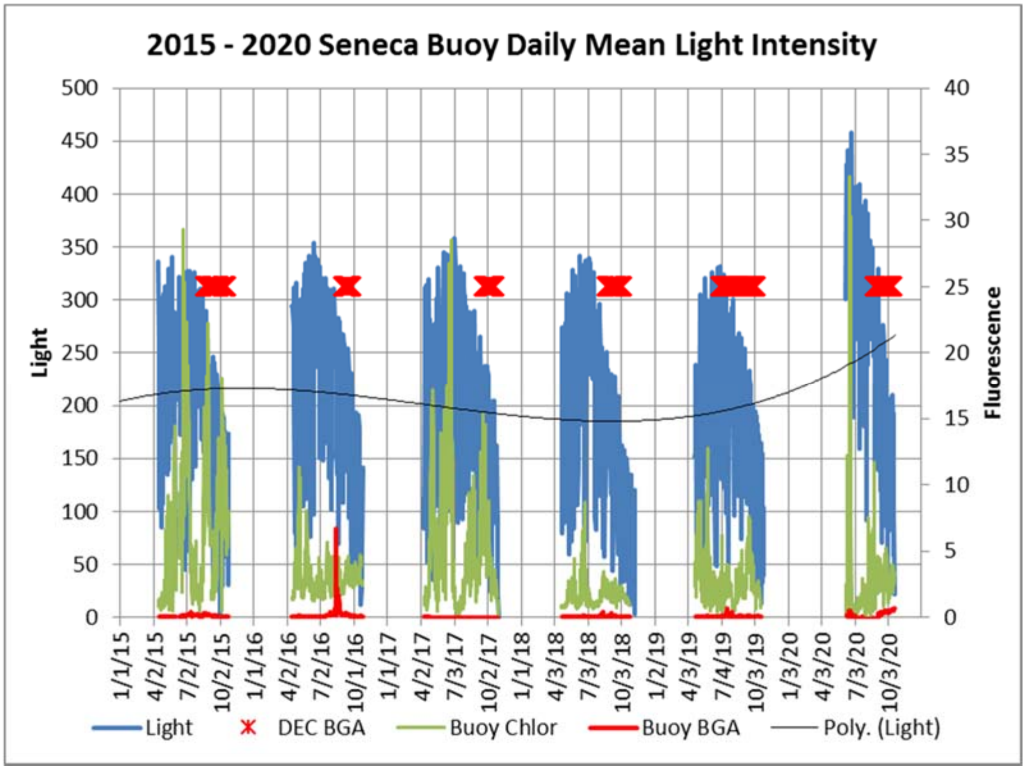


Fig. 12. Seven years of air temperatures at the Seneca (above) & Owasco (below) FLI Buoys. The 2020 Seneca data used the USGS buoy, anchored farther north than the FLI site in shallower water. The weeks these lakes were on DEC's Notification Page are also shown.

Buoy Sunlight Intensity: The first cyanobacteria blooms for the season typically happened after summer solstice, the day of maximum insolation for the year, and cyanobacteria blooms were no longer detected in this study when mean daily insolation (sunlight) decreased from just above 340 μE/cm^2 in mid-June to below 150 μE/cm^2 by mid to late October in both lakes (Fig. 13). The insolation data for 2020 from the USGS buoy are slightly larger than previous years by the FLI buoy and those detected at the dock sites. The increase is an artifact of using different sensors. FLI light intensity data are more consistent with the meteorological data from the dock sites. Warmest water and air temperatures also peaked after summer solstice and all three typically peaked before the cyanobacteria blooms. Lower light levels experienced in the early fall might favor cyanobacteria blooms because cyanobacteria can position themselves at depths with optimum light and nutrient levels. Thus, warmer air and water temperatures were detected after summer solstice, and the delayed timing favors blooms. However, blooms were NOT detected on every warm and sunny day. Thus, solar intensity, air and water temperatures were associated with, but were not the sole trigger for a bloom.

The similarity in sunlight intensity between lakes, and probably was not a reason for the difference in the 2020 cyanobacteria bloom counts in these two lakes as well.



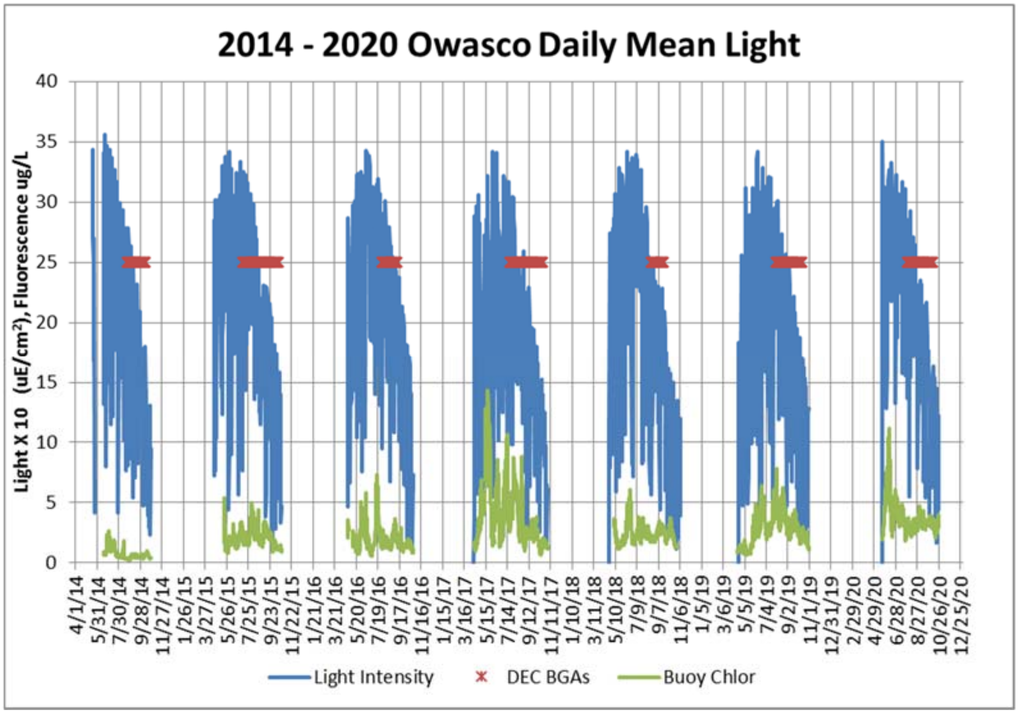


Fig. 13. Seven years of light intensity data at the Seneca & Owasco FLI Buoys. The 2020 Seneca data used the USGS buoy that used a different sensor thus different results. The weeks these lakes were on DEC's Notification Page are also shown.

Buoy Wind Speed & Direction: At both lakes, the summers of 2015, 2016, 2017 and 2019 were not as windy as 2018 and 2020 (Fig. 14). The mean daily wind speeds in 2015, 2016, 2017 and 2019 during August and September were at or below 10 mph (5 m/s, small waves) with only a few days with wind speeds above 15 mph (7 m/s, large waves with white caps). Fewer calm to light-breeze days and more days with wind speeds above 15 mph were detected during 2018 and 2020. Faster winds combined with large fetch distances in Seneca Lake would create larger waves to more severely impact the exposed shorelines in Seneca Lake compared to Owasco Lake. The increased wind speeds in 2020 parallels fewer detected blooms in Seneca Lake. Winds above 20 mph (8.9 m/s, very large waves with white caps) coincided with the end of the bloom activity in previous years. Perhaps these larger wind speeds in 2020 mixed any nearshore cyanobacteria and their nutrient sources throughout the entire epilimnion and towards open water, decreasing nearshore blooms in Seneca Lake.

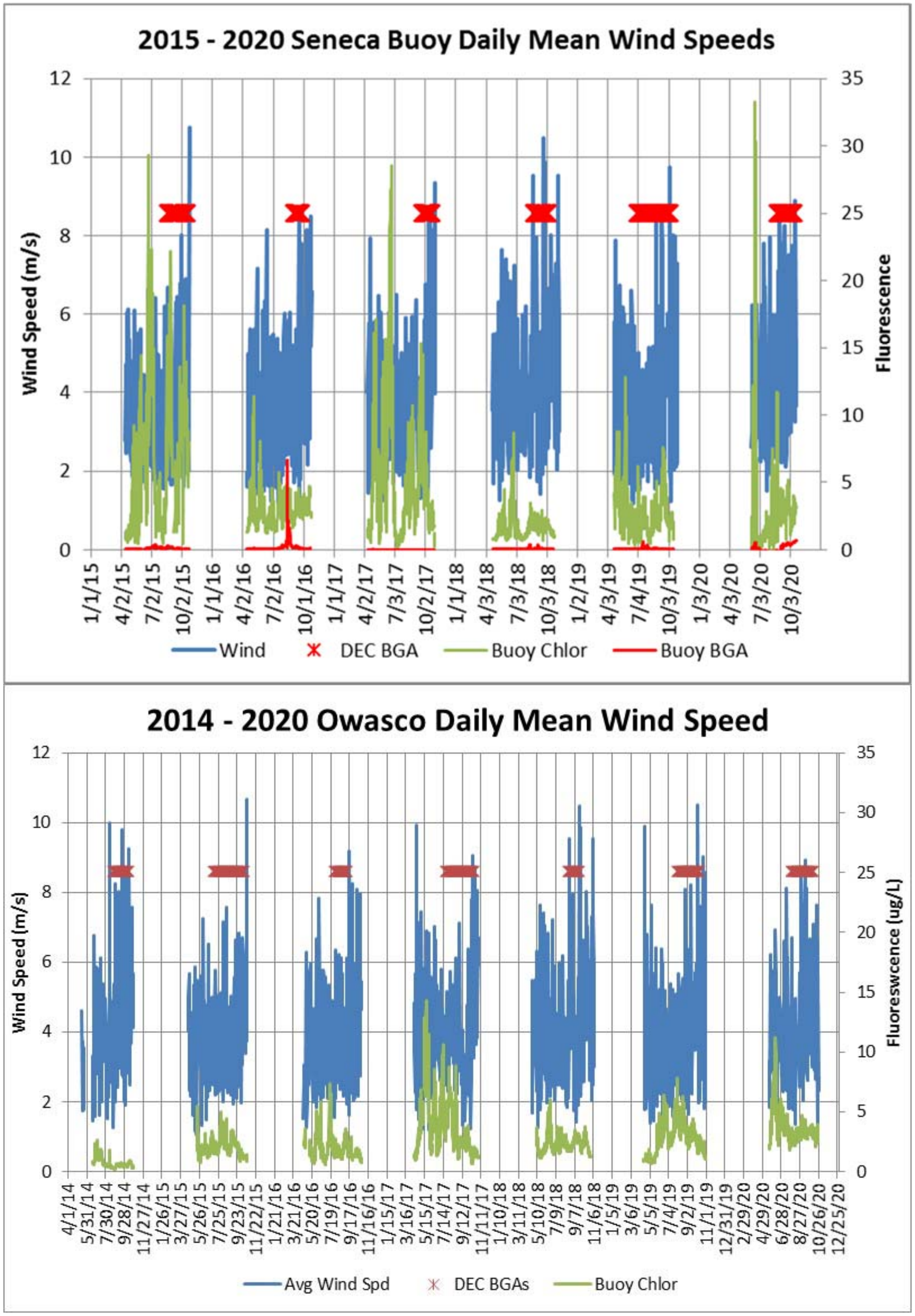


Fig. 14. Seven years of wind speed and light intensity data at the Seneca & Owasco FLI Buoys. The 2020 Seneca data used the USGS buoy, anchored farther north than the FLI site in shallower water. The weeks these lakes were on DEC's Notification Page are also shown.

Seasonal (1/2 month intervals) mean wind speeds at Seneca Lake during 2020 were fastest during the September through mid-October HABs season (Fig. 15). Fifteen wind events clocked wind speeds above 20 mph during this interval, wind speeds that terminated cyanobacteria blooms in past years. The August 31 blooms occurred during a calm period just after the first 15 to 20 mph wind event of 2020. It reaffirms that cyanobacteria prefer calm or nearly calm weather. It also suggests that the late August wind event stirred up nutrients that proliferated the following bloom, and perhaps subsequent wind events were too fast and occurred too frequently, and periods of calm or nearly calm weather were too infrequent for subsequent bloom development in Seneca Lake.

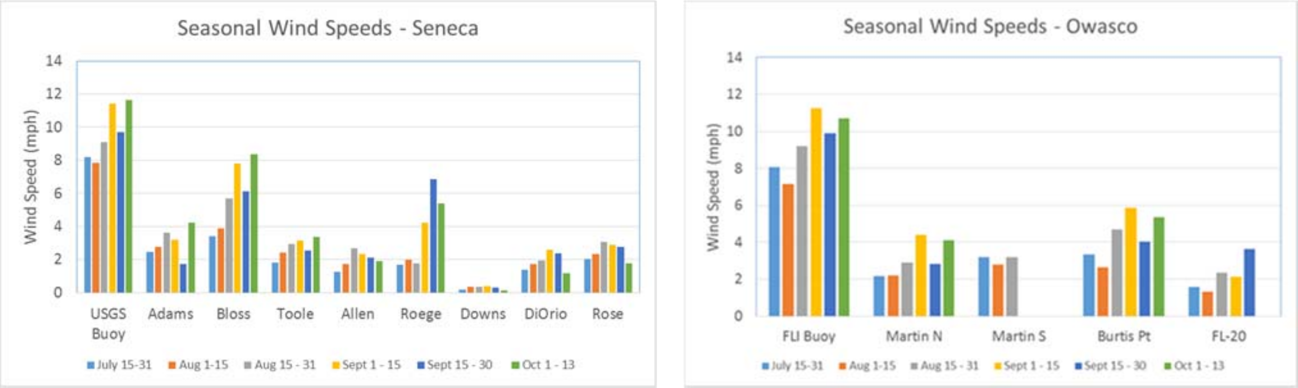


Fig. 15. Seasonal mean wind speeds at the buoy and dock sites in Seneca (left) and Owasco (right) Lakes.

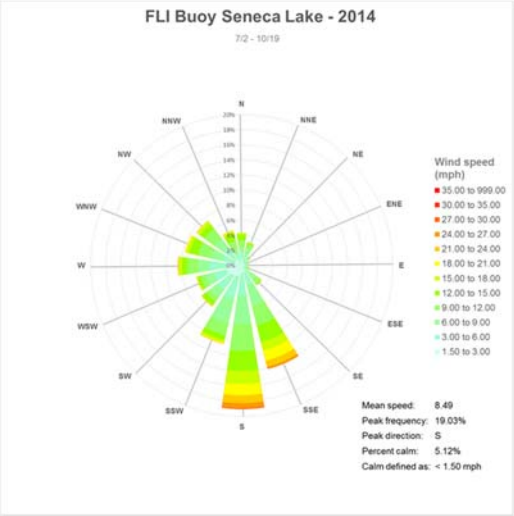
Annual mean wind speeds at Owasco Lake recorded faster winds in 2020 than earlier years as well. But Owasco Lake also experienced much larger bloom counts in 2020 than its windier weather should predict. A more detailed analysis indicates that the nearshore blooms occurred mostly during calm or relative calm days in 2020. Thus, cyanobacteria still prefer calm or nearly calm days to develop surface blooms along the shoreline and is more evident in the season distribution of wind speeds.

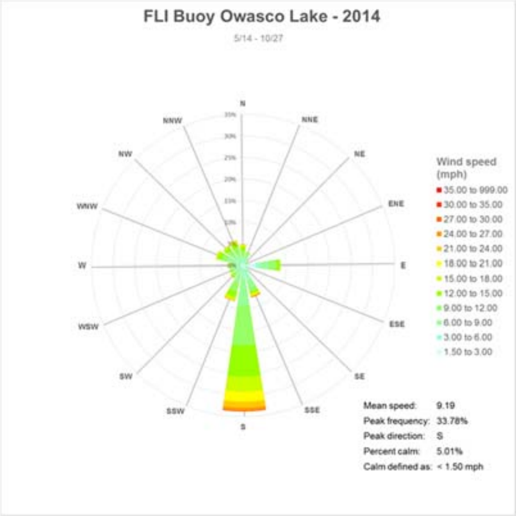
Seasonal mean wind speeds at Owasco Lake in 2020 also revealed windier conditions during most of the mid-August through mid-October HABs season with up to 10 events clocking wind speeds above 20 mph (Fig. 15). An important exception existed. Smaller mean wind speeds were measured in mid to late September. This period corresponds to the majority of the cyanobacteria blooms in Owasco Lake. Even though mean annual wind speeds were faster in 2020 in both lakes, apparently Owasco Lake experienced enough periods of calm weather, especially during late September, to promote the development of more cyanobacteria blooms than Seneca Lake.

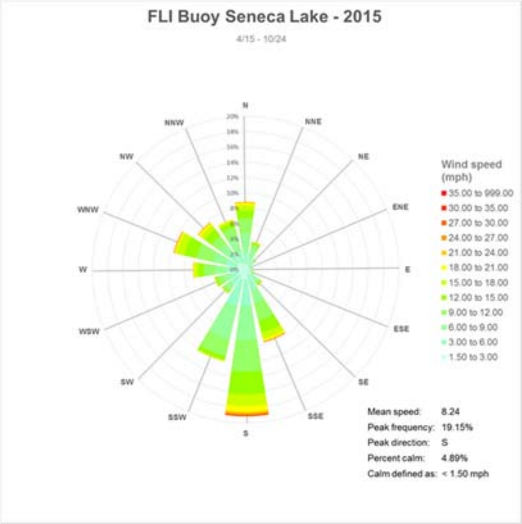
Wind speeds, and its seasonal distribution, are important for bloom genesis in lakes, and probably contributed to the difference in bloom counts in these two lakes.

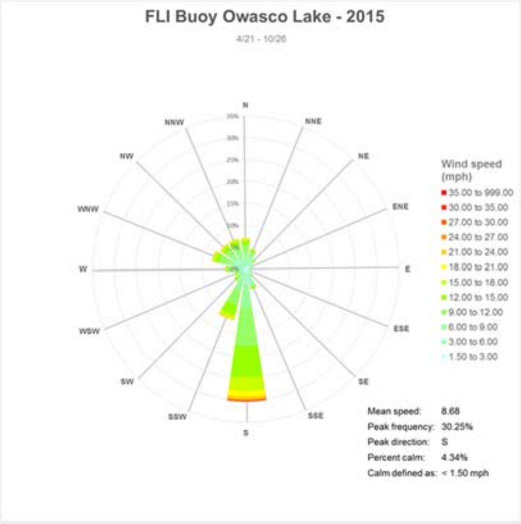
The dominant wind direction measured at the buoys was typically from the south, just east (SSE) or just west (SSW) of south, consistent with the North/South elongation of both lakes (Fig. 16). The dominant direction was slightly west of south (SSW) in 2014, 2015 and 2019, and this shift was more obvious in the Owasco data (Fig. 16). The next common wind directions were from the west, northwest and north, especially in Seneca Lake. The dominant southerly directions were consistent with the majority of the cyanobacteria blooms located along the northern and northeastern margins of both lakes (Fig. 5). A slight shift in the dominant wind direction in Owasco Lake to the SSE in 2020 potentially fostered significantly more blooms detected along the more protected, eastern shoreline than the exposed western shoreline (Fig. 5). If a similar slight eastward shift observed in Owasco Lake occurred at Seneca Lake in 2020, strong winds would have impact the northwestern shorelines (see dock site wind discussion below). Wind directions detected by local meteorological stations on land are significantly different than the directions detected by the lake buoys. So any shift in the dominant wind direction at Seneca Lake and its impact on bloom counts is open to speculation.

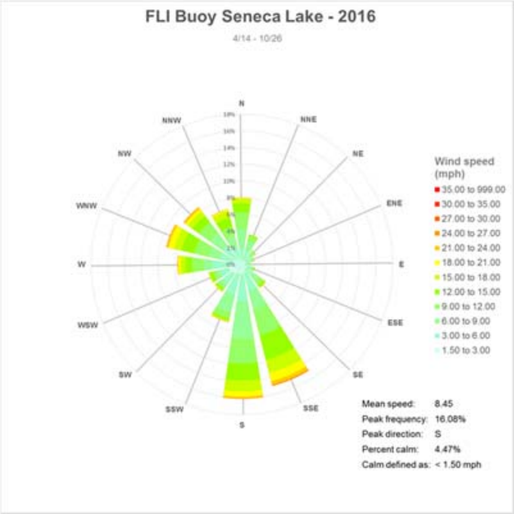
A suspected slight shift in wind direction may have contributed to the detection of fewer blooms in Seneca Lake but this linkage is open to speculation at this time.










FLI Buoy Seneca Lake - 2016
4/14 - 10/26
N
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Wind speed (mph)
35.00 to 999.00
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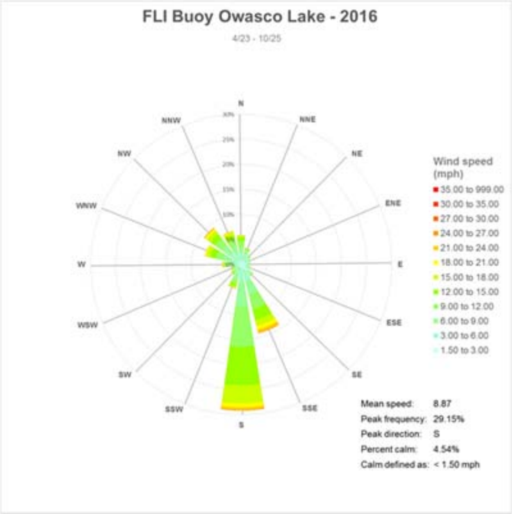
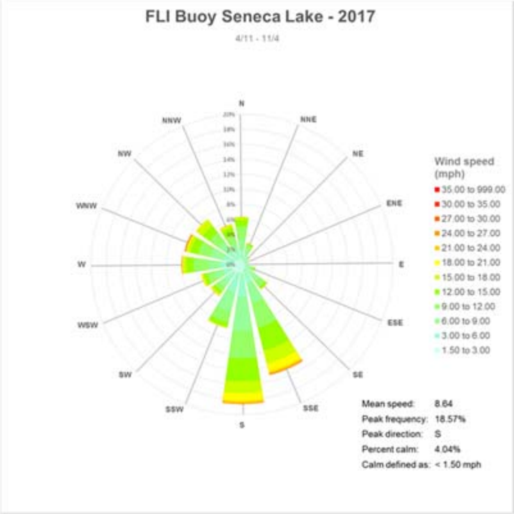
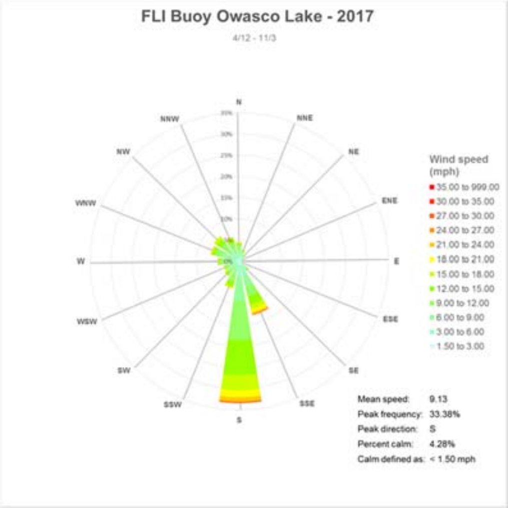
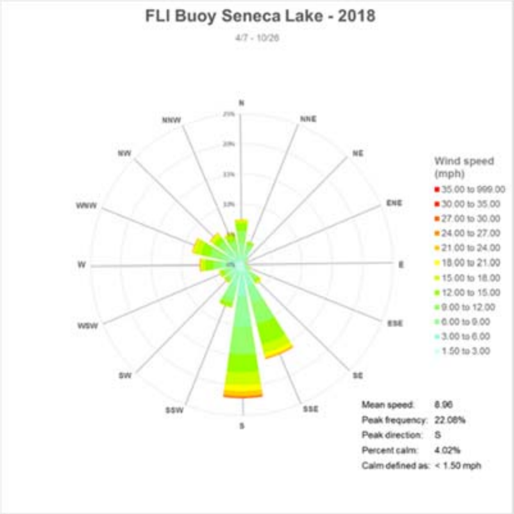
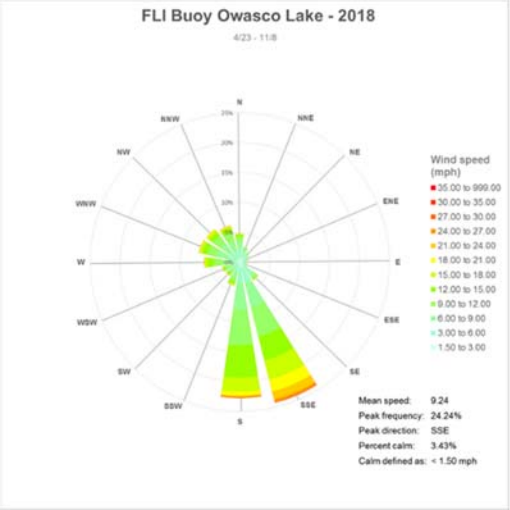
27.00 to 30.00
24.00 to 27.00
21.00 to 24.00
18.00 to 21.00
15.00 to 18.00
12.00 to 15.00
9.00 to 12.00
6.00 to 9.00
3.00 to 6.00
1.50 to 3.00
Mean speed: 8.45
Peak frequency: 16.08%
Peak direction: S
Percent calm: 4.47%
Calm defined as: < 1.50 mph


FLI Buoy Owasco Lake - 2016
4/23 - 10/25
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
Wind speed (mph)
35.00 to 999.00
30.00 to 35.00
27.00 to 30.00
24.00 to 27.00
21.00 to 24.00
18.00 to 21.00
15.00 to 18.00
12.00 to 15.00
9.00 to 12.00
6.00 to 9.00
3.00 to 6.00
1.50 to 3.00
Mean speed: 8.87
Peak frequency: 29.15%
Peak direction: S
Percent calm: 4.54%
Calm defined as: < 1.50 mph


FLI Buoy Seneca Lake - 2017
4/11 - 11/4
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
Wind speed (mph)
35.00 to 999.00
30.00 to 35.00
27.00 to 30.00
24.00 to 27.00
21.00 to 24.00
18.00 to 21.00
15.00 to 18.00
12.00 to 15.00
9.00 to 12.00
6.00 to 9.00
3.00 to 6.00
1.50 to 3.00
Mean speed: 8.64
Peak frequency: 18.57%
Peak direction: S
Percent calm: 4.04%
Calm defined as: < 1.50 mph


FLI Buoy Owasco Lake - 2017
4/12 - 11/3
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
Wind speed (mph)
35.00 to 999.00
30.00 to 35.00
27.00 to 30.00
24.00 to 27.00
21.00 to 24.00
18.00 to 21.00
15.00 to 18.00
12.00 to 15.00
9.00 to 12.00
6.00 to 9.00
3.00 to 6.00
1.50 to 3.00
Mean speed: 9.13
Peak frequency: 33.38%
Peak direction: S
Percent calm: 4.28%
Calm defined as: < 1.50 mph


FLI Buoy Seneca Lake - 2018
4/7 - 10/26
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
Wind speed (mph)
35.00 to 999.00
30.00 to 35.00
27.00 to 30.00
24.00 to 27.00
21.00 to 24.00
18.00 to 21.00
15.00 to 18.00
12.00 to 15.00
9.00 to 12.00
6.00 to 9.00
3.00 to 6.00
1.50 to 3.00
Mean speed: 8.96
Peak frequency: 22.08%
Peak direction: S
Percent calm: 4.02%
Calm defined as: < 1.50 mph


FLI Buoy Owasco Lake - 2018
4/23 - 11/8
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
Wind speed (mph)
35.00 to 999.00
30.00 to 35.00
27.00 to 30.00
24.00 to 27.00
21.00 to 24.00
18.00 to 21.00
15.00 to 18.00
12.00 to 15.00
9.00 to 12.00
6.00 to 9.00
3.00 to 6.00
1.50 to 3.00
Mean speed: 9.24
Peak frequency: 24.24%
Peak direction: SSE
Percent calm: 3.43%
Calm defined as: < 1.50 mph

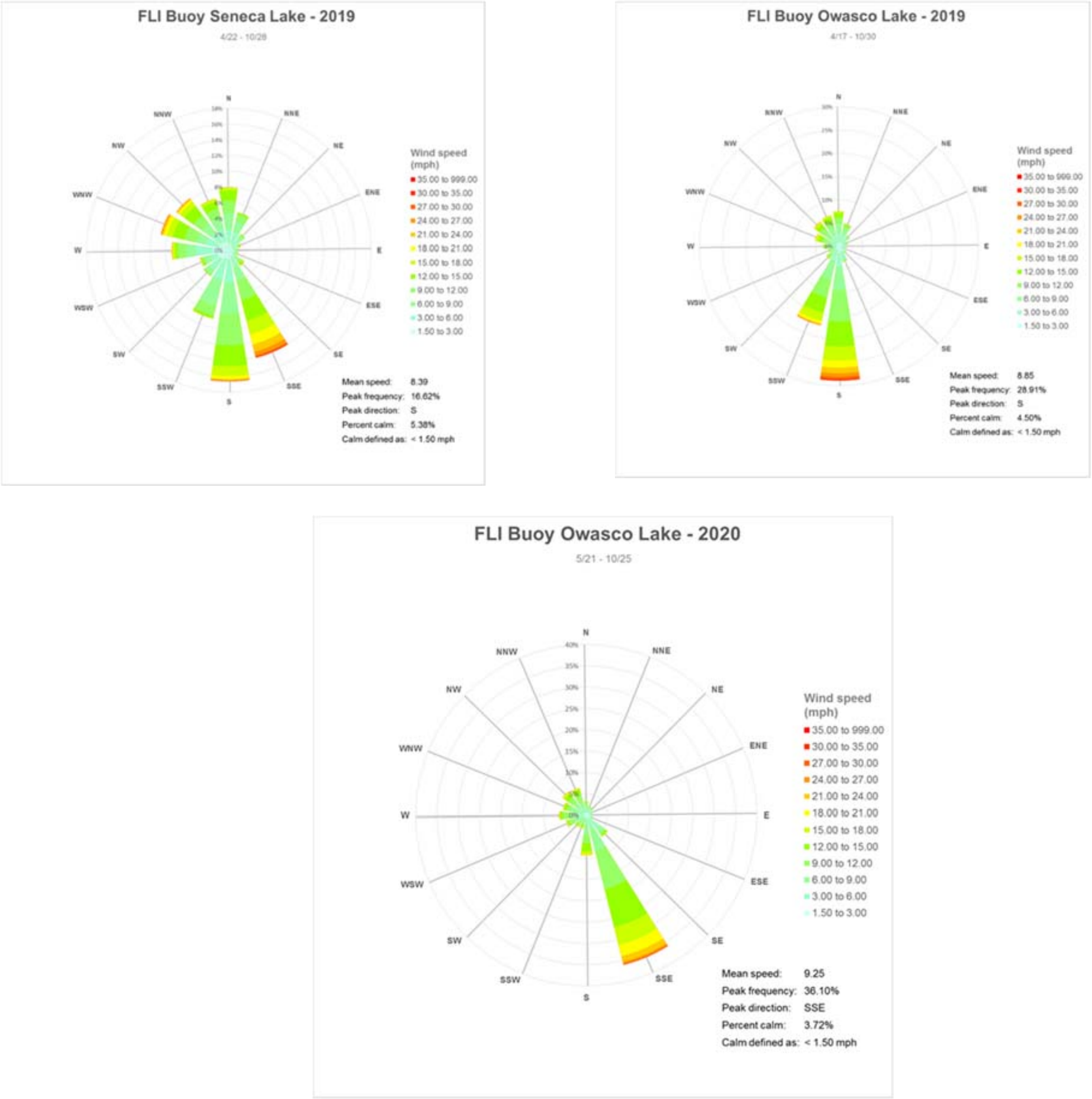
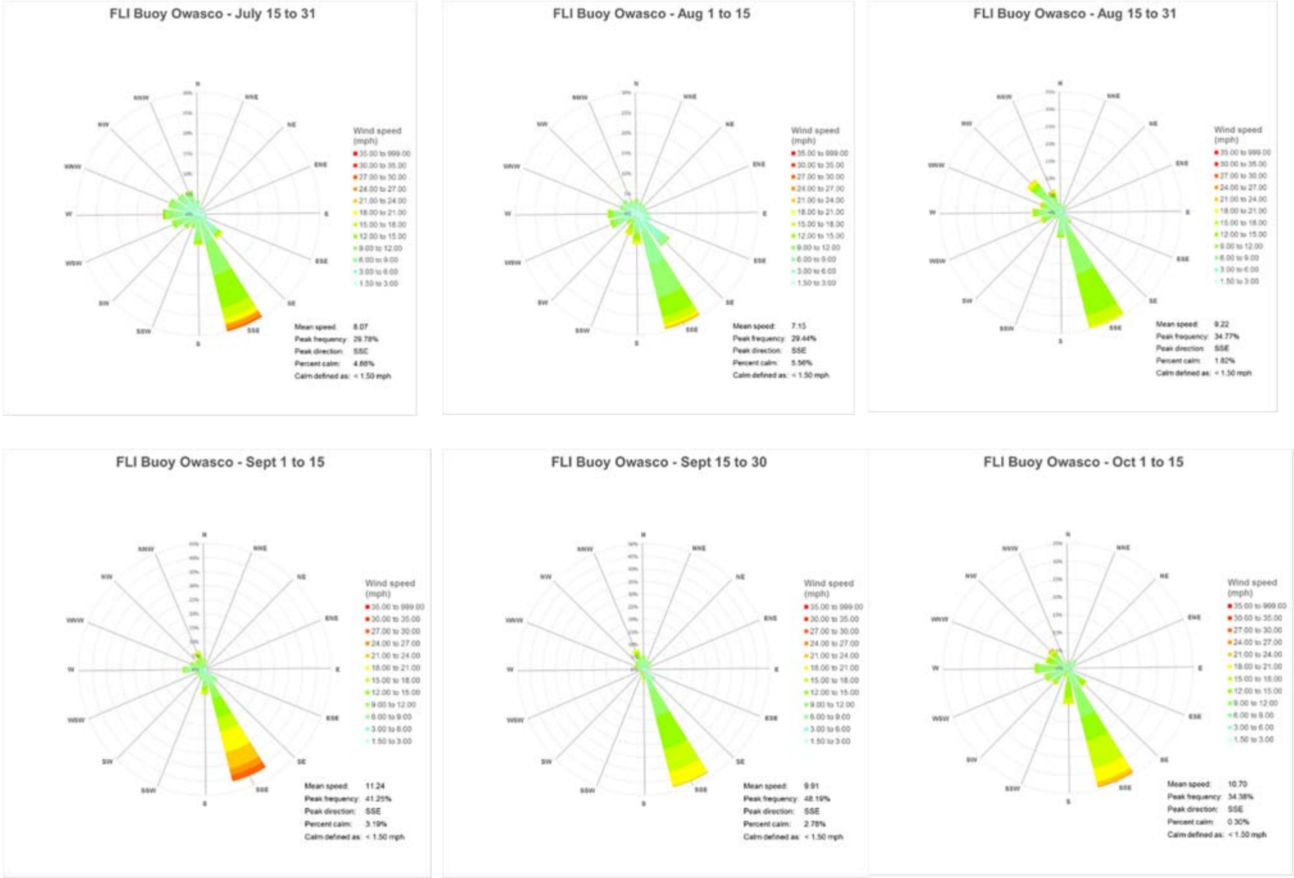


Fig. 16. Wind rose diagrams showing frequency of wind direction and speed during 2014 – 2019 at the Seneca Lake buoy (left) and 2014 – 2020 at Owasco buoy (right). Unfortunately, the USGS buoy did not record wind directions, and wind data from onshore meteorological stations do not mimic the lake buoy data.

Previously, it was suggested that the dominant winds might push surface cyanobacteria blooms towards the downwind shore. Direct observations noted the disruption of cyanobacteria blooms that formed on calm days after the development of even light winds. Apparently, wind and its vertical mixing of the water column by waves (gravity not capillary waves) are sufficient to overcome the buoyancy provided by the cyanobacteria gas vacuoles. Wind directions might still play a role in bloom genesis as dead macrophytes, *Cladophora* and other organic matter would concentrate along the downwind shoreline. The nutrients released by bacterial decomposition of the accumulated organics could be an important nutrient source for cyanobacteria blooms.

Wind direction did not seasonally change at the Owasco Buoy during 2020 (Fig. 17). The dominant winds blew from the SSE through the extent of the mid-August through mid-October HABs season.


FLI Buoy Owasco - July 15 to 31

FLI Buoy Owasco - Aug 1 to 15

FLI Buoy Owasco - Aug 15 to 31

FLI Buoy Owasco - Sept 1 to 15

FLI Buoy Owasco - Sept 15 to 30

FLI Buoy Owasco - Oct 1 to 15

Fig. 17. Season variability in wind direction and speed at the Owasco Lake recorded by the FLI buoy.

DOCK SITE RESULTS

Water Temperatures: Surface water temperatures revealed nearly consistent temperature records among the dock temperature loggers (deployed at 1-m depth) and surface water (1 m) temperatures detected offshore by the buoy within and between both lakes (Fig. 18). In Seneca Lake, the most northern site, NNW (Allen) experienced the warmest water through mid-September. The southern sites were few tenths of degree cooler than the northern sites and the monitoring buoy. The two southern sites, SW (Rose) and SEC (Toole), also experienced an occasional spike to cooler water temperatures (up to 8°C) from the other sites, most noticeably after a wind event. The lake floor at these southern sites descends quickly into very deep water without an extended nearshore shelf observed at the other nearshore sites. Perhaps internal seiche activity induced by these wind events more easily brought colder hypolimnetic (bottom) water to these southern sites.

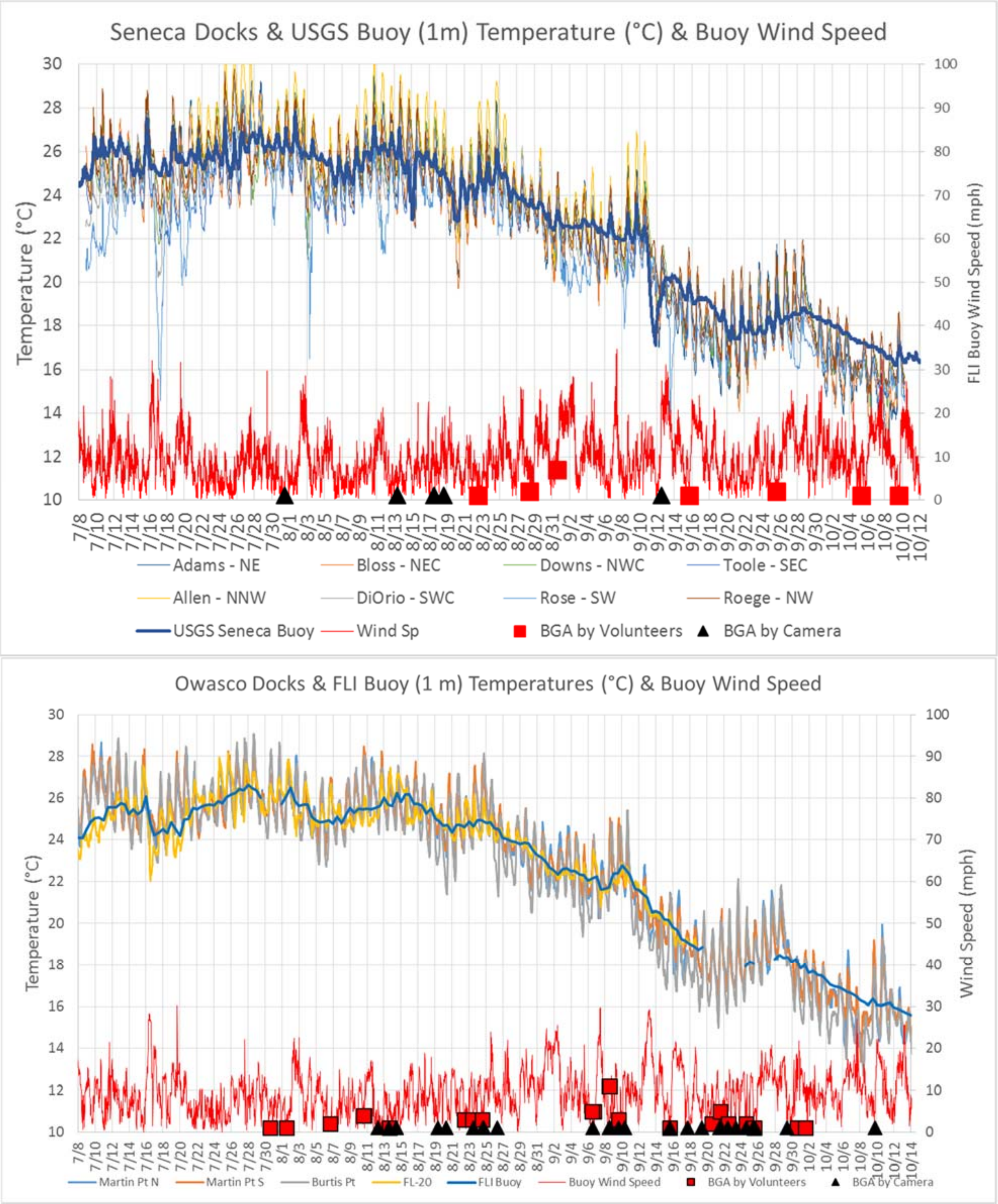


Fig. 18. The 2020 dock and buoy surface water temperatures, nearshore cyanobacteria blooms and mean daily wind speeds measured in Seneca (above) and Owasco (below) lake. A plot for each site is in the report's data repository.

Daily fluctuations in surface water temperatures were observed in both lakes, with a mean amplitude (daily maximum – minimum) of 0.5 to 5°C over the course of the study. The largest daily oscillations were detected at the northern sites, smaller oscillations at the southern sites, and smallest oscillations at the USGS buoy site (< 1°C). Similar daily fluctuations and spatial patterns were detected in previous years. The daily oscillations are interpreted to reflect the daily warming of the lake by the sun and radiative heat loss and evaporitic cooling of the lake at night, the heat transfer happening at the lake's surface. The differences in magnitude are expected, as shallow water masses are easier to warm (or cool) than deeper water masses during sunny (or cloudy) days and the differences observed here are probably related to the extent of the shallow water shelf at each site. The daily oscillations were subdued or absent when the wind was blowing onshore, as the movement by waves mix the water column.

Daily temperature oscillations were not detected at depth. Instead, the thermocline, the boundary between the colder bottom water and warmer surface water oscillated up and down, with a periodicity of a few days. The seesaw motion at the thermocline is interpreted as internal seiche activity in both lakes. The period of time between oscillations was longer in Seneca Lake due to its larger size (theoretically calculated at 1.6 vs. 1.2 days in Seneca and Owasco, respectively).

In Owasco Lake, daily cycles in surface water temperature also ranged from 0.5 to 5°C. The largest fluctuations were detected at the more isolated Burtis Pt location (mean amplitude of 4.1°C), and smallest at the southern Fire Lane 20 site (mean amplitude 1.8°C). Burtis Pt site is more protected from mixing events by a point of land and has an extensive shallow shelf, whereas the Fire Lane 20 site is exposed to deep water much closer to shore. The FLI buoy on Owasco Lake did not detected daily oscillations as only two temperatures are collected each day. However, the USGS Owasco Buoy detected oscillations and like Seneca Lake, the mean amplitude (~1°C) was smaller at this offshore, deeper water site. The occasional cooler spikes in water temperature were not observed in Owasco like Seneca, however only one site was located in the southern lake and data were not collected at this site after Sept 18, when wind events were more frequent, faster and more likely induce upwelling events. The lack of cooler spikes might also reflect the smaller size of Owasco Lake.

In addition to the 1-m dockside temperature loggers, water temperatures were measured at the lake's surface (a few cm below the lake's surface) at the dock sites (see data repository). These loggers recorded warmer temperatures, typically 2 but up to 4°C warmer, than the 1-m loggers, especially at the northern sites during calmer, sunnier days, and recorded more similar temperatures as the 1-m logger on windier and cloudier days. Isothermal (similar) temperatures were detected at night. It indicates that even the nearshore water column periodically stratified, warmer water overlying cooler water. The surface water warmed during the daylight hours and the stratification would break down at night, and suggests warming by the sun during the day and radiative and evaporative cooling at night. Diminished thermal stratification occurred during water column mixing by winds and/or decreased solar insolation.

Larger temperature deviations were occasionally observed in the surface float temperature data, but the majority of these deviations occurred when the surface floats got stuck on a dock leg (e.g., Martin S), and the logger recorded cooler air temperatures.

Blooms were more often detected when the nearshore water column was stratified in Owasco Lake (stratification observed for 21 of 24 camera detected blooms). Perhaps stratification enabled the cyanobacteria with their internal gas vacuoles to more easily float at the surface of the lake. It also confirms that calm or near calm conditions with sunny skies that fostered stratification also favored bloom development. However, blooms were not detected during every stratified event nor every calm or nearly calm day in Owasco Lake. Despite stratified nearshore events in Seneca Lake, blooms were rarely detected in Seneca Lake during 2020.

Thermal stratification of the nearshore waters is typically concurrent with bloom genesis but does not explain the differences in blooms counts between these two lakes.

Like previous years, the 2020 August and early September shoreline cyanobacteria blooms were occasionally preceded by a lake-wide decrease (up to 5°C) in temperature in both lakes. Unlike previous years, the 2020 dips in temperature were not as pronounced. Lake-wide temperature declines in the surface water may reflect cooler air, cloudier conditions, and/or wind/storm events that generate surface waves and internal seiche activity ultimately mixing some colder hypolimnetic water into the epilimnion. These same events could also introduce nutrient-rich hypolimnetic waters to the nearshore areas and release nutrients buried in nearshore sediments from decaying macrophytes, mussel poop, and other sources of organic matter. This suggests that waves and internal seiche activity might be an important nutrient source to propagate cyanobacteria blooms. Both lakes revealed a similar surface water temperature record but incongruent bloom histories in 2020. A lack of mid-summer mixing events may help explain the lack of substantial temperature declines in 2020.

As in previous years, dips in temperature observed in the early summer did not result in cyanobacteria blooms. The delay to late summer may reflect the time required for bacteria to increase the nutrient concentrations in the hypolimnion and nearshore sediments to promote cyanobacteria blooms. Bacterial decay is also faster in warmer temperatures. The macrophytes and other attached plants like *Cladophora* also need time to grow, mature and die. Once they die or get uprooted by wind events, their biomass, once decayed, probably contributed to the nutrient pool in nearshore areas.

Lake-wide surface water temperature dips promote blooms but are not the sole trigger for nearshore blooms nor do they explain the difference in bloom counts in these two lakes.

Automated Cameras: The Brinno cameras recorded ~2 x 3 meter images of the lake from 7/8 through 10/10, a 94 day deployment in Seneca Lake; and 7/7 through 10/14, a 99 day deployment at Owasco Lake in 2020. Positioning the camera closer to shore in 2020 compared to 2019 detected multiple blooms within a meter of the shoreline that would have been missed in 2019. Consistently positioning the camera to collect images towards the north in 2020 minimized glare from the sun, and suggests that careful camera orientation corrected a glare issue that hampered image analysis in 2019. Camera power or memory issues in 2020 hampered image recovery, especially the cameras at situated at the Downs (26 days missed), Rose (41), Adams (28), Bloss (64) and Fire Lane 20 (25) sites. Perhaps water found its way into the camera housing and slowly degraded the electronics over time. It suggests that these cameras have a short useful lifetime in harsh environments, and the faulty cameras identified above should be replaced with new ones in future deployments.

The cameras detected from 0 to 1 cyanobacteria appearances at each site in Seneca Lake and from 0 to 17 blooms at each site in Owasco Lake (Table 2, Fig. 19, daily logs are in the data repository). Like the volunteer data presented above, Seneca Lake experienced far fewer blooms than Owasco Lake in 2020 at these sites. At Owasco Lake, blooms were detected throughout the day but favor the early afternoon, whereas the occasional bloom appeared earlier in the morning at Seneca Lake (Fig. 19). The cameras appeared to faithfully record the presence or absence of blooms at each deployed site.

More importantly, a larger number of blooms were detected at the northern sites than Fire Lane 20. These northern sites have a more extensive shallow-water shelf in Owasco Lake. The extent of shallow water areas near a specific site might provide more (or less) area for the development of more (or less) macrophytes and other benthic plants like *Cladophora*. Therefore, sites with extensive shelves potentially have a greater nutrient source for bloom development. Future benthic surveys should confirm this hypothesis.

Each bloom lasted from 0.2 to 9.3 hours in a given day and averaged 3 hours. Dockside cyanobacteria concentrations were measured by FluoroProbe in Owasco Lake during the dock visits, and concentrations during identified blooms were significantly above 25 mg/L, the minimum threshold to be classified as a DEC confirmed bloom. Even though the other blooms imaged in this lake lacked concurrent water samples, the images revealed similar surface appearances/algal densities to those above and thus suggests that most the imaged cyanobacteria blooms were concentrated enough to be a confirmed bloom. Some of the blooms identified in the Seneca Lake images at the Adams site were suspect and instead might have been dark green coloration of the water column from rotting *Cladophora* or other plant debris, especially early in the field season. The faster wind speeds during the suspect "blooms" at this site confirm this suspicion, i.e., consistent with ripping up and imaging benthic plants and not cyanobacteria blooms during calm or nearly calm conditions.

Table 2. Brinno Automated Camera Results Seneca & Owasco Lakes

Camera Results (in days)	NNW Allen	NW Roege	NWC Downs	SWC DiOrio	SW Rose	NE Adams	NEC Bloss	SEC Toole
Blooms Detected (unknown conc.)	0	1	1	0	0	5**	0	0
Turbid Water (lake floor invisible)	18	48	14	51	9	44	15	19
Clear Water (lake floor visible)	57	44	47	37	37	13	8	68
Glare Impacted Image	0	0	0	0	0	0	0	0
Camera Malfunctioned*	7	1	26	0	41	28	64	0
SLPWA Volunteers (#Blooms)	0	0	0	0	1	2	0	0
Calm Winds (<1 mph average)	12	18	88	16	12	21	3	15
Sunny Skies (> 130 W/m^2)	52	64	54	44	59	22	67	65

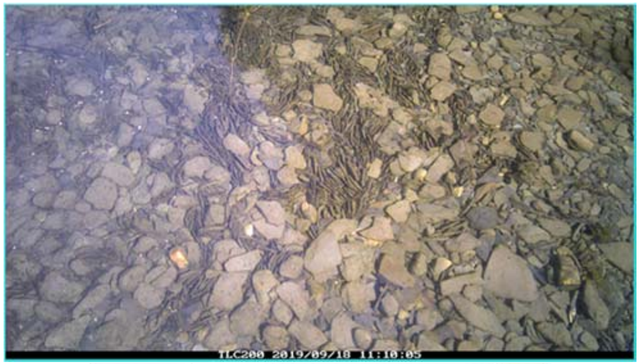
Camera Results (in days)	Martin Pt N	Martin Pt S	Burtis Pt	Fire Lane 20
Blooms Detected (unknown conc.)	9	17	12	0
Turbid Water (lake floor invisible)	13	13	8	6
Clear Water (lake floor visible)	83	81	89	67
Glare Impacted Image	0	0	0	0
Camera Malfunctioned*	0	0	0	25
OWLA Volunteers (#Blooms)	1	2	0	0
Calm Winds (<1 mph average)	19	7	11	16
Sunny Skies (> 130 W/m^2)	99	47	94	70

*faulty camera or power issues. Cameras might have gotten wet early in the field season. A few cameras had issues recording images every 10 minutes near the end of the field season, and others drained batteries quickly.
**some of these identification were probably not cyanobacteria but instead green "goo" from rotting plants.

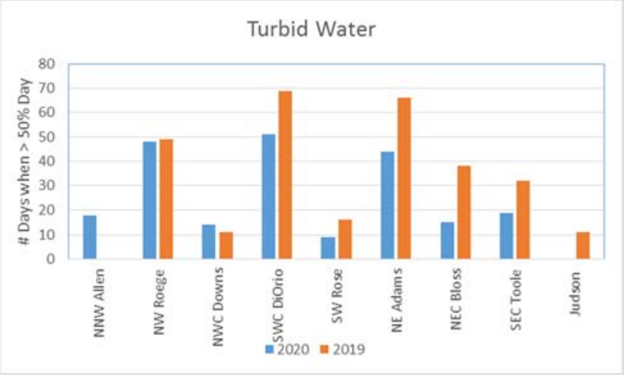

TLC200 2019/10/08 13:30:04

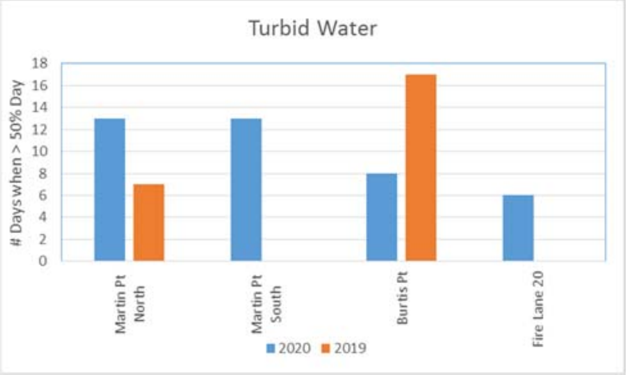

TLC200 2019/10/08 13:10:05


TLC200 2019/08/06 10:30:05


TLC200 2019/09/18 11:10:05


TLC200 2019/09/05 16:10:04


Turbid Water
Days when > 50% Day
0
10
20
30
40
50
60
70
80
NNW Allen
NW Roege
NWC Downs
SWC DiOrio
SW Rose
NE Adams
NEC Bloss
SEC Toole
Judson
■ 2020 ■ 2019


Turbid Water
Days when > 50% Day
0
2
4
6
8
10
12
14
16
18
Martin Pt North
Martin Pt South
Burtis Pt
Fire Lane 20
■ 2020 ■ 2019

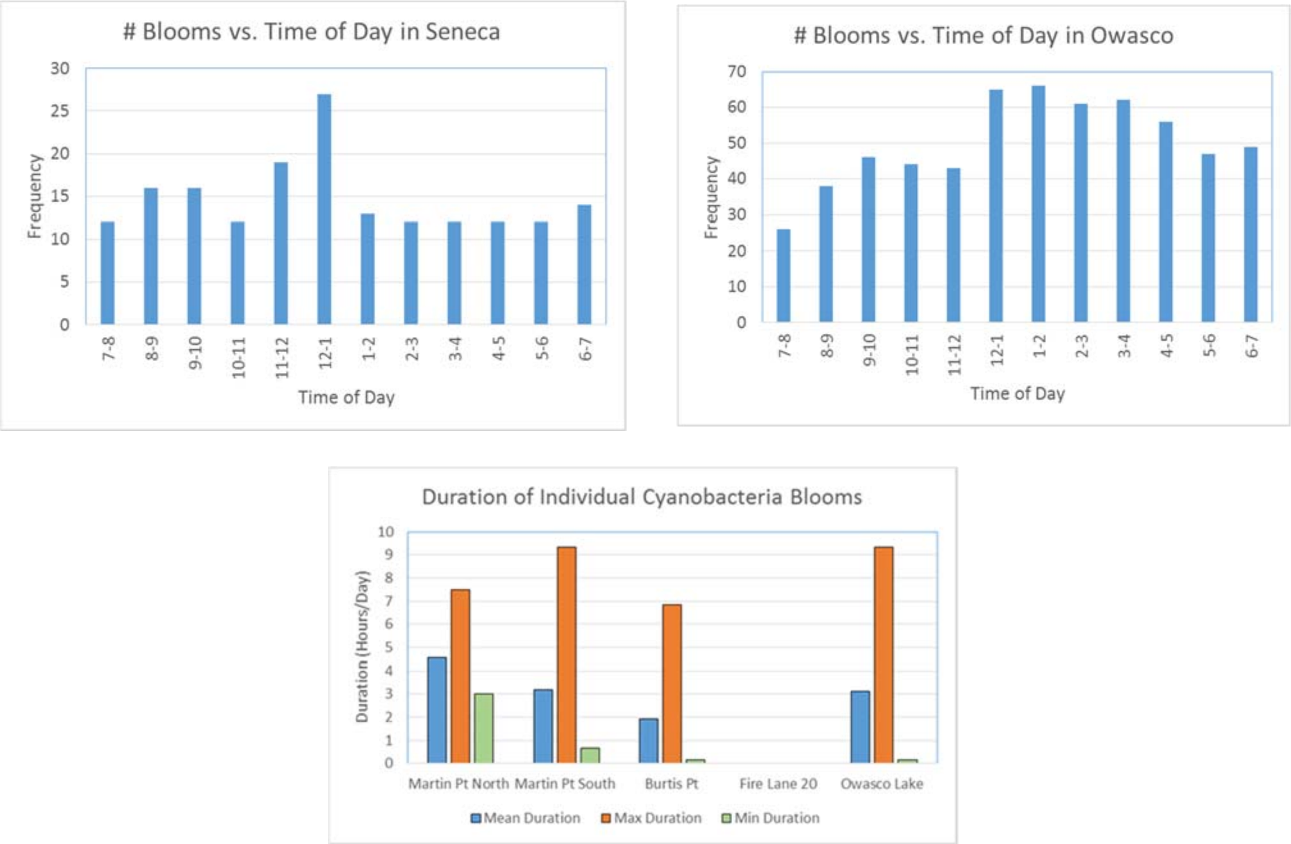


Fig. 19. Example camera images from 2019 revealing cyanobacteria appearances (top), turbid and clear conditions (2nd row), a sandy bottom subsequently covered by leaves and organic debris (3rd row). Similar images were collected in 2020. The frequency of turbid days in 2019 and 2020 at Seneca and Owasco Lakes (4th row). A tally of bloom frequency and duration (Owasco only) detected in Seneca and Owasco images (bottom).

Seneca Lake Pure Waters Association HABs volunteers detected a similar number of blooms in the surveillance "zones" adjacent to the camera, but like 2019, blooms were typically detected on different dates by the different methods. Owasco HABs volunteers detected fewer blooms at the camera sites. Perhaps the volunteers missed blooms during other times of the day, other days of the week (likely as volunteer surveys were only once a week), and/or they focused their surveys outside of the camera's field of view.

The images also differentiated between turbid (lake floor invisible) and clear water (lake floor visible) episodes, and occasionally detected fish, ducks, swimmers and other animals (daily logs are tabulated in the data repository). Days with turbid and clear water also varied from site to site across the lake, and paralleled when the wind was blowing onshore (turbid) or not (clear). In Owasco Lake, a twig influenced the shoreline parallel northward migration of the bloom at Martin N (lower right photo, Fig. 19). Migrating blooms were also noted by HABs volunteers. Although current meters are expensive, perhaps nearshore currents should be measured at selected sites in the future.

The number of days with turbid water increased at DiOrio, Rose, Adams, Bloss, Toole and Burtis Pt sites from 2019 to 2020 (Fig. 19). The increase reflects faster winds blowing onshore. The increase is surprising as turbidity was defined as not seeing the lake floor in the images.

Moving the cameras closer to shore, and thus imaging shallower water, should have decreased turbidity not increased it. These factors suggest that more sites experienced increased turbidity in 2020.

One set of images collected from the Martin N site were informative on bloom development (Fig. 20). As small, cm-high, waves with relatively clear water lapped onto the organic debris littered shoreline, the receding water was full of cyanobacteria. It suggests that the cyanobacteria originated from within the shoreline pile of debris, and is consistent with this material providing a source of nutrients for cyanobacteria blooms. Cell phone images from just south of the Burtis Pt site on 9/9, revealed more cyanobacteria adjacent to larger piles of accumulating organic debris along the shoreline than small piles or no macrophytes along the shoreline (Fig. 20).

Decaying organic matter probably provides an important nutrient source for nearshore cyanobacteria blooms.

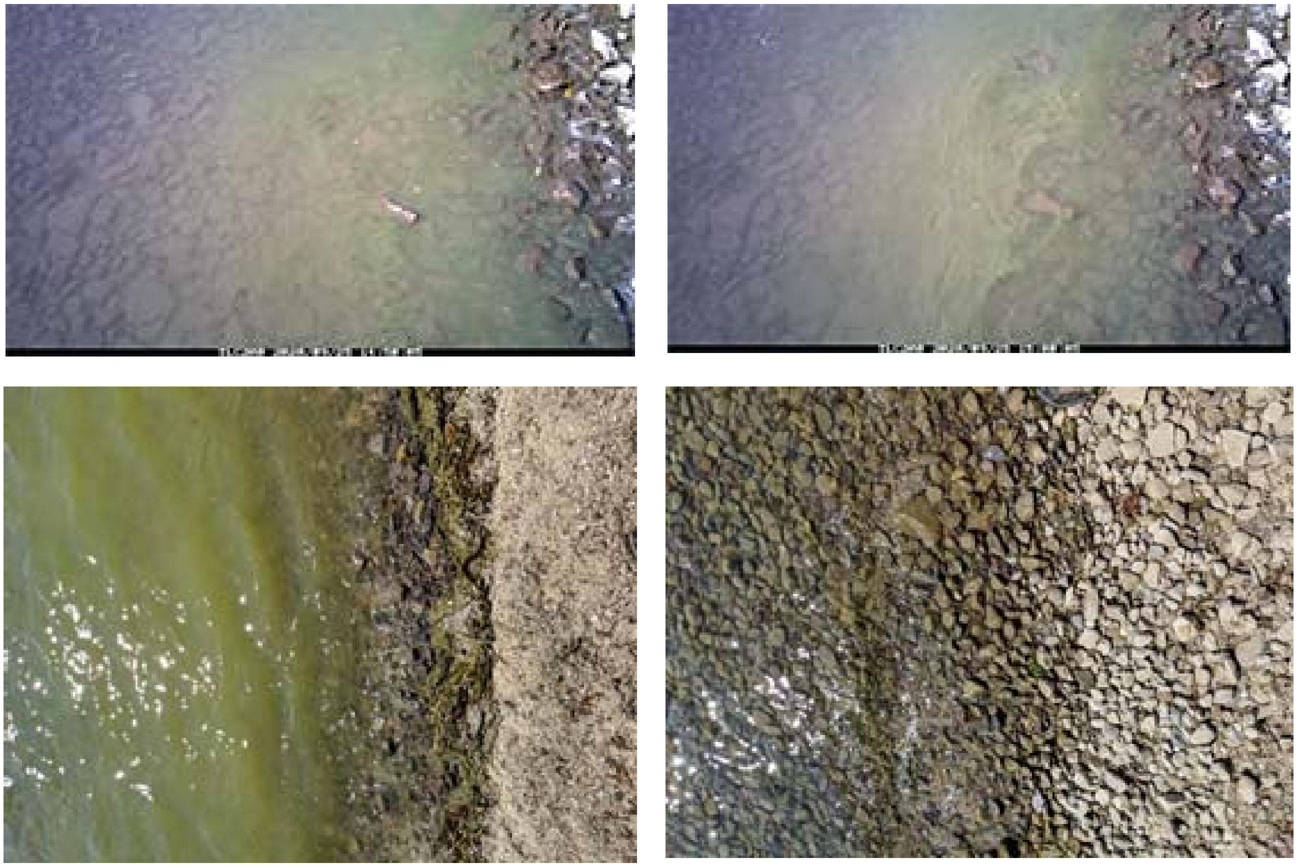


Fig. 20. Cyanobacteria were more abundance in the back wash moving away from shore (above left) than waves lapping onto (above right) a macrophyte covered shoreline. Larger cyanobacteria concentrations (below right) were detected adjacent to larger piles of macrophytes than smaller piles or no macrophytes (below left) along the shoreline.

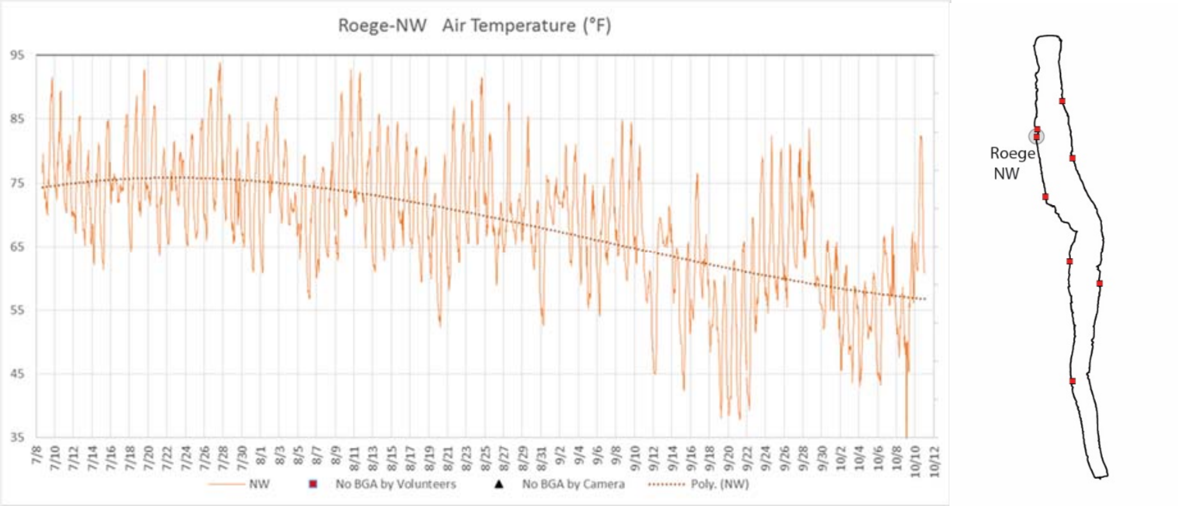
Nearshore Weather: Air temperature, rainfall, solar radiation, wind speed and direction data are consistent with cyanobacteria blooms occurring after wind/rain events on the next calm or nearly calm sunny day. Weather data from the NW site (Roege) in Seneca Lake and Martin N site in Owasco Lake are shown (Fig. 21). Data from the other sites on Seneca and Owasco Lakes are available in the companion data repository. A few issues were noted. A few weather stations initialized with the wrong date & time (e.g., Jan 1, 2017) but it was correctable. Two others blew over in strong gusts of wind. Subsequently, each mast support was augmented with string. These two meteorological sensors might need replacement in future deployments. One site, Martin S had a later start (7/12), missed readings on 7/13, and an early end 8/31, due to a delay while a suitable location was identified for the monitor, and failure of the monitor to reconnect with the weather sensors after a power loss.

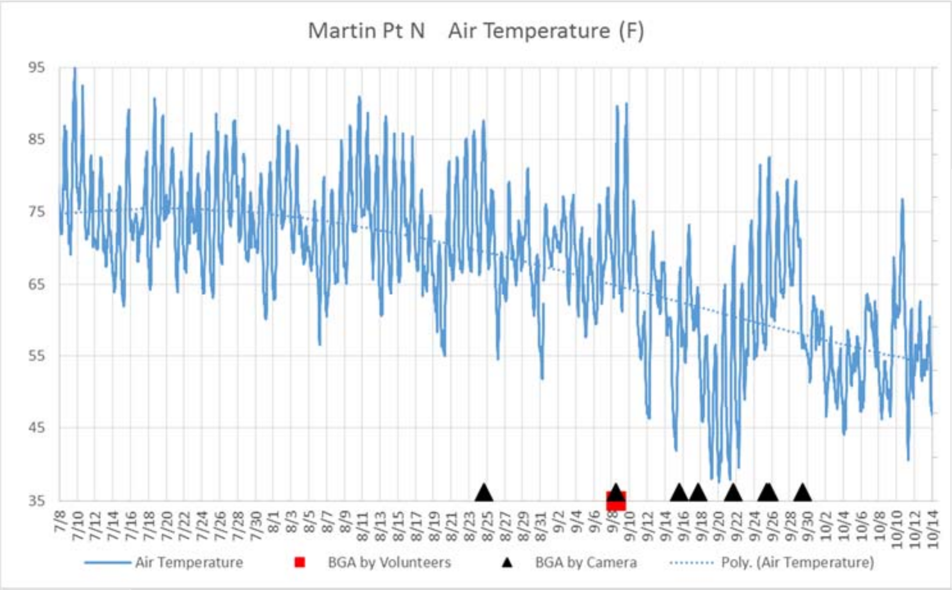
In Owasco Lake, cool air temperature, cloudy skies, windy conditions and occasionally some rain preceded most cyanobacteria appearances at the sites. The blooms occurred on the next sunny, calm or nearly calm day. For example, the mean wind speed during blooms was slower than the mean for the entire deployment at those sites with detected blooms in Owasco Lake (Fig. 22, Table 3). The infrequent blooms in Seneca Lake and the non-bloom character of the greenish “goo” identified as blooms at the Adams site are inconsistent with this interpretation.

Blooms were detected on calm or nearly calm days but not every calm and nearly calm day.

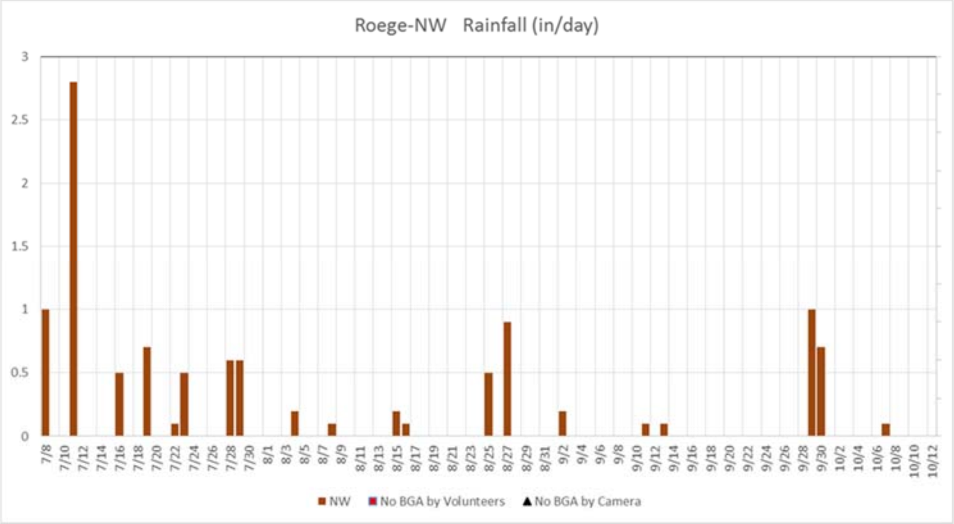
Table 3. Mean wind speeds (mph) during cyanobacteria blooms and over the entire field season.

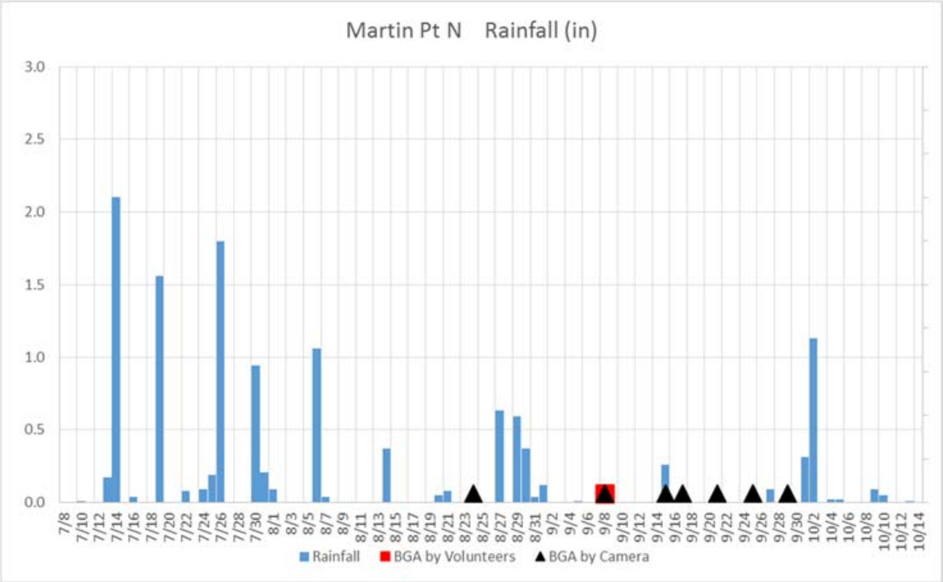
Site	Cyanobacteria Blooms	Season	Site	Cyanobacteria Blooms	Season
NNW Allen	n/a	2.9	SW-Rose	n/a	2.4
NW-Roege	3.5	3.4	NE-Adams	n/a	2.9
NWC-Downs	2.6	0.3	NEC-Bloss	n/a	5.6
SWC-DiOrio	n/a	1.9	SEC-Toole	n/a	2.6
Martin N	1.0	3.1	Burtis Pt	1.8	4.3
Martin S	1.6	3.0	Fire Lane 20	n/a	1.9

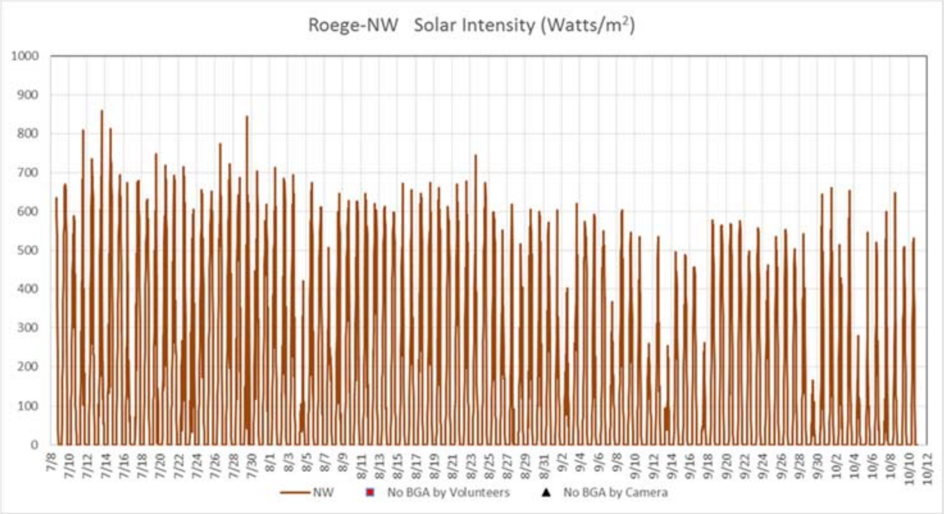



Martin Pt N Air Temperature (F)
95
85
75
65
55
45
35
7/8 7/10 7/12 7/14 7/16 7/18 7/20 7/22 7/24 7/26 7/28 7/30 8/1 8/3 8/5 8/7 8/9 8/11 8/13 8/15 8/17 8/19 8/21 8/23 8/25 8/27 8/29 8/31 9/2 9/4 9/6 9/8 9/10 9/12 9/14 9/16 9/18 9/20 9/22 9/24 9/26 9/28 9/30 10/2 10/4 10/6 10/8 10/10 10/12 10/14
Air Temperature
BGA by Volunteers
BGA by Camera
Poly. (Air Temperature)


Martin N


Roege-NW Rainfall (in/day)
3
2.5
2
1.5
1
0.5
0
7/8 7/10 7/12 7/14 7/16 7/18 7/20 7/22 7/24 7/26 7/28 7/30 8/1 8/3 8/5 8/7 8/9 8/11 8/13 8/15 8/17 8/19 8/21 8/23 8/25 8/27 8/29 8/31 9/2 9/4 9/6 9/8 9/10 9/12 9/14 9/16 9/18 9/20 9/22 9/24 9/26 9/28 9/30 10/2 10/4 10/6 10/8 10/10 10/12
NW
No BGA by Volunteers
No BGA by Camera


Martin Pt N Rainfall (in)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
7/8
7/10
7/12
7/14
7/16
7/18
7/20
7/22
7/24
7/26
7/28
7/30
8/1
8/3
8/5
8/7
8/9
8/11
8/13
8/15
8/17
8/19
8/21
8/23
8/25
8/27
8/29
8/31
9/2
9/4
9/6
9/8
9/10
9/12
9/14
9/16
9/18
9/20
9/22
9/24
9/26
9/28
9/30
10/2
10/4
10/6
10/8
10/10
10/12
10/14
Rainfall
BGA by Volunteers
BGA by Camera


Roege-NW Solar Intensity (Watts/m²)
1000
900
800
700
600
500
400
300
200
100
0
7/8
7/10
7/12
7/14
7/16
7/18
7/20
7/22
7/24
7/26
7/28
7/30
8/1
8/3
8/5
8/7
8/9
8/11
8/13
8/15
8/17
8/19
8/21
8/23
8/25
8/27
8/29
8/31
9/2
9/4
9/6
9/8
9/10
9/12
9/14
9/16
9/18
9/20
9/22
9/24
9/26
9/28
9/30
10/2
10/4
10/6
10/8
10/10
10/12
NW
No BGA by Volunteers
No BGA by Camera

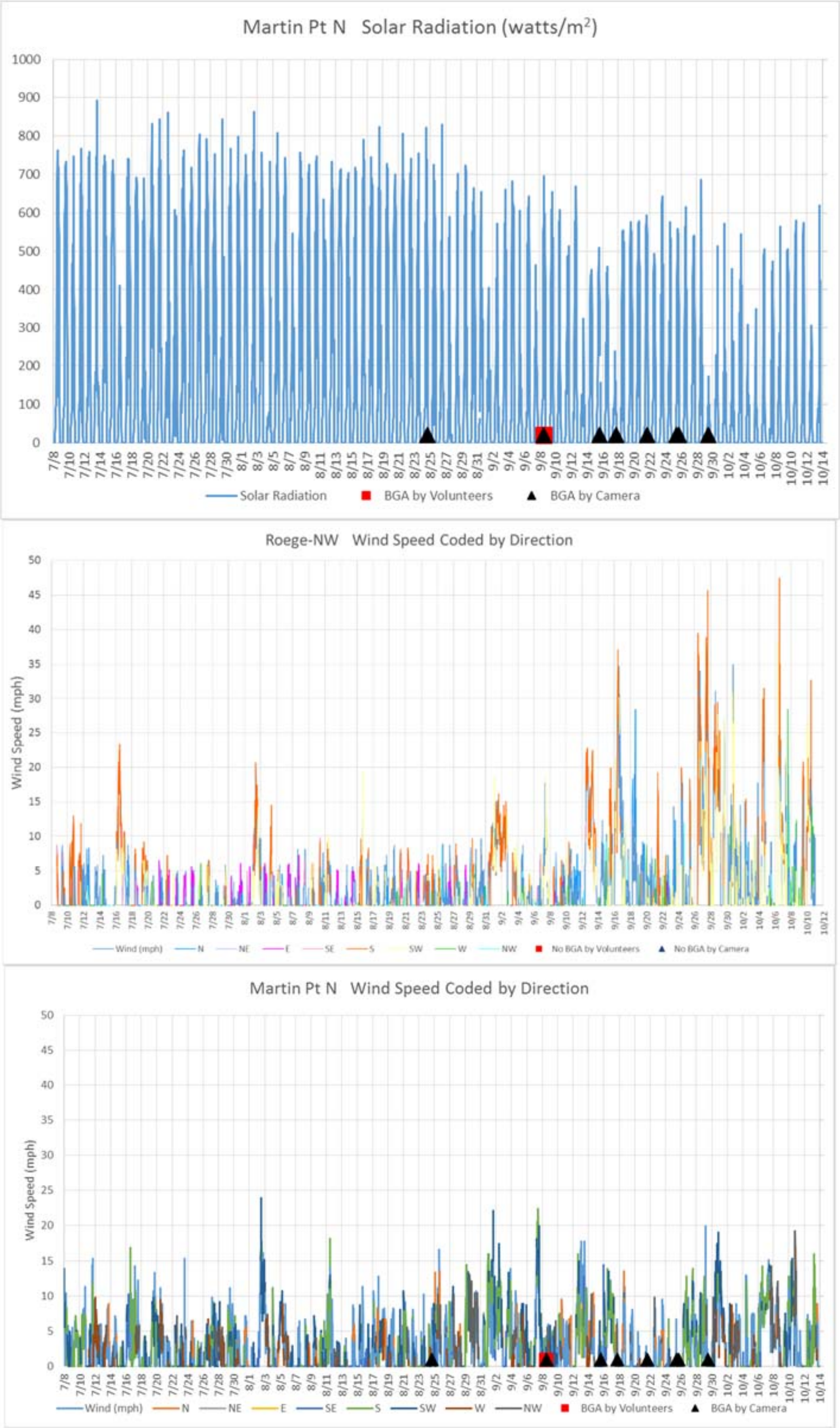
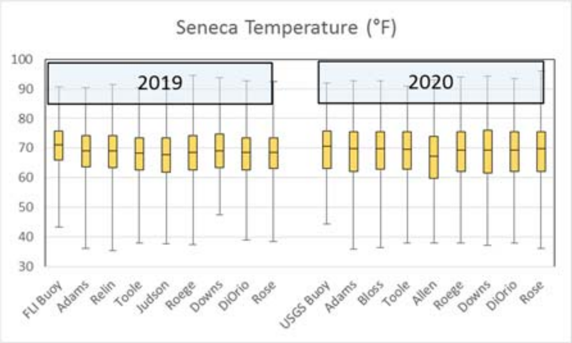
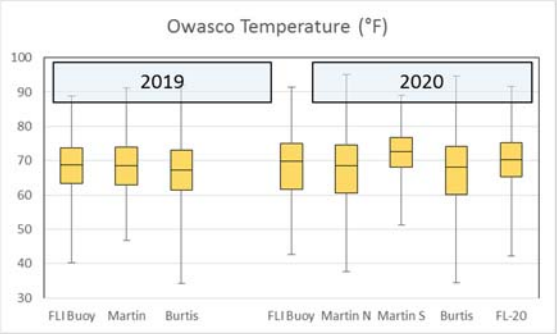


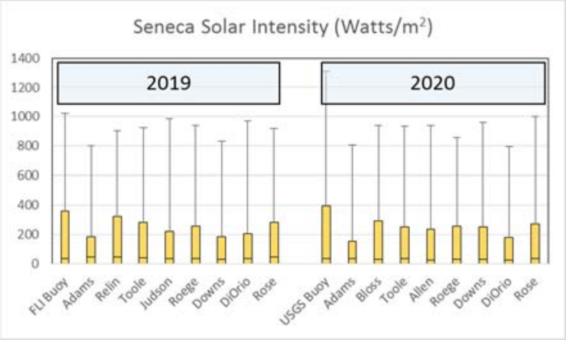
Fig. 21. Dockside air temperature, daily rainfall, solar intensity and wind speed data from the NW site (Roege) in Seneca Lake and Martin N Site in Owasco Lake. Wind speed is color coded by its direction. The red boxes mark dates when cyanobacteria were observed by the SLWPA HABs volunteers, the black triangles mark dates when cyanobacteria were imaged by the camera. Plots for the other sites are located in the data repository.

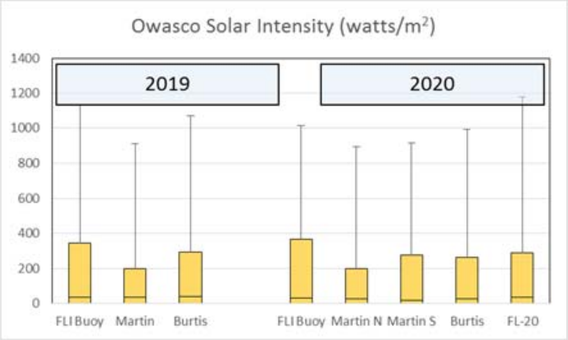
Wind Speed & Direction: Like 2019, the mean wind velocities were significantly slower at all the dock sites compared to the mid-lake buoy site (Fig 22). Wind speeds were also slower during bloom events in Owasco Lake (Fig. 23). Seasonal variability was detected in wind speed at each dock site in both lakes (Fig. 15). Typically, dock site wind speeds were faster during the mid-August through mid-October HABs season in both lakes. However, mean wind speeds at each dock site were slightly slower in Owasco than Seneca, especially during mid to late September. This timing was consistent with the majority of the detected blooms in Owasco Lake. Apparently, wind speeds never decreased long enough and/or were slow enough in Seneca Lake during the prime HABs season to proliferate additional bloom development after the August 31 multiple bloom event.

Faster winds, huge waves at Seneca Lake probably decreased bloom development. Enough calm or nearly calm days happened at Owasco Lake to foster a bumper crop of blooms.









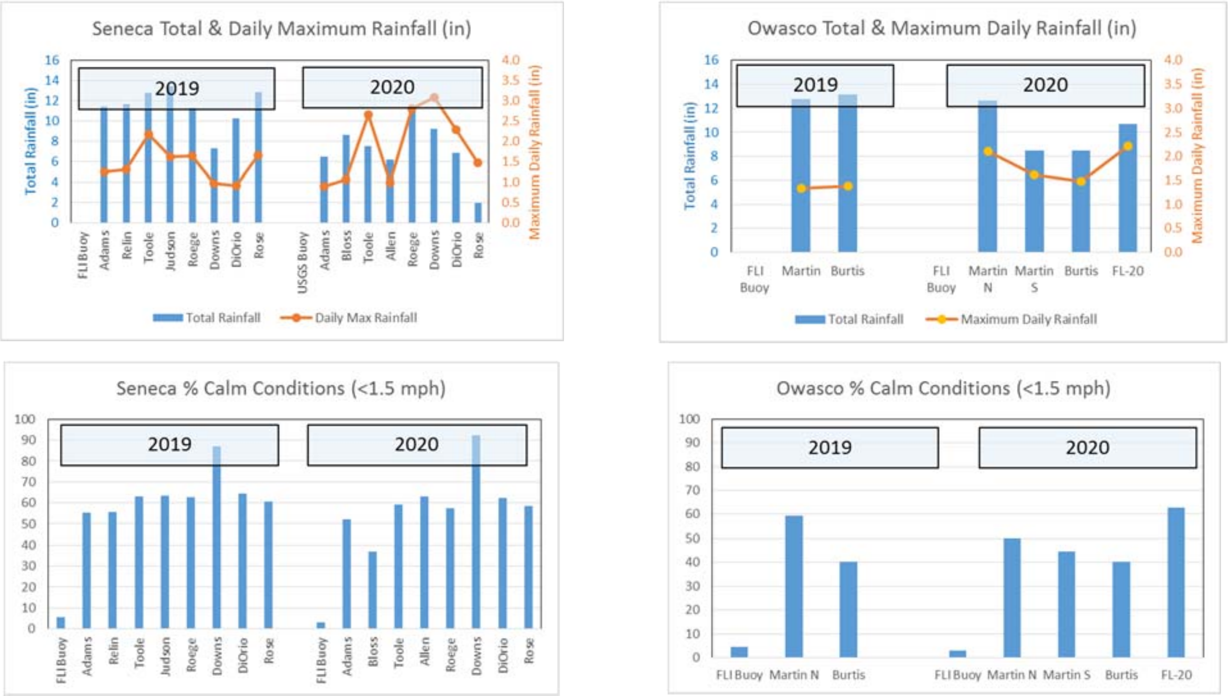


Fig. 22. Box and whisker or bar/line plots of air temperature (top), wind speed (2nd row), solar intensity (3rd row) rainfall (4th row), and % calm (<1.5 mph) conditions (bottom) at the eight Seneca sites (left) and the four Owasco sites (right) in 2019 and 2020. The USGS (Seneca) and FLI (Owasco) buoy data are included except the buoys did not detect rainfall.

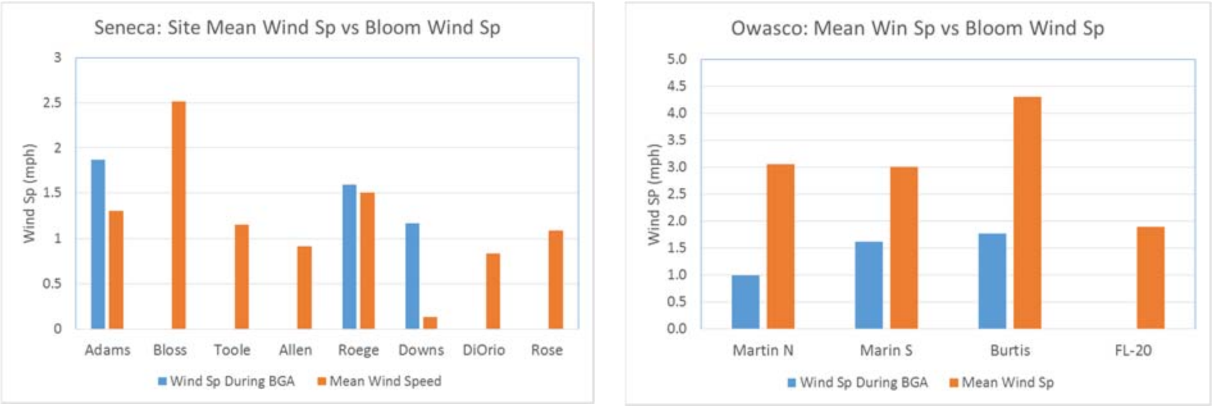
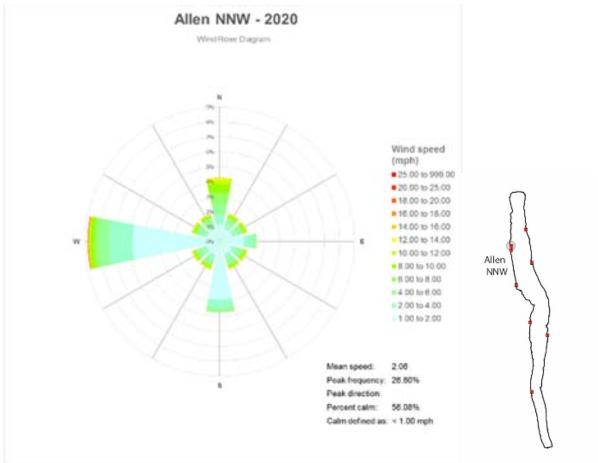


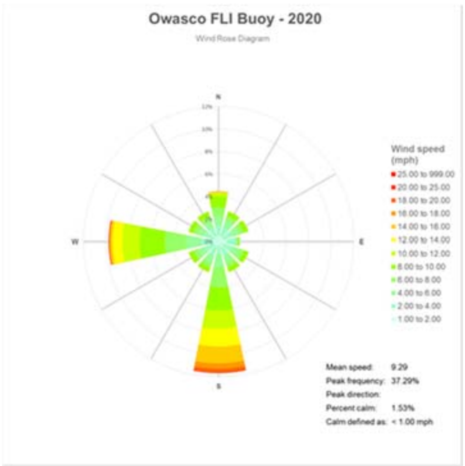
Fig. 23. Mean wind speed during detected blooms and over the entire field season at each site, Seneca above, Owasco below.

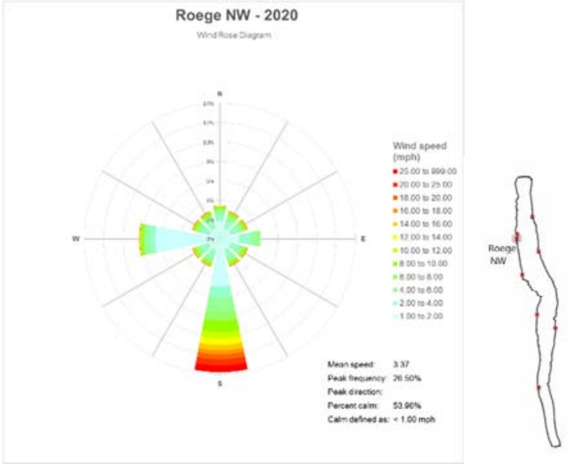
The most frequent wind direction detected at each dock varied between sites in both lakes as well (Fig. 24). Even sites in close proximity, e.g., at north and south Kashong Point, and north and south Martin Point revealed significantly different wind speeds and directions over the course of the study and explained by the unique shoreline orientations at each site. Occasionally light breezes originated from land, especially during the early hours at sites with agricultural or grassy fields inland. The timing and speed suggests that these breezes originate from the differential heating and cooling of land/water surfaces, and the sensors detected these land breezes. Even though variability was detected between sites, each site's season long dominant wind direction(s) were consistent between 2019 and 2020. It reaffirms the observation made last year that the shoreline orientation at each site modified non-onshore wind directions and wind speeds, and may dictate which shoreline locations will experience subdued regional winds and which do not. Onshore winds clearly impact water clarity, i.e., turbid *vs.* clear water, as mentioned above and suggested in the 2019 reports. The local variability in winds provide a plausible explanation why the water column can be turbid (windy) at some sites but clear (calm) at other sites on the same day. More importantly, if one shoreline is experiencing calm and sunny conditions, and a bloom appears, the other shorelines may not develop a bloom because those sites may be experiencing onshore winds. It may explain why cyanobacteria blooms appear along different segments of shoreline on different days.

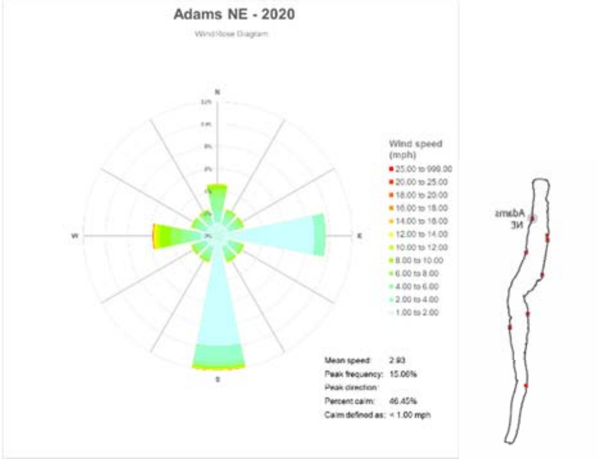
Shoreline orientation and its impact of the regional winds can explain the seeming random nature of blooms in both space and time.

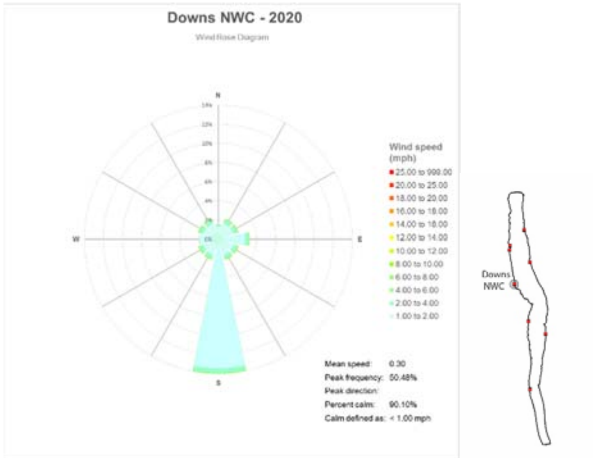
In Seneca Lake, the dominant wind directions detected at the Roege, DiOrio, Toole and Bloss sites in 2020 were more aligned with a southerly direction. Mean annual wind speeds were also faster at these four sites than the other sides in Seneca Lake. It suggests that their shoreline orientation were exposed to the open water winds, and thus faster and more frequent winds retarded significant bloom development at these sites.

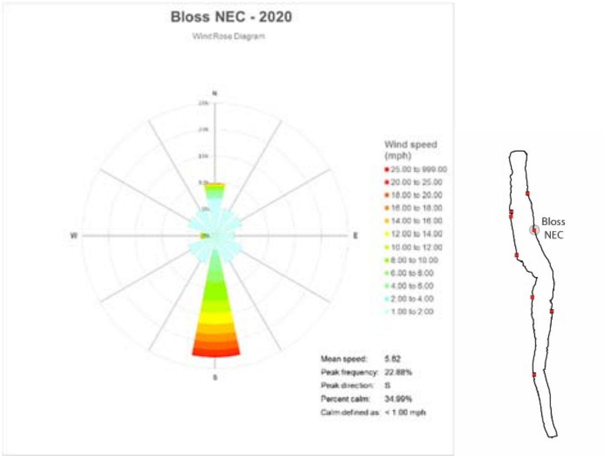


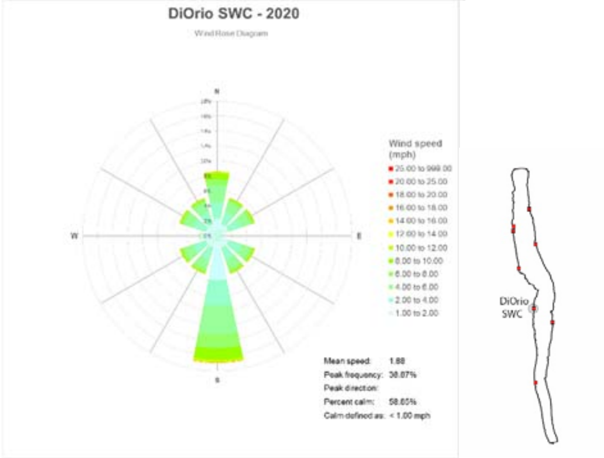


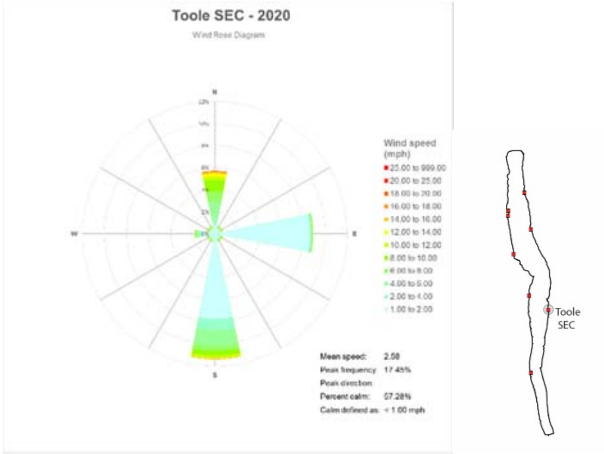


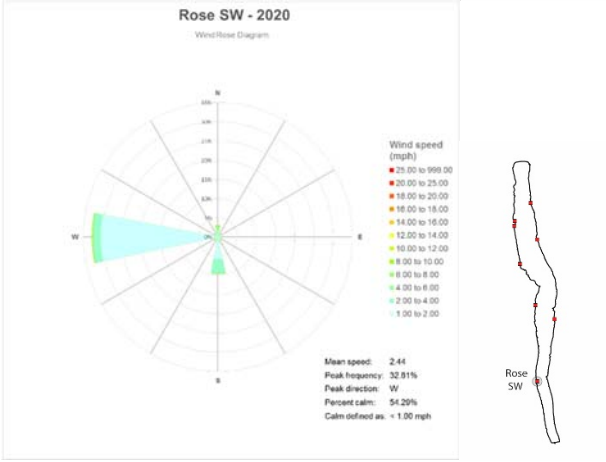












Seneca Sites above and left.
Owasco Sites below

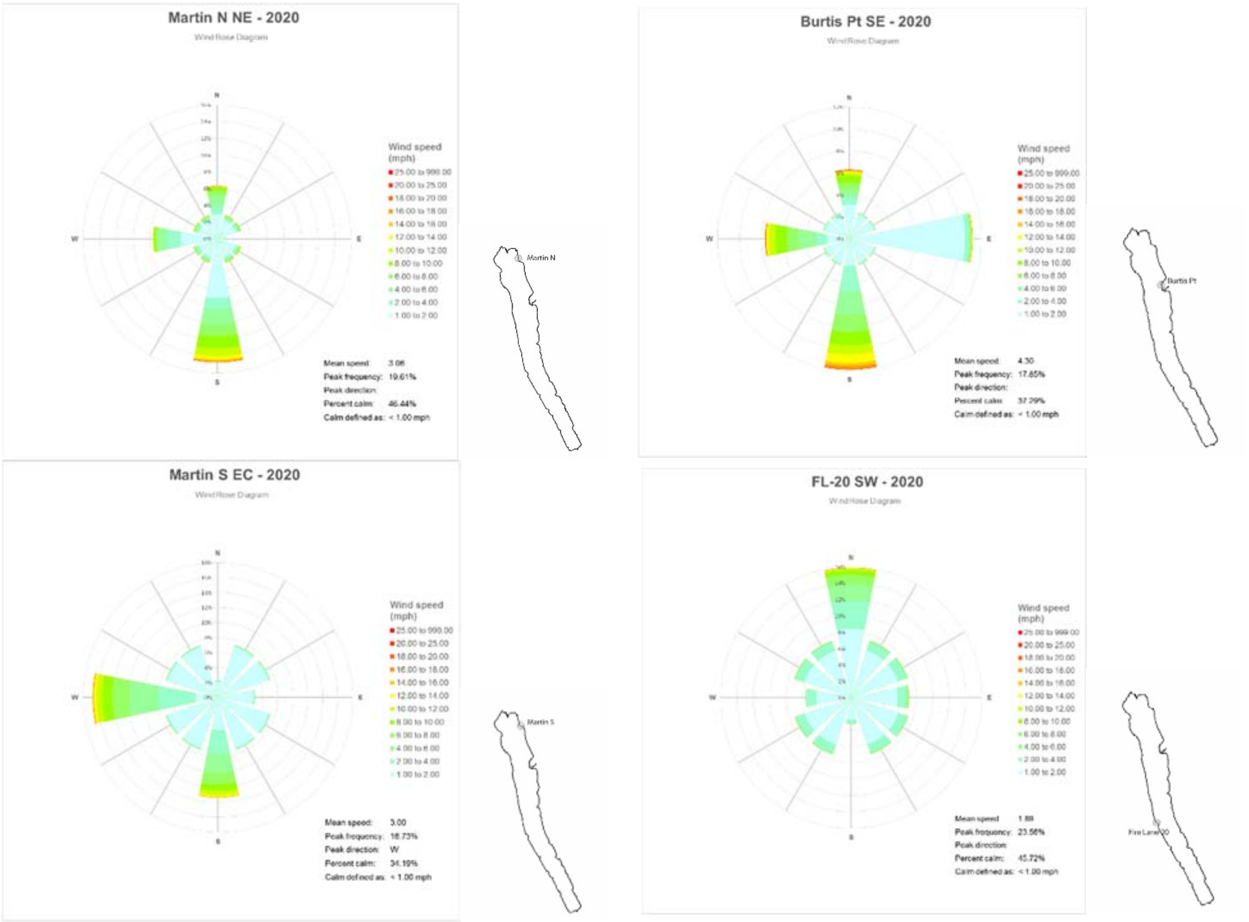


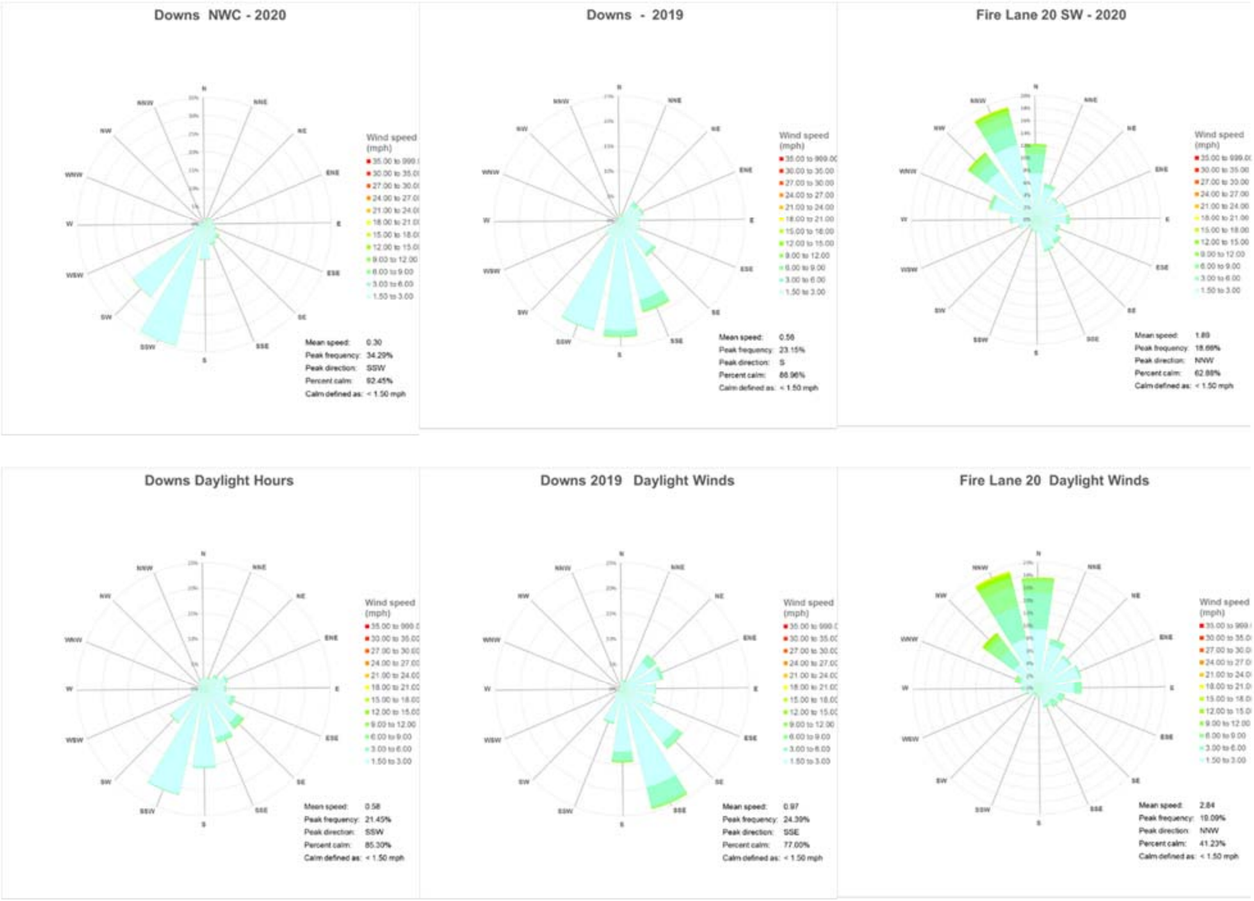
Fig. 24. Rose diagrams of wind speed and direction at the eight Seneca sites, the four Owasco sites, and the Owasco Lake FLI Monitoring Buoy.

Minor seasonal variability in wind direction was detected at the dock sites (data repository). For example, wind velocities and directions were slower and more from the SSE and SE during the 2nd half of July, August and September at the Adams site compared to faster and SSW directions and slightly faster during other seasons of the deployment. During the SSE shifts, with a direction and timing during the day consistent with land breezes, more blooms were detected at Martin N.

Based on the slowest recorded wind speeds and % calm weather recorded at each site, two sites should have experienced more blooms in 2020, Downs (NWC) in Seneca Lake and Fire Lane 20 in Owasco Lake. Both sites experienced the slowest wind speeds and larger percentage of calm (<1.5 mph) measurements, but a minimal number (0 to 1) of blooms in 2020. Perhaps the winds were sufficiently faster in the daytime, or the fastest winds more frequently blew towards the shore. The mean wind speeds increased (from 0.3 to 0.6 at Downs and from 1.9 to 2.8 at Fire Lane 20) and percentage of calm recordings decreased (from 92 to 85% at Downs and from 63 to 41% at Fire Lane 20) if the dataset only includes daytime (7 am to 7 pm) winds (Fig. 25), i.e., the sites experienced faster winds and fewer calm periods during the daylight hours. The dominant wind direction also shifted (from SSW & SW to SE & SSE at Downs and from NW & NNW to NNW & N at Fire Lane 20) if only winds faster than 2 mph are included in the analysis, i.e., the faster winds blew more often towards shore. But the increased winds speeds impacting the shoreline were still smaller than the other sites in each lake.

Were these wind shifts an anomaly of 2020? The second largest number of confirmed blooms (8) were detected at Downs in 2019 compared to the other monitored sites in Seneca Lake. The 2019 mean wind speed increased from 0.6 to 1.0 and percentage of calm intervals decreased from 87 to 77% when restricting the dataset to daylight hours. The dominant wind direction also shifted (from S & SSW to SSE & S) at Downs if only winds faster than 2 mph are included in the analysis. It suggests that it was too calm at Downs in 2020 for blooms. Perhaps winds were unavailable to stir up and release enough nutrients trapped in the sediments to promote cyanobacteria blooms. In support, wind speeds never exceeded 12 mph at Downs in 2020 whereas they exceeded 12 mph twice in 2019. Alternatively, perhaps insufficient biomass was available adjacent to these sites to provide the necessary nutrients for subsequent cyanobacteria blooms. In support, Fire Lane 20 has a very narrow nearshore shelf and limited DO daily oscillations. Quadrant surveys of the benthic biota should resolve this issue.

Bloom events also require nutrients, and a lack of sufficient winds may have decreased the release of nearshore nutrients.



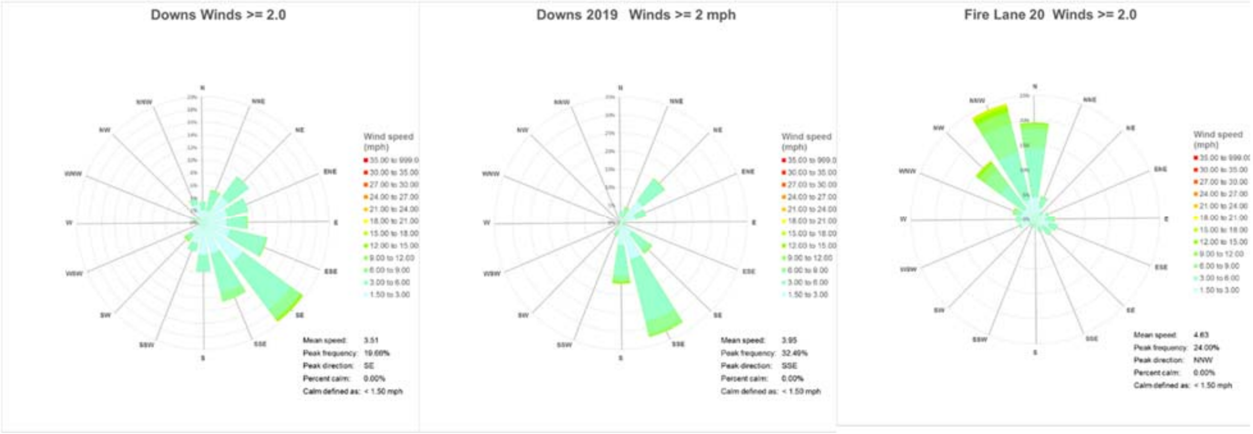


Fig. 25. Rose diagrams of wind speed and direction at Downs (both 2020 & 2019) and Fire Lane 20 (2020 only). Top row included all the data, middle row included only daylight winds and bottom row only included winds faster than 2 mph.

Rainfall: Like 2019, rainfall totals, both seasonal and daily accumulations, varied from site to site (Fig. 26). Daily variability was significant, from no rain at a number of sites to nearly 2 inches of rain at another site. More sites detected rainfall when daily rain accumulations were larger. The variability was due to numerous factors including localized and intense thunderstorms, orographic lifting, and lake effect enhancements. The associated runoff can deliver nutrients to the nearshore regions, and potentially stimulated cyanobacteria blooms. However, not all rainfall events stimulated blooms, and not all blooms occurred immediately after a rain event.

More importantly, rainfall totals were significantly smaller in 2020 than 2019 at every dock site, and neighboring national weather stations, e.g., Geneva, Penn Yan and Ithaca (Fig. 27). The very dry conditions induced smaller stream flows (many streams were dry by mid-summer), lower lake levels and deeper water table depths during the middle to end of the 2020 summer season (Fig. 28). The lower rainfall and lower runoff should have reduced a source of nutrients to the shoreline and thus decreased bloom development. The dry weather and associated decrease in runoff-induced nutrient loads to the lake may have contributed to the low bloom counts in Seneca Lake but it clearly did not decrease the bloom counts in Owasco Lake. Perhaps the larger watershed to lake surface area stemmed the nutrient loading decline in Owasco Lake. Alternatively, nutrients delivered by streams have a smaller impact on bloom genesis than previously thought.

The dry 2020 summer season may have contributed to decreased bloom activity in Seneca Lake but not Owasco Lake. Perhaps rainfall is not as important source of nutrients for bloom development as previously thought.

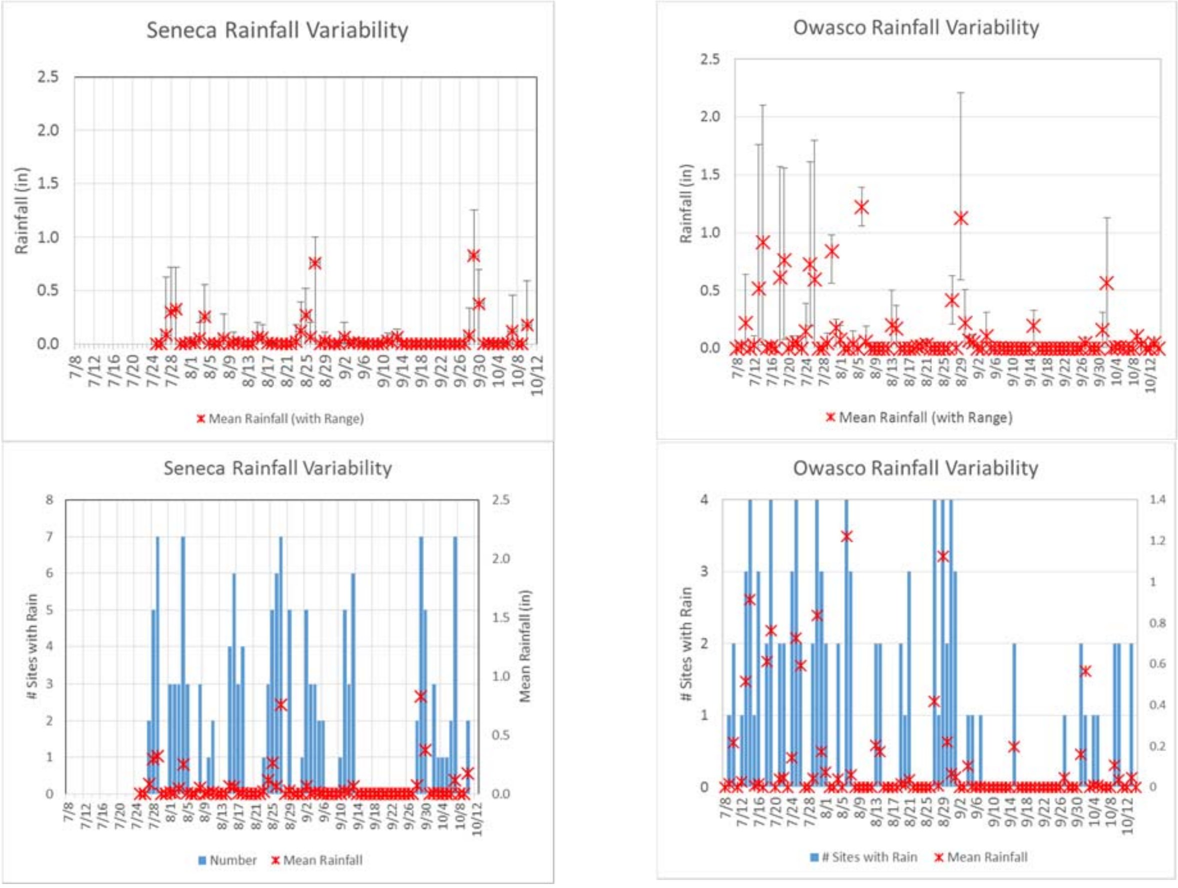


Fig. 26. Rainfall variability between sites Seneca (left) and Owasco (right). The mean, and minimum and maximum range for rainfall on any given day (above), and the mean rainfall and number of sites with any rain on any given day (below)

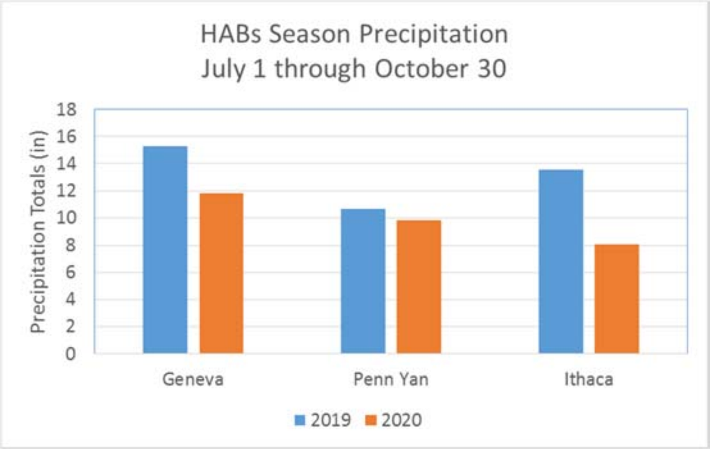
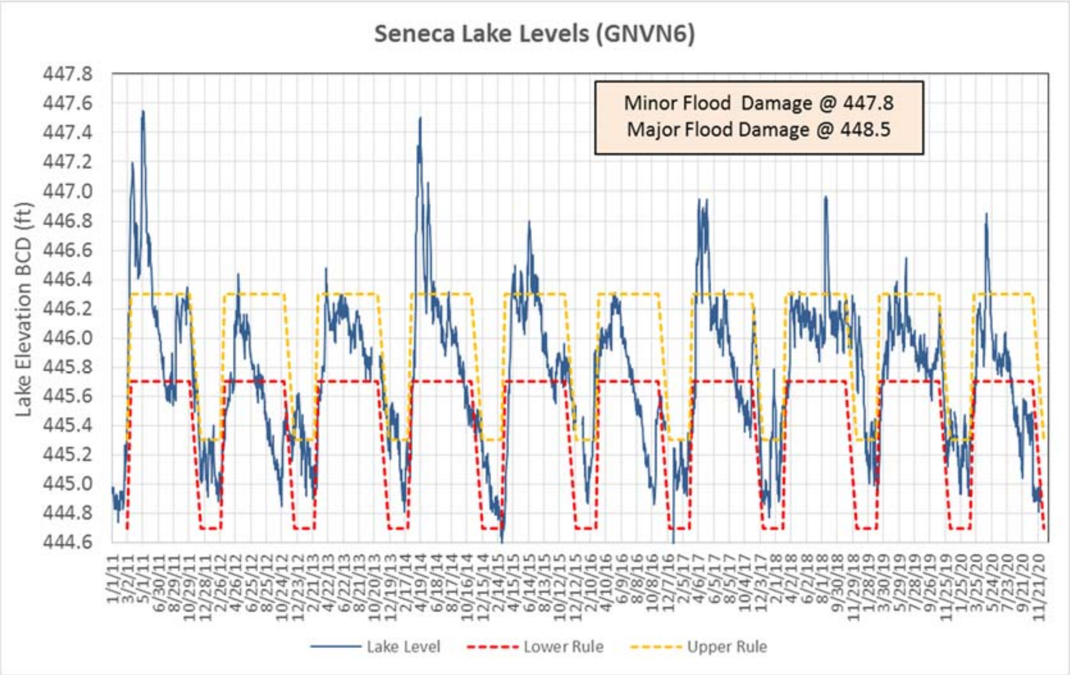


Fig. 27. HABs season precipitation totals for Geneva, Penn Yan and Ithaca, NY.


Seneca Lake Levels (GNVN6)
Minor Flood Damage @ 447.8
Major Flood Damage @ 448.5
Lake Elevation BCD (ft)
447.8
447.6
447.4
447.2
447.0
446.8
446.6
446.4
446.2
446.0
445.8
445.6
445.4
445.2
445.0
444.8
444.6
1/1/11
3/2/11
5/1/11
6/30/11
8/29/11
10/29/11
12/28/11
2/26/12
4/26/12
6/25/12
8/25/12
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6/5/17
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12/3/17
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4/2/18
6/2/18
8/1/18
9/30/18
11/29/18
1/28/19
3/30/19
5/29/19
7/28/19
9/26/19
11/25/19
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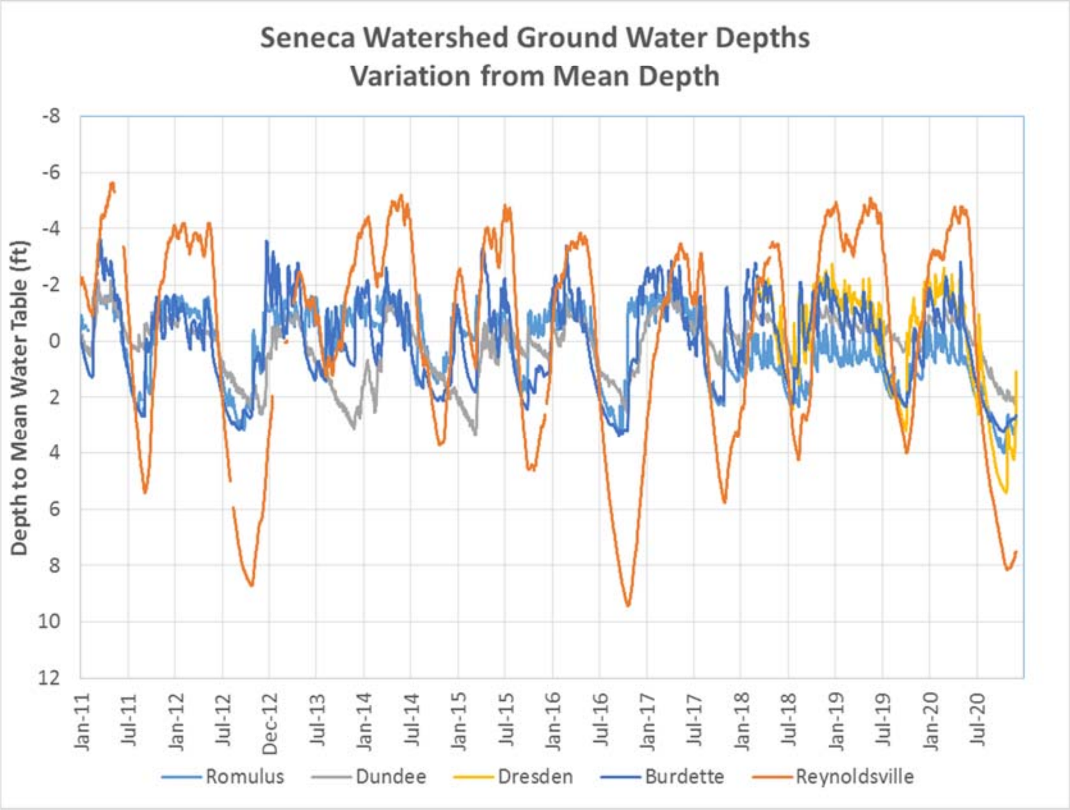
11/21/20
Lake Level
Lower Rule
Upper Rule


Seneca Watershed Ground Water Depths
Variation from Mean Depth
Depth to Mean Water Table (ft)
-8
-6
-4
-2
0
2
4
6
8
10
12
Jan-11
Jul-11
Jan-12
Jul-12
Dec-12
Jul-13
Jan-14
Jul-14
Jan-15
Jul-15
Jan-16
Jul-16
Jan-17
Jul-17
Jan-18
Jul-18
Jan-19
Jul-19
Jan-20
Jul-20
Romulus
Dundee
Dresden
Burdette
Reynoldsville

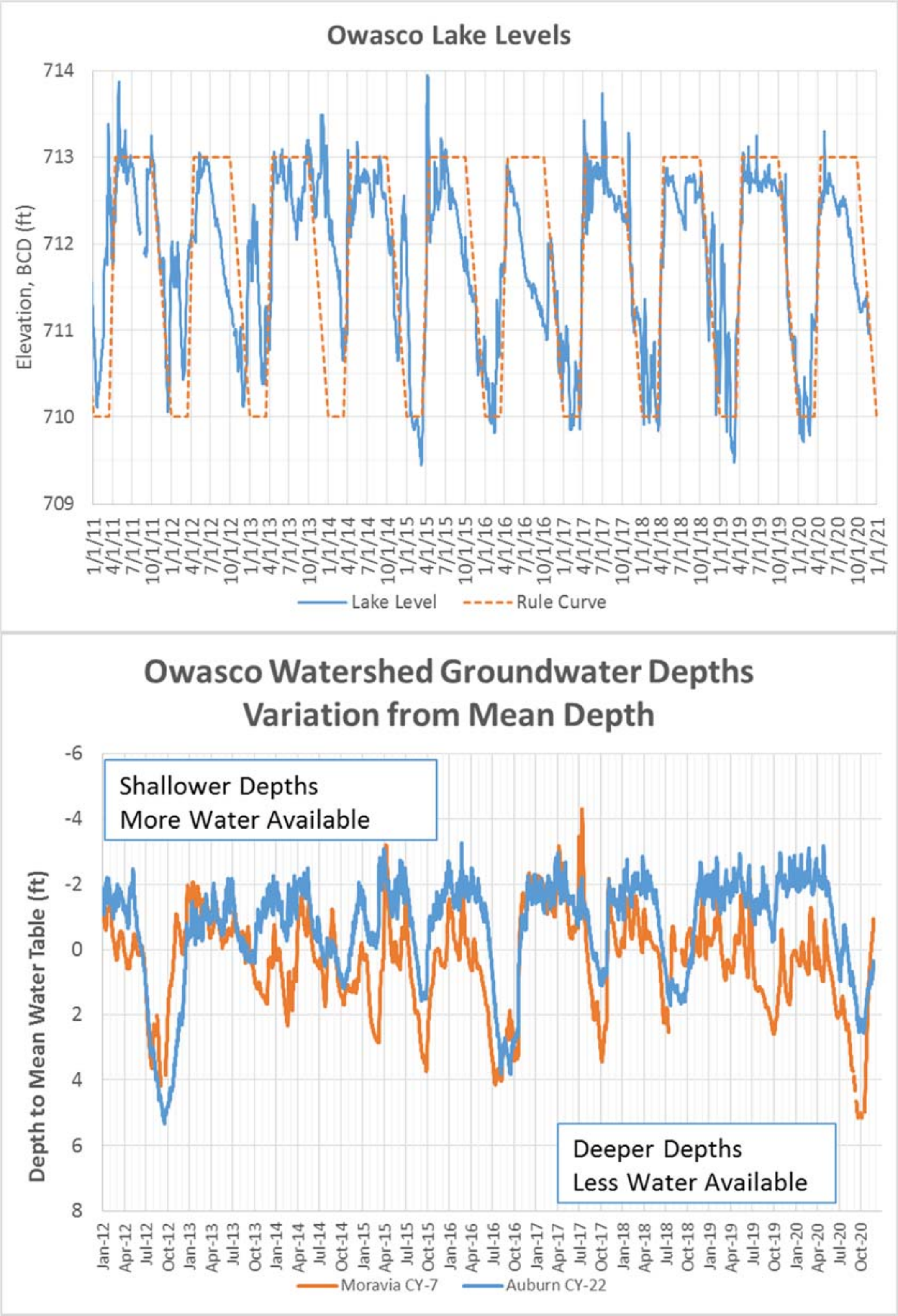
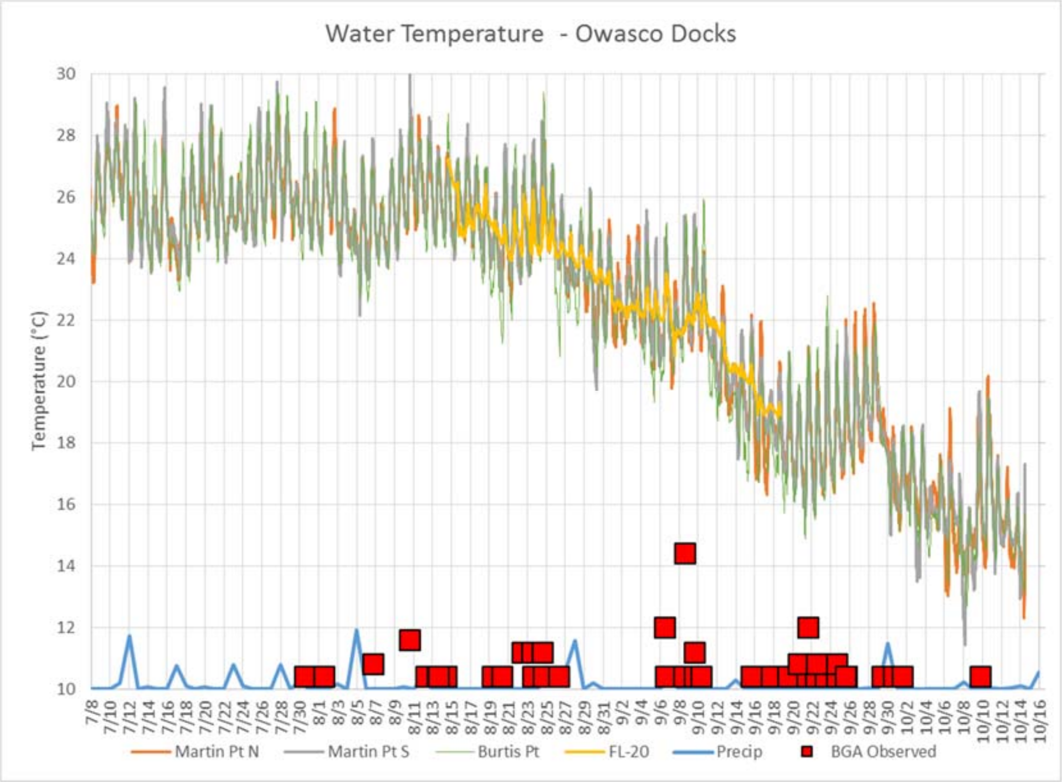


Fig. 28. Lake level at Seneca and Owasco Lakes and water table depths at USGS monitoring wells in the Seneca and Owasco Watersheds.

Water Quality Sonde Data (Owasco Only): Water quality (WQ) sondes were deployed at the four Owasco dock sites to measure temperature, salinity, and fluorescence, both total chlorophyll and cyanobacteria-PC concentrations. The sensors were deployed approximately 1-m below the lake's surface inside a PVC pipe. Data recovery was shortened at the Martin S site because macrophytes clogged its PVC deployment tube at the Martin South site and influenced the results from 9/8 through the remainder of the deployment. YSI sonde deployment was delayed at Fire Lane 20 until it became available from another project, and recovered it earlier than the other sites to meet homeowner wishes (deployed from 8/14 through 9/18).

The sonde temperatures revealed similar long term and daily oscillations in temperature as the 1-m temperature loggers at each site (Fig. 29). The salinity data was typically uneventful and paralleled open water concentrations (Fig. 29). It decreased by ~10 µS/cm each night at Burtis Pt. The reasons for these daily changes are unclear at this time and may reflect the sensor's temperature sensitivity. Salinity decreased to 50 or 150 µS/cm on a few occasions in early July (7/8, 7/9, 7/10, 7/13 and 7/15) at Martin N for unknown reasons. It may reflect the input of relatively less saline rainfall.



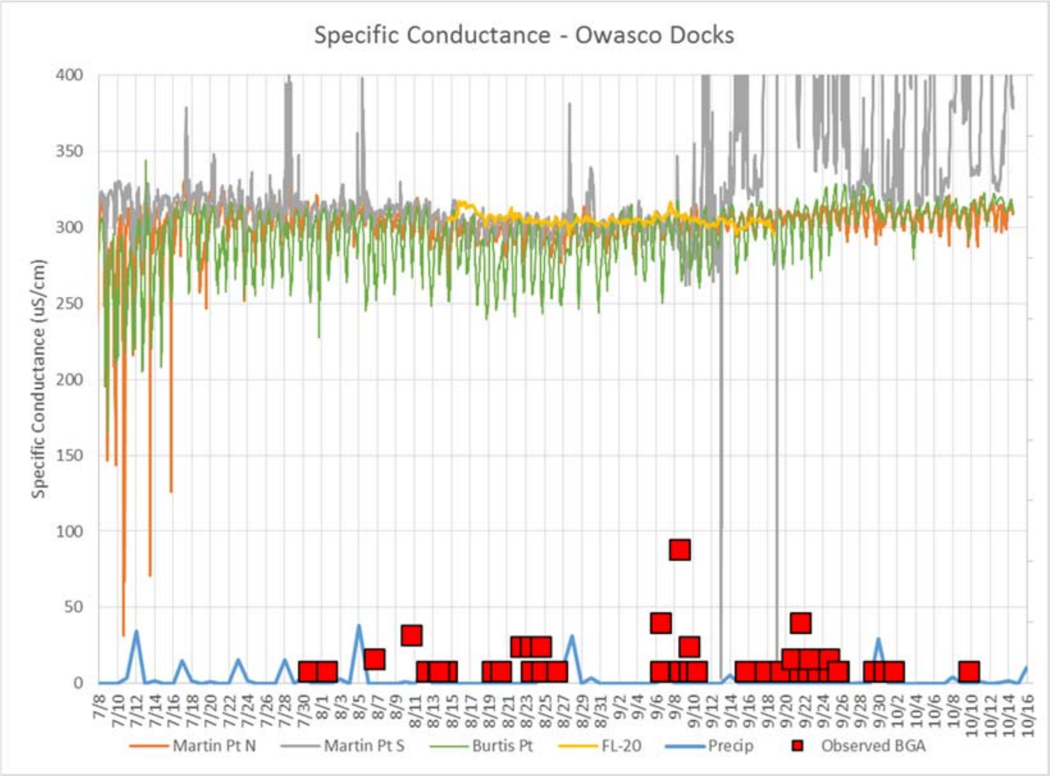


Fig. 29. Surface water temperatures and salinity measured by the WQ sondes at the dock sites in Owasco Lake. The long-term and daily temperature oscillations were identical to the temperature loggers.

Salinity increased to 375 to 400 μS/cm (and larger) at the Martin S site on 7/17, 7/28, 8/5, 8/27 and 8/30. The increase in salinity happened after 9/6 when the Martin S PVC deployment pipe clogged with macrophyte and other organic (e.g., *Cladophora*) debris. Once clogged, water flow between inside the pipe and the lake water outside the pipe was compromised allowing for salts and other constituents to concentrate inside the pipe. It was not a permanent blockage, as the salinity occasionally fluctuated up and down, the lowest concentrations approached open lake concentrations, after the initial clogging on 9/6. It suggests periodic flushing of the water inside of the pipe with outside lake water by wave action during wind events. The increase in salinity may reflect bacterial decay of the organic debris inside the pipe, as respiration by bacteria releases dissolved nutrients and other ions that in this case concentrated inside the pipe when clogged. The water within the pipe may have preferentially evaporated during the reduced flow, increasing the salinity, as well. Perhaps the temporary increases in salinity detected earlier in the deployment at this site, e.g., 7/17, 7/28, 8/5, 8/27 and 8/30, reflected brief episodes of clogging by organic debris. Future deployments must guard against clogging.

The dissolved oxygen (DO) concentrations revealed daily oscillations that co-varied with water temperature, and duplicating daily oscillations detected in 2019 by the FLI Sensor Nodes (Fig. 30). The daily variations were largest at Burtis Pt and smallest at Fire Lane 20. Two parameters control DO concentrations in water, water temperature and biological activity. Water temperature inversely controls saturated dissolved oxygen concentrations. The covariance in water temperature and dissolved oxygen concentrations in Owasco Lake indicates that water temperature and the diffusion of oxygen between the water and the atmosphere did not control the observed daily variability in dissolved oxygen concentrations. Instead, photosynthesis and respiration by macrophytes and other organisms affected the DO concentrations. When biological activity is intense enough, oxygen is produced during the daylight hours through photosynthesis; oxygen is removed from the water column through respiration by all organisms, and the decline in DO is most noticeable at night. The covariance between the temperature and DO fluctuations indicates that biological activity had a major impact on nearshore dissolved oxygen concentrations. This suggests that nearshore bacterial decay could be a (or the) source of nutrients for nearshore cyanobacteria blooms.

The change in the daily oscillations magnitudes parallels the amount of macrophyte biomass at it site, as visual inspection suggests that Burtis Pt had the most and Fire Lane 20 had the least. Martin N and Martin S have rocky lake floors but still experienced DO fluctuations. It highlights the important of biological activity in a variety of lakeshore settings. It confirms the importance of photosynthesis and respiration in the nearshore portions of the lake, and suggests the organic debris, e.g., macrophytes and *Cladophora*, might provide a viable source of nutrients for cyanobacteria blooms. Future benthic quadrat surveys should provide more information on this topic.

Dissolved oxygen decreased to anoxic conditions at the Martin S site after 9/6, when the deployment pipe was clogged with organic debris (Fig. 30). Bacterial respiration of the organic material inside the pipe could have depleted the dissolved oxygen in the water within the pipe. This respiration would have released dissolved nutrients and other ions, increasing the salinity inside the pipe. The occasional increase in dissolved oxygen since 9/6 probably reflected the flushing of the water inside the pipe with lake water by waves.

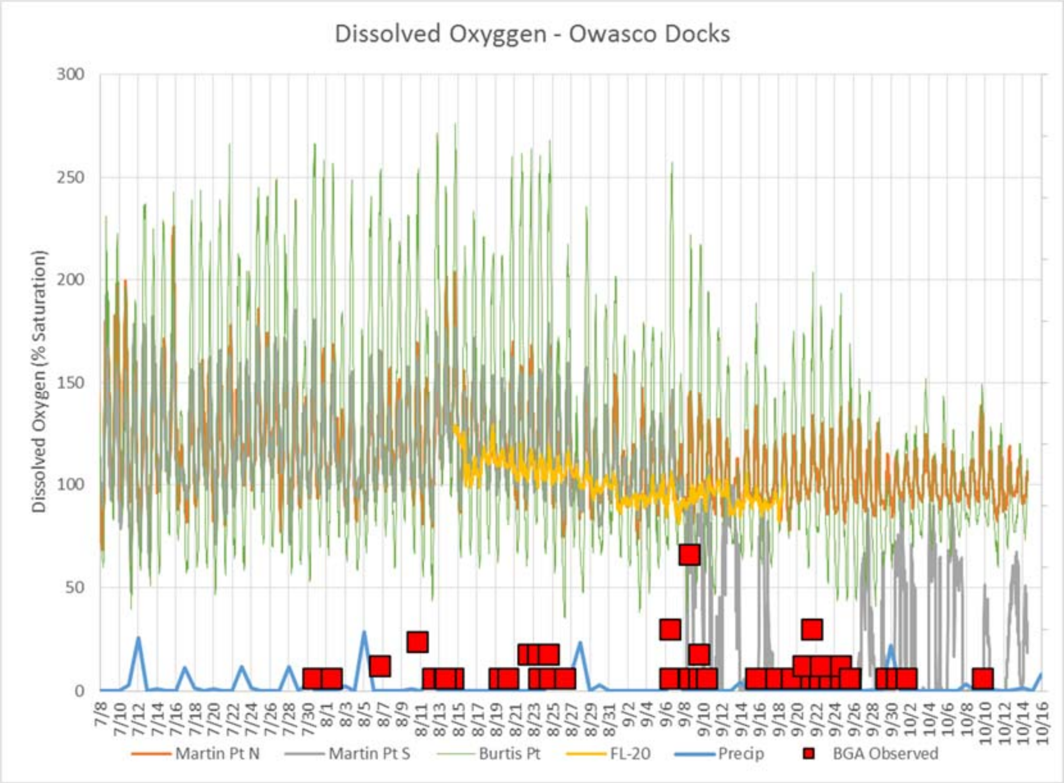
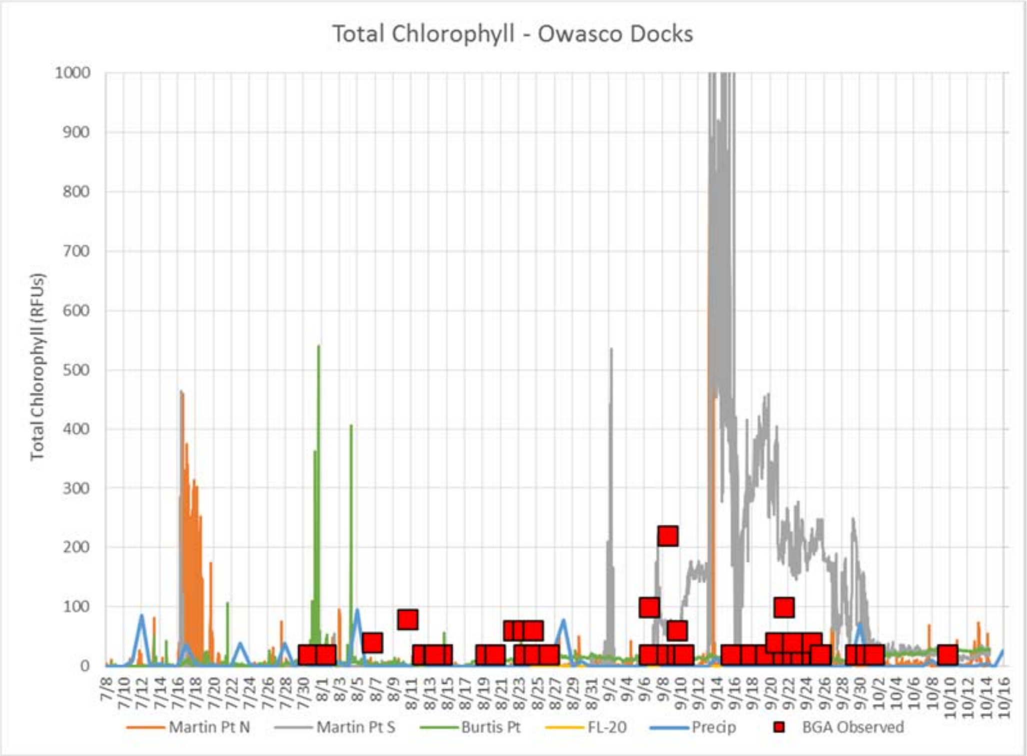


Fig. 30. WQ sonde dissolved oxygen concentrations revealed daily oscillations that co-varied with water temperature.

The WQ sonde total fluorescence sensor revealed brief, a few hours to day long, and random periods of increased in fluorescence at the three northern sites (Fig. 31). Similar bloom events were not detected at Fire Lane – 20. These northern fluorescence events were not synchronous in time between sites, nor synchronous with peaks in the cyanobacteria-PC fluorescence. Cyanobacteria blooms were not imaged at the site during these fluorescence events as well. They were however, synchronous with increased water turbidity (detected by the camera). It suggests that wave action that induced the nearshore turbidity also suspended algae attached to the lake floor into the water column. It highlights a robust algal community attached to the lake floor even along the rocky shorelines at Martin N and S. The algae, after their decay, potentially provide yet another source of nutrients for cyanobacteria blooms. Interestingly, once the Martin S pipe was clogged, the total fluorescence increased for a few days, from 9/8 through 9/16. We speculate that the sensor detected the chlorophyll in the plant derived debris. The decay of the signal is consistent with bacterial decay and eventual degradation of the plant chlorophyll and other easily degradable parts. This scenario is consistent with the salinity and dissolved oxygen variability.

Total chlorophyll concentrations were rarely elevated during obvious cyanobacteria blooms detected by the camera. It highlights the surface floating character of cyanobacteria blooms, where the camera images detect them, in contrast to the attached nature of the nearshore plant life to the lake floor. A WQ sonde sensor deployed at ~0.5 m below the surface would miss both, unless waves mixed the water column and available plant biomass.



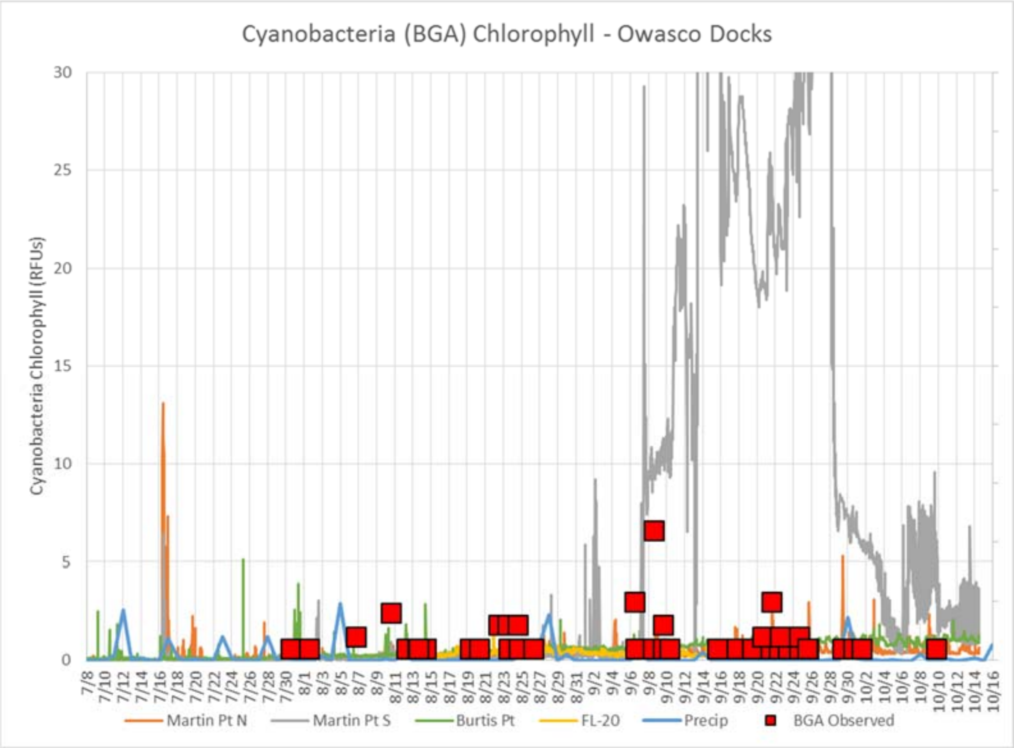


Fig. 31. Total chlorophyll by fluorescence and cyanobacteria-PC fluorescence measured by the WQ sondes at the Owasco dock sites. Non synchronous blooms were detected at the three northern sites. Significant deviations after 9/6 at the Martin S site were probably induced by organic debris, e.g., macrophytes and *Cladophora*, clogging the deployment pipe.

Finally, the WQ sonde cyanobacteria-PC fluorescence sensors also revealed brief, a few hour duration, and random blooms at the three northern sites but not at Fire Lane 20 (Fig. 31). Like the total fluorescence data, these blooms were not synchronous in time between sites, nor synchronous with peaks in the total algal fluorescence, and cyanobacteria blooms were not imaged at these sites during these fluorescence events. They were however, synchronous with increased water turbidity detected by the cameras. It suggests that wave action, that induced the nearshore turbidity, also suspended cyanobacteria in the sediments into the water column, and a robust lake floor cyanobacteria community exists in the nearshore area even along rocky shorelines. It is unclear why these cyanobacteria-PC detections were asynchronous with the other forms of benthic (lake floor) algae. The cyanobacteria, after their decay, provide yet another source of nutrient for additional cyanobacteria blooms.

Like the total fluorescence results, cyanobacteria-PC concentrations were rarely elevated during obvious cyanobacteria blooms detected by the camera. It highlights the surface floating character of cyanobacteria blooms, where the camera images detect them, in contrast to a WQ sonde sensor deployed at ~0.5 m below the surface.

Interestingly, once the Martin S pipe was clogged, the cyanobacteria-PC fluorescence increased for the remainder of the month of September. We speculate that the sensor detected the development of cyanobacteria within the pipe, supported by the release of nutrients from the decay of organic matter that clogged the deployment pipe, and decaying macrophytes are a viable source of nutrients for cyanobacteria blooms (see above).

The WQ sonde at the Martin S site, once clogged, provided valuable information. The nearshore region has a robust plant community, and once decayed may provide a critical nutrient source for cyanobacteria blooms.

NUTRIENT SOURCES

Mesocosm Experiments: A series of three preliminary mesocosm experiments to determine the limiting nutrients in Owasco water were conducted in June, July and September following the procedures of Lewis et al 2020[14]. Typically, the limiting nutrient in lakes is assumed to be phosphorus, but some lakes algae are nitrogen limited or co-limited with phosphorus and nitrogen. The limiting nutrient can also change from month-to-month.

For the June incubations, the starting chlorophyll concentration for the incubation, or T_0, was 5.8 µg/L (Fig. 32). After seven days, the average chlorophyll concentration for the three controls was 6.6 µg/L. The chlorophyll concentration for the nitrogen treatment was not statistically different than the control. However, the phosphorus only treatment was significantly higher than the nitrogen only treatment. Finally, the nitrogen plus phosphorus treatment was statistically higher than all three treatments. This likely indicates a serial limitation for phosphorus for June Owasco Lake water meaning that phosphorus is limiting, but the addition of nitrogen further enhances productivity as demonstrated by higher chlorophyll concentrations. The phytoplankton community remained consistently dominated by green algae and diatoms although the phytoplankton in single nutrient treatments were only green algae (Fig. 33).

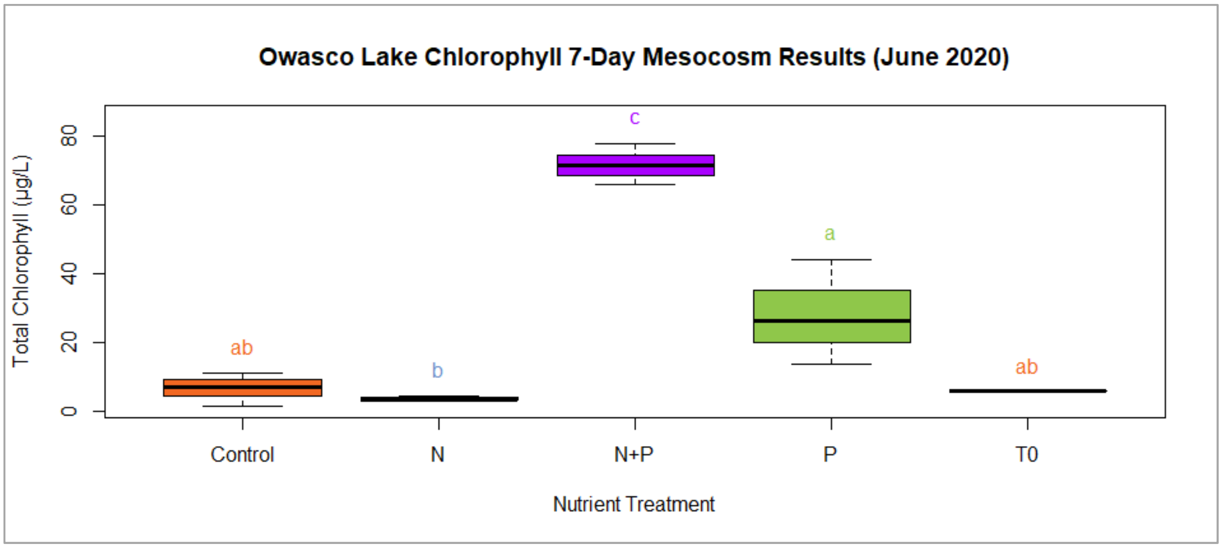


Fig. 32. Results from June mesocosm experiments. Statistically significant ($p < 0.05$) differences between treatments are indicated by different letters and colors for treatments.

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[14] Lewis et al. (2020). Prevalence of phytoplankton limitation by both nitrogen and phosphorus related to nutrient stoichiometry, land use, and primary producer biomass across the northeastern United States. Inland Waters, 10:1, 42-50, DOI: 10.1080/20442041.2019.1664233

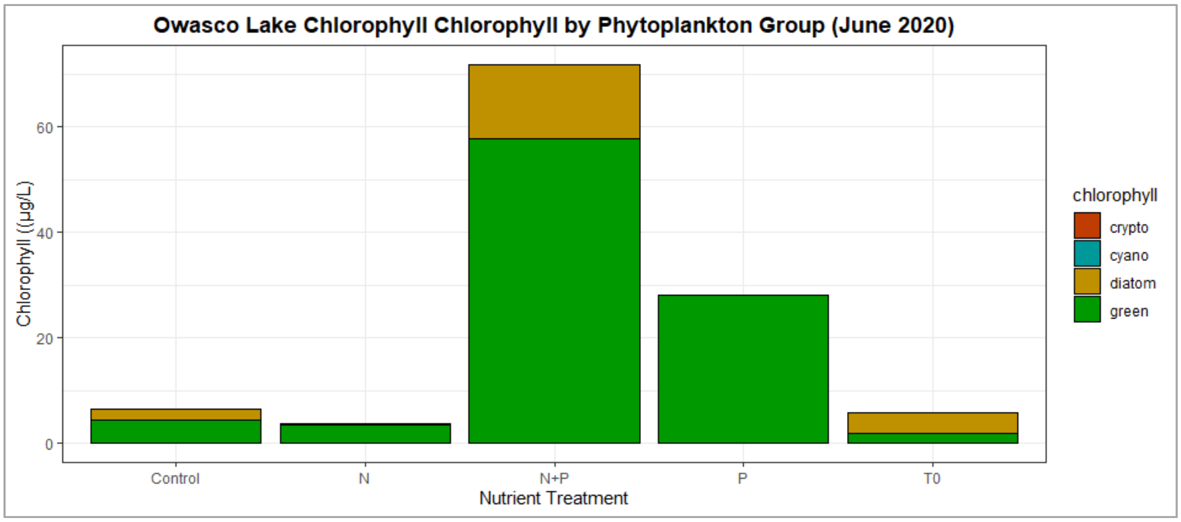

Fig. 33. FluoroProbe chlorophyll concentrations from June mesocosm experiments showing major algal groups present. Key: crypto = cryptophytes, cyano = blue-green algae, diatom = diatom, green = green algae.

In July, a similar finding was observed but with higher overall chlorophyll concentrations likely due to the warmer temperatures observed in July (Fig. 34). For the July series of incubations, the phosphorus only treatment was statistically higher than the control and nitrogen, and once again, the nitrogen plus phosphorus treatment resulted in statistically higher chlorophyll concentrations than all treatments. This serial co-limitation could be due to factors that will be explored in more depth in the future. The phytoplankton community was once again dominated by green algae at the end of the seven day incubation period (Fig. 35).

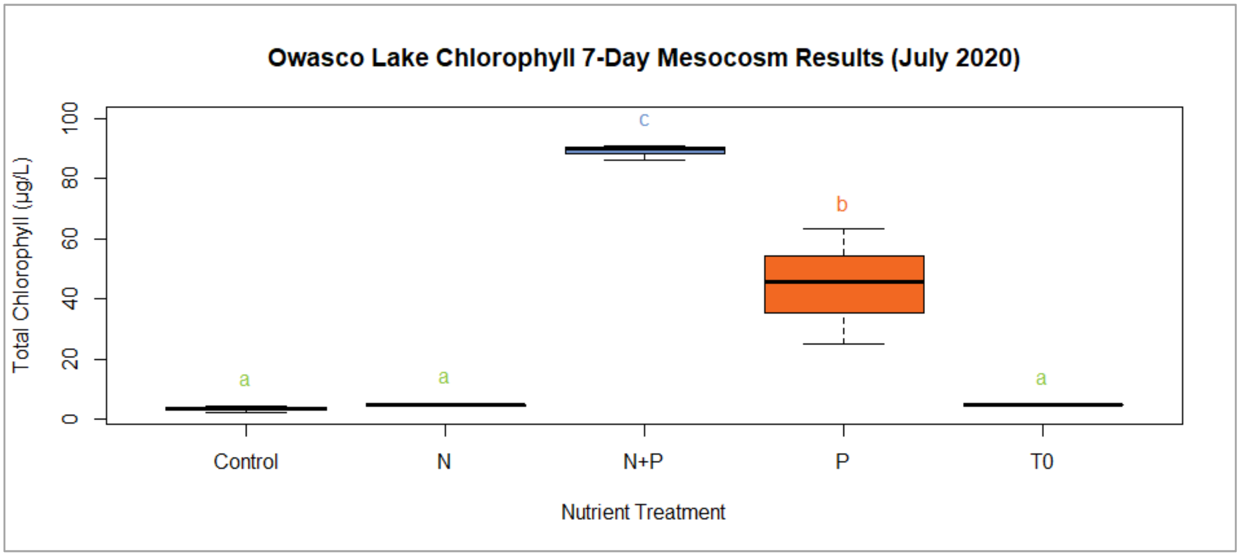

Fig. 34. Results from July mesocosm experiments. Statistically significant ($p < 0.05$) differences between treatments are indicated by different letters and colors for treatments.

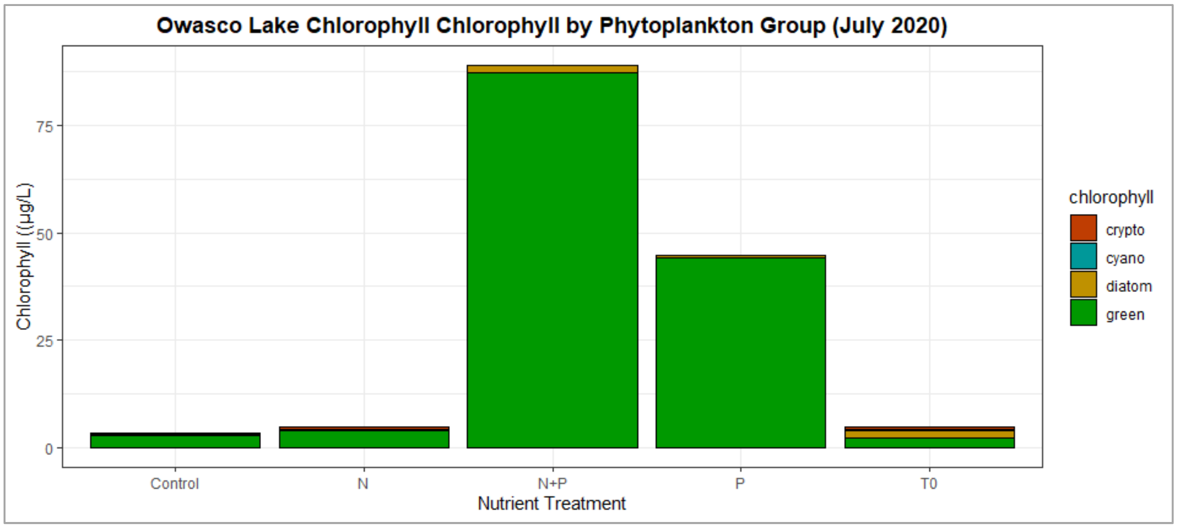

Fig. 35. FluoroProbe chlorophyll concentrations from July mesocosm experiments showing major algal groups present. Key: crypto = cryptophytes, cyano = blue-green algae, diatom = diatom, green = green algae.

For September, a shorter incubation period was used for the mesocosm experiments. The goal of the shorter incubation period was to try to prevent the phytoplankton communities in the incubations from changing to all green algae especially when the T_0 or starting water exhibited more phytoplankton diversity. The FLI experimented with a shorter incubation period for other lake mesocosm studies and showed that a three to four day period was long enough to show effects from the addition of nutrients, but short enough to maintain a similar phytoplankton community composition. For the Owasco Lakes, we found mixed results.

In September, the average chlorophyll concentrations for all treatments were not statistically significantly different (Fig. 36). A major reason for this is that there was a large variation in the chlorophyll concentrations of the three control incubation replicates. On average, the phosphorus only had the highest concentration after three days with an approximately 3-fold increase. The phytoplankton community remained consistent between the start (T_0) to the end of the incubation period in all of the treatments. So the shorter incubation did not change the phytoplankton community to all green algae as was the case in similar to June and July (Fig. 37).

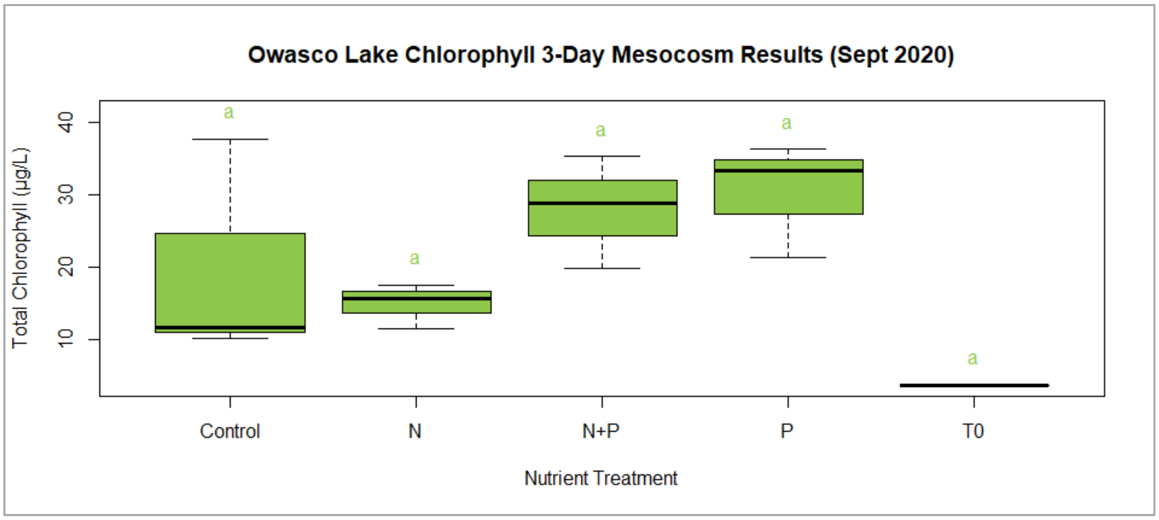

Fig. 36. Results from September mesocosm experiments. No statistically significant ($p < 0.05$) differences between treatments were observed.

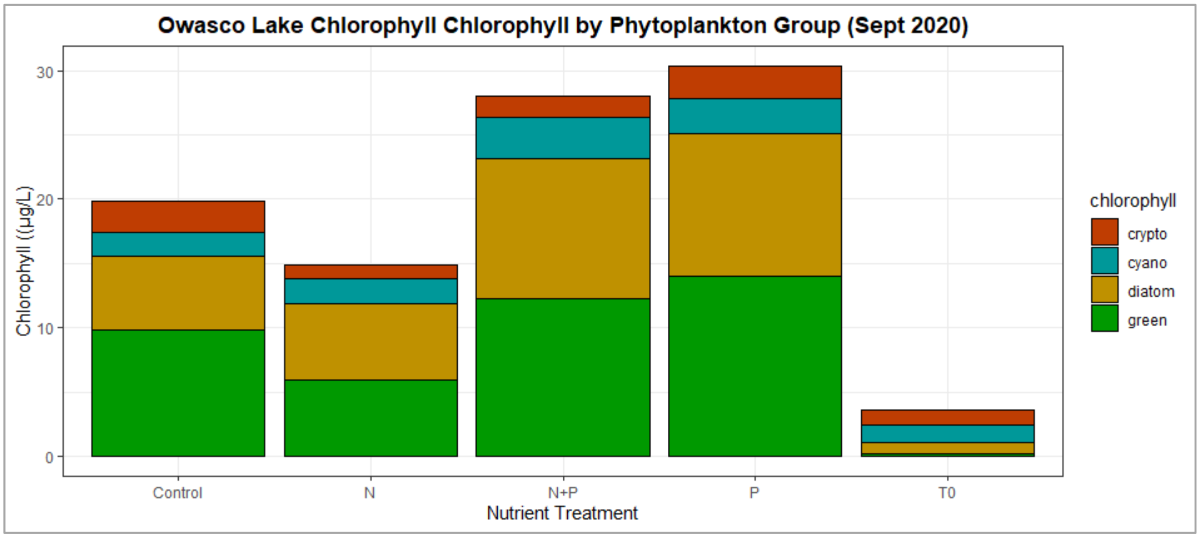

Fig. 37. FluoroProbe chlorophyll concentrations from September mesocosm experiments showing major algal groups present. Key: crypto = cryptophytes, cyano = blue-green algae, diatom = diatom, green = green algae.

Compared to other Finger Lakes tested in 2020 including Cayuga, Seneca, Canandaigua, and Honeoye, Owasco Lake was the only lake to show serial phosphorus limitation. As explained in Lewis et al. (2020), serial limitation could be due to a number of factors. For instance, additional nutrients can enable phytoplankton to obtain nutrients that were previously not accessible. An example of this could be the production of amino acids spurred by the addition of nitrogen that may enable the production of enzymes to consume additional sources of phosphorus. In 2021, we plan to continue experiments with shorter incubation periods to ensure that the phytoplankton community does not change relative to the lake water. We also hope to analyze the phytoplankton community for DNA using 16S community analysis to further understand the community composition of the phytoplankton community and associated bacteria.