2022 NEARSHORE MONITORING OF CYANOBACTERIA (BLUE-GREEN ALGAE) IN SENECA & OWASCO LAKES.

THE FINAL 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 (Fig. 1). Blooms were first reported in Owasco Lake during 2012 and in Seneca Lake during 2015 with similar initial detection dates for the other Finger Lakes. The Finger Lake blooms were typically localized and along the shoreline, where lakeshore residents use the lake, but occasionally spanned across larger offshore areas. The blooms have also impacted municipal drinking water supplies. For example, cyanobacteria toxins were detected in the Auburn and Owasco municipal drinking water supplies in 2016 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. All of the Finger Lakes had confirmed blooms by 2017, many with high toxins, even the three oligotrophic (low productivity) lakes, Skaneateles, Canandaigua and Keuka. 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) spearheaded volunteer HABs monitoring efforts. They also advanced methods to report HABs events to the local community. With exceptional leadership, SLPWA's program grew quickly, and typically over 120 HABs volunteers survey approximately 100 km of the 130 km long shoreline entering, HABs detection reports and photos electronically using cell phones or tablets. HABs locations and photos are then linked to a google earth map. The mapping app was adopted by neighboring watersheds and New York State DEC, and it forms the backbone of the State's current NYHABs statewide monitoring/mapping system. A critical finding of these monitoring programs was that cyanobacteria blooms are concentrated along the shoreline, and are sporadic in both space and time, during the August through October HABs season.

This final report details the 2022 findings from our dockside monitoring program and summarizes the results from the past four years of research. Data from both lakes were combined into one report to provide an interesting comparison. This research followed up on promising research by Halfman and his collaborators[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 biomass.
- HABs were hypothesized to form along the shoreline after onshore wind and/or rain events, appearing on the next calm or nearly calm day.
- Shoreline geometry influenced nearshore wind speeds and directions enough to dictate where and/or when localized shoreline blooms develop.

This study was designed to investigate the following questions:

- Why are bloom events variable in both space and time?
- What is(are) the source(s) of nutrients for the shoreline blooms?
- Most importantly, what is(are) the trigger(s) for cyanobacteria blooms in both Seneca and Owasco Lakes?

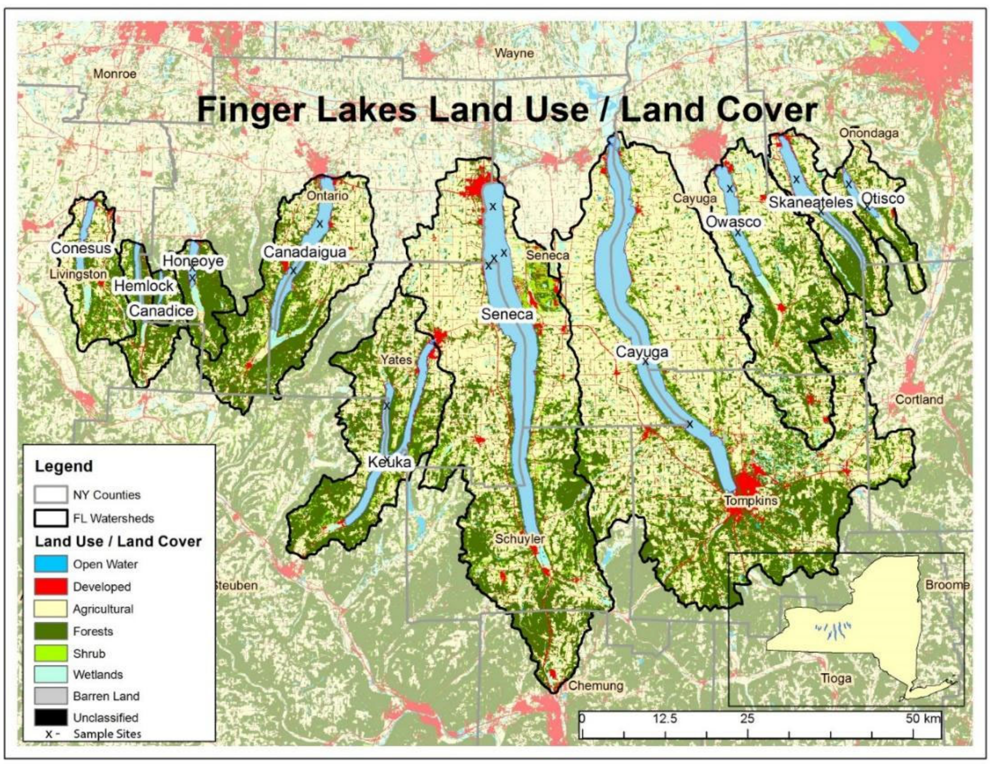


Fig. 1. Land Use / Land Cover (NLCD 2011 data) map of the Finger Lakes Watersheds. Seneca & Owasco Lakes are the focus of this report.

[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.
Halfman, J.D., et al., 2021. 2020 Nearshore Monitoring of Cyanobacteria (Blue-Green Algae) in Seneca & Owasco Lakes. The 2020 Report to the Seneca Lake Pure Waters Association, Fred L. Emerson Foundation and Cayuga County. Finger Lakes Institute, Hobart & William Smith Colleges. 62 pg.
Halfman, J.D., et al., 2022. 2021 Nearshore monitoring of Cyanobacteria (Blue-Green Algae) in Seneca and Owasco Lakes. Finger Lakes Institute, Hobart and William Smith Colleges. 70 pg.

EXECUTIVE SUMMARY

- Cyanobacteria blooms were again detected in both Seneca (57, 3rd largest) and Owasco Lakes (26, 4th largest) in 2022. The bloom counts decreased from last year's total, and was smaller than a maximum of 84 in Seneca Lake in 2019 and 72 in Owasco Lake in 2020.
- Water quality - limnological data from both lakes revealed borderline oligotrophic-mesotrophic systems, previously thought unable to support cyanobacteria blooms. The nutrient deficiency was also detected in the shoreline areas where the reported blooms were concentrated.
- The relative amount of cyanobacteria in the open water decreased in both lakes during 2022, although Seneca Lake offshore surveys were lacking during the 2022 bloom season. Let's hope that the decreasing cyanobacteria counts and decreasing offshore cyanobacteria concentrations and relative percentages is a sign of the future.
- The offshore plankton assemblages in Owasco Lake had significantly more cyanobacteria than Seneca Lake. The difference may reflect the earlier detection of cyanobacteria, a slightly more productive state, and/or additional or more extensive nutrient sources in Owasco then Seneca Lake.
- The relative percentage of cyanobacteria in Owasco's plankton has decreased over the past few years.
- The FLI water quality and meteorological monitoring buoys on Owasco and Seneca Lakes recorded multiple warm air and water temperatures, calm periods, and sunny conditions, i.e., "ideal" conditions for blooms.
- Water temperatures in 2022 were as warm as 2020, and spanning the past 7 years were the warmest on record in both lakes and part of the gradual warming trend observed over the past few decades. The recent warmth coincided with the onset of HABs events. It suggests that both lakes exceeded a water temperature tipping point favoring cyanobacteria blooms.
- Faster winds were detected by the offshore buoys in 2020 than 2019, 2021 and 2022 during the HABs season, especially in Seneca Lake. Persistently faster winds and the associated larger waves in Seneca Lake during 2020 may have reduced bloom development, whereas a mid-season dip in wind speeds and a smaller number of wind events may have promoted bloom development in Owasco Lake. The return to pre-2020 wind speeds in 2021 and 2022 may have allowed for a middling number of blooms in both lakes.
- Nearshore and offshore surface water temperature across Seneca and Owasco Lakes occasionally decreased just before cyanobacteria blooms. The declines suggest that precursor 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 the water column that stimulated nearshore blooms. The bloom(s) typically occurred on the next calm or nearly calm day.
- The dock site cameras detected blooms missed by local HABs volunteers; and conversely, the volunteers detected blooms missed by the camera's limited field of view.
- Seasonally, imaged blooms were detected from late July through October in both lakes with a late August peak. Blooms were most frequent during the afternoon hours in any given day, typically lasted a few hours from less than an hour up to 12 hours over the past four years. The timing and duration varied from site to site.
- The shoreline geometry decreased wind speeds and altered wind directions detected at the dock sites from that detected at the offshore buoys. Because each shoreline orientation is unique, each site experienced unique wind fields. It suggests that one shoreline can experience calm conditions and a cyanobacteria bloom, whereas neighboring shorelines with

a different orientation may experience sufficient winds to retard bloom development. The patterns helped explain why surface blooms are localized in time and space.

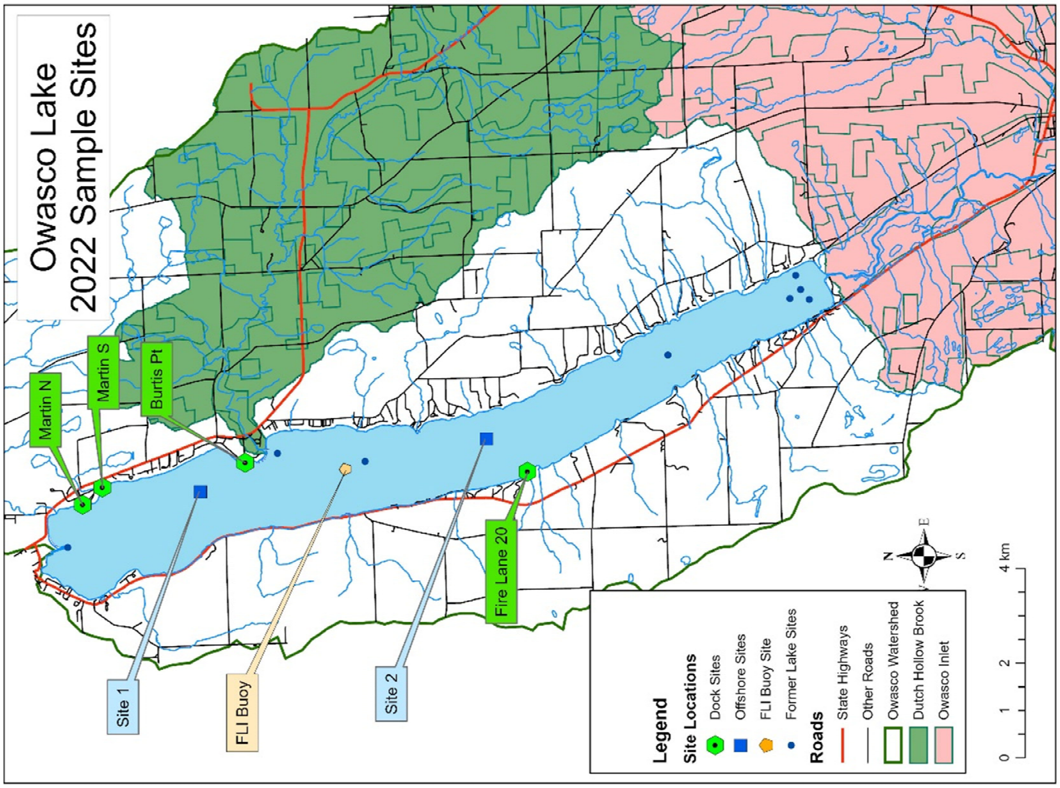
- Very large precipitation events, e.g., 2021, and their associated nutrient loads contributed to many blooms across Owasco Lake. Small rain events, though, lacked associated blooms.
- Histograms of the 30-minute dockside data divided into bloom and no bloom plots from each lake indicated that blooms occurred during the "ideal" calm (< 0.5 mph), sunny (600 – 900 W/m^2), warm water (23 – 25°C) and warm air (18 – 27°C) episodes. Unexpectantly, more blooms were detected during overcast/shady (< 250 W/m^2), cooler water (16 to 21°C), and/or windier (1 to 15 mph) conditions.
- More importantly, significantly (~100x's) more "ideal" sunny, calm and/or warm air/water episodes did not experience a bloom.
- Furthermore, only one or two of the "ideal" conditions, and rarely all four, were detected during a bloom. Blooms most often coincided with "ideal" calm or nearly calm winds, and least often with "ideal" water temperatures, and "ideal" solar intensities.
- Concurrent meteorological and water temperature inconsistencies during blooms point to nutrient availability as the essential ingredient to trigger blooms in these nutrient-poor lakes.
- Water quality (WQ) sondes deployed dockside detected daily oscillations in dissolved oxygen (DO). 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. DO oscillations were subdued offshore, and where an extensive shelf was lacking, e.g., FL-20.
- 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, again highlighting the importance of nearshore biological activity.
- The sondes deployed ~1m below the water surface did not detect surface hugging cyanobacteria blooms imaged by the automatic cameras.
- Like the Martin S site in 2020, organic matter clogged the Burtis Pt deployment pipe in 2021, and temporarily caused dissolved oxygen to decrease and total chlorophyll and cyanobacteria-chlorophyll to increase inside the pipe. We interpret the sequence as a release of nutrients by bacterial degradation of the dead macrophytes, nutrients that then stimulated cyanobacteria blooms inside the pipe. It was consistent with cyanobacteria oozing from decomposing organic debris along the shoreline and floating offshore mats. It reinforces the importance of localized nutrients for a bloom.
- Nutrient limitation studies indicated that the phosphorus plus nitrogen and, to a smaller extent, phosphorus-only treatments stimulated plankton growth, whereas nitrogen-only treatments did not.
- Preliminary nutrient flux experiments indicated that the nearshore sediments are a viable source of ammonium and to a lesser degree soluble reactive phosphate to the water column.
- Macrophyte and bottom "hardness" surveys document a potential supply of nutrients to the nearshore regions once the macrophytes die and decompose in the latter part of the summer.

METHODS

Nearshore Data: This project monitored the meteorological and limnological conditions at four dock sites around Owasco Lake in 2022 to discern the precursors to cyanobacteria blooms since. It augments dockside data from 8 sites in Seneca Lake monitored from 2019 – 2021. The docks around Seneca Lake were not surveyed in 2022. The current and former sites utilized homeowners who already were SLPWA and OWLA HABs volunteers and were willing to host the dockside instrumentation (Fig. 2). The Owasco sites duplicated those surveyed in 2020 and 2021: Martin North, Martin South, Burtis Point, and Fire Lane 20. Martin N and Burtis Pt were also monitored in 2019.

At each site, an automated camera, a weather station, a water temperature logger and water quality sonde were deployed to detect and elucidate occurrences of nearshore cyanobacteria blooms, and water quality and weather information for each bloom (Fig. 3). A Brinno TLC-200 automated camera, deployed on the weather station pole approximately 3 m above the lake's surface, recorded images of the lake's surface every 10 minutes from dawn to dusk (7 am to 6 pm). Each day was saved in a separate file, and used to manually 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. 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. 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 initially in ~1-m of water to record water temperature every 30 minutes. PVC pipes protected the loggers from wave action. An *In-Situ* Aqua Troll 600 water quality sonde with temperature, conductivity, total fluorescence (chlorophyll) and cyanobacteria phycocyanin fluorescence sensors was deployed at each dock except one (Fire Lane -20 Site), where a *YSI/Xylem* EXO2 water quality sonde with temperature, conductivity, dissolved oxygen, turbidity, and total fluorescence and cyanobacteria phycocyanin fluorescence was deployed instead. The sondes were deployed inside 4" diameter PVC pipes for their protection from waves. Each deployment pipe had numerous holes originally thought sufficient for continuous water flow.

The instrumentation was deployed on 7/20 and recovered on 10/5 in 2022, a timeframe that spanned the HABs season and dock availability. Each site was visited every two to three weeks to replace the camera batteries (if necessary), swap the camera's SD memory card for subsequent image analysis, and collect surface water grab samples for nutrient, suspended sediment and algal group analyses back in the laboratory.



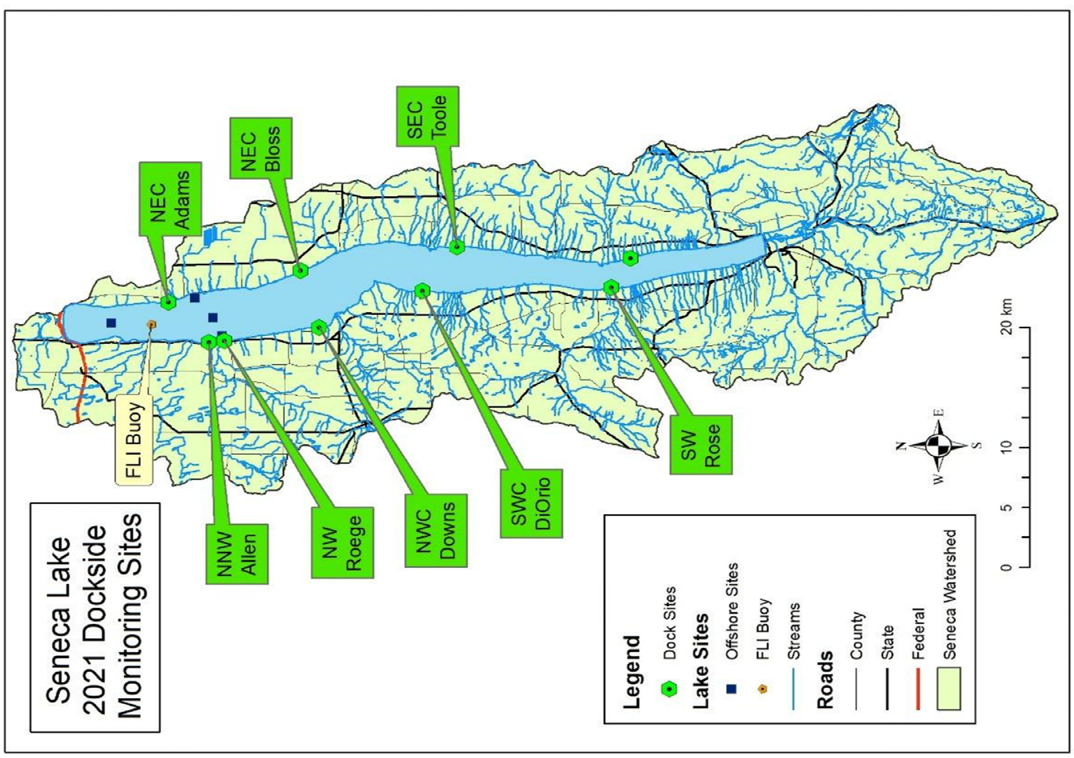


Fig. 2. The 2022 dock, nearshore and offshore site locations in Owasco (above) and Seneca (below) Lakes. The dock instrumentation was not deployed around Seneca Lake in 2022.

Fig. 3. Brinno camera, Weather station, 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. 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 buoys were used to place the nearshore data in perspective. Four sites were sampled in the northern portion of Seneca Lake and two sites in Owasco Lake, as these sites provided representative data for the entire lake in the past (Fig. 2). Unfortunately, the sites on Seneca Lake were not surveyed during the August through September HABs season in 2022 while the William Scandling was in dry dock undergoing repairs.

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, $\mu E/cm^2$-s), and total fluorescence (a measure of total chlorophyll, 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 cast. Phytoplankton was collected using an 80 µm mesh net integrating the algae through a depth of ~20 m (the epilimnion). The net contents were preserved in a lugols (iodine) 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), dissolved oxygen (mg/L), and alkalinity (mg/L, $CaCO_3$) using hand-held probes and field titration kits, and aliquots were analyzed in Halfman's research laboratory for total phosphate (TP, µg/L, P), soluble reactive phosphate (SRP, µg/L, P), nitrate-nitrite (NO_x, mg/L, N), chlorophyll-a (µg/L) and total suspended solid (TSS, mg/L) concentrations using standard limnological techniques. Additional aliquots were analyzed by FluoroProbe at the Finger Lakes Institute lab to determine the concentrations of: 'green' algae (Chlorophyta and Euglenophyta), 'brown' algae (diatoms: Baccillariophyta, Chyrsophyta, and Dinophyta), 'blue-green' algae (Cyanophyta), and 'red' algae (Cryptophyta).

FLI Monitoring Buoys: A FLI meteorological and water quality monitoring buoy manufactured by YSI/Xylem was redeployed at its mid-lake site in Owasco Lake from 4/13 through 10/11, and at its northern mid-lake site in Seneca Lake from 5/9 through 10/10 in 2022 (Fig. 2). Each 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/ and http://fli-data.hws.edu/buoy/seneca/). Leaking floats on the Owasco Buoy prevented collection of water quality and meteorological data from 5/31 through 6/6 to repair the floats, and minimal power and software issues precluded WQ data from 6/20 through 6/28. Minimal solar power and other issues prevented collection of water quality data on 9/24 – 9/26 in Seneca Lake.

Each 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. The calibrated buoy data are presented in this report, and will be available on the FLI buoy website soon. The cyanobacteria concentrations were normalized to a constant temperature due to the sensor's temperature sensitivity.

Limiting Nutrient Incubations: A series of mesocosm experiments to determine limiting nutrients in Owasco water were conducted between June and August on Owasco Lake following the procedures of Lewis et al[2]. Typically, the limiting nutrient for lakes is assumed to be phosphorus, but some lakes can also be nitrogen limited or co-limited with phosphorus and nitrogen. The limiting nutrient can also change from month-to-month. For these experiments, filtered water (153 µm mesh was used to exclude large invertebrates and colonial forms of phytoplankton) was distributed to twelve 500 mL Bitran bags representing triplicates of four treatments – control (no amendments), phosphorus (addition of 13 µg/L of soluble reactive phosphorus, a lower concentration than was used in 2020 mesocosm experiments), nitrogen (addition of 168 µg/L each of nitrate and ammonium), and a combination of the phosphorus and nitrogen treatments.

The mesocosm chambers were then randomly placed into a PVC rack with mesh that allowed for incubation at the water surface using a small pond on the HWS Hanley Preserve property (Fig. 4a). A screen was placed over the top of the rack to decrease the bag's exposure to solar radiation. Solar radiation and temperature were measured throughout the incubation period using Onset dataloggers. At the conclusion of the five-day incubation period, individual samples were poured off for chlorophyll analysis using the bbe FluoroProbe in the FLI laboratory. Box and whisker plots were completed to determine differences in chlorophyll concentrations within and across treatments.

[2] Lewis et al. (2020) Inland Waters, 10:1, 42-50, DOI: 10.1080/20442041.2019.1664233

Fig. 4a. Mesocosm racks floating in a pond at Hanley Preserve (above right). 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 five-day incubation.

Fig. 4b. Site locations for the mesocosm effort (above right).

Fig. 4c. Locations for the bottom hardness mapping in Owasco Lake: Emerson Park in the north, Owasco Yacht Club on the eastern shore, and Burtis Point at the bottom of this map (above left).

Sediment Nutrient Flux Experiments: Sediment flux experiments were conducted on sediment cores collected at four nearshore locations within Owasco Lake from June-August (Fig. 4b). These experiments build on previous studies to better understand the cycling of nutrients to and from sediments. Specifically, these experiments aim to characterize sediments as a source or sink of nutrients to surface waters in various nearshore areas of Owasco Lake across the primary production season.

For 2022, sampling sites were selected based on previous sampling efforts (Site D) and expanded to include the southern end of Owasco Lake (Site H) as well as additional north end sites where macrophyte sampling had been done previously including Sites C and F. The sediment core experiments are modeled after previously completed work on Honeoye and Owasco Lakes examining fluxes of phosphorus and nitrogen species between sediment cores and overlying water.

Specifically for 2022, the design and rationale for three different sediment core incubation experiments can be found in Table 1. This builds on the two previous years when sediment experiments were conducted on cores collected from Site D in late summer. Site D is located near the mouth of Dutch Hollow Brook and HABs are frequently detected in this location and others. In addition to testing nutrient fluxes from different locations within Owasco Lake, a comparison of nutrient fluxes from sediment cores with and without biofilms was conducted in July from Sites D and H.

Table 1. Overview of sediment core experiments for 2022 field season.

Month	Sites	Rationale
June 2022	C, D, F, H	Compare spatial differences in flux among four sites
July 2022	D, H	Compare flux of nutrients from sediment cores with top of sediment left intact (+biofilm) and scraped (-biofilm)
August 2022	C, D, F, H	Compare spatial differences in flux among four sites and with June flux

For each sediment core incubation site and period, ambient water samples were collected, filtered in the field using sample-rinsed, 0.22-µm nylon syringe filters and analyzed for nutrients including soluble reactive phosphorus (SRP), total phosphorus (TP), nitrite-nitrate (NO_x), and ammonium (NH_4). These water samples represent starting concentrations, or time zero (T_0), for the nutrient concentration in the water used for the sediment incubations (Table 2).

Table 2. Initial site-water nutrient concentrations for sediment experiments.

Site - Month	SRP (µg/L)	TP (µg/L)	NH_4 (µg/L)	NO_X (mg/L)
C-06	3.24	8.71	73.7	977
D-06	2.41	9.14	55	988
F-06	2.48	7.97	35	926
H-06	2.28	11.05	63	987
D-07	2.92	9.72	83.8	795
H-07	3.68	13.36	142.4	699
C-08	2.26	9.99	36.5	626
D-08	1.69	8.22	23	676
F-08	1.51	8.16	30.3	613
H-08	1.73	10.82	47.8	492

For each month's sediment incubation experiments, two nearshore cores (~10-15 cm of depth) with overlying water were collected from each site using a pole coring device with core tubes (6.75 cm diameter) in water depths of ~2-3 m using the methods of Gardner and McCarthy, 2009[3]. In addition, site water for the sediment flux incubations was also collected in pre-rinsed, 20-L cubitainers® for each site and treatment group. This water was used for the continuous water that was passed over the incubating sediment cores.

After transport to the laboratory, continuous-flow incubations of intact sediment cores were initiated within ~2 hr of field collection (Fig. 5). For June and August, a total of eight sediment cores collected from sites C, D, H, and F (two per site) were incubated over 72 hr with site water to investigate temporal and spatial variations in nutrient fluxes. As per protocol, the top biofilm of the sediment cores was removed to ensure that nutrients released from or lost to the sediments was due to the sediment core and not to the organic layer typical at the sediment/water interface. For July, sediment cores collected from sites D and H in July were separated into two treatment groups based on presence or absence of a biofilm at the sediment water interface. For all experiments, sediment cores were subsampled for organic matter content; an additional subsample was preserved for future analyses (potentially genetic material) by storing at -80°C at the FLI.

Fig. 5. Sediment nutrient flux experiment setup showing the system inflow of amended source water being pumped at a constant rate to the sediment interface and outflow water being captured for analysis.

For the incubations, core tubes were 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 (Fig. 6). Each core replicate received aerated site water from the cubitainer through polyetheretherketone tubing connected to the inflow and outflow ports of a peristaltic pump at a flow rate of ~1 mL of site water per minute[4]. This means that a volume of 1.44 L of water was exchanged over a 24 hr period.

Inflow and outflow waters were sampled at 24 hr intervals and filtered for SRP, NO_x, and NH_4. Unfiltered water was also collected for TP analysis. All nutrient samples were frozen until analysis. For analysis, nutrient concentrations were measured with an automated, colorimetric flow-injection analysis system (QuikChem 8500 Lachat Instruments) according to manufacturer methods and standard EPA protocols for SRP, TP, TN, NO_3, and NH_4. All laboratory analyses were conducted in the FLI's NYS Department of Health Certified Laboratory (#12144).

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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.

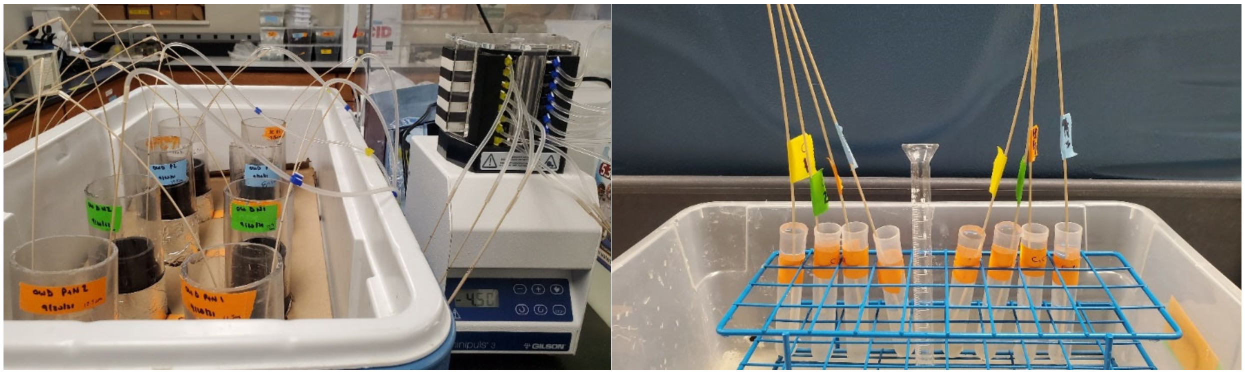


Fig. 6. Flow rates of water for individual sediment cores are adjusted to specific flow rates via a roller tensioning pump to allow for controlled nutrient, water, and sediment interactions.

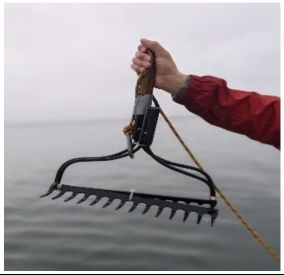
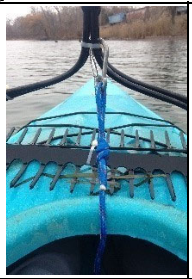
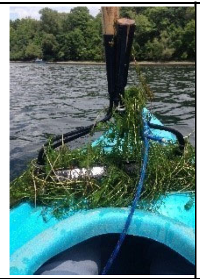
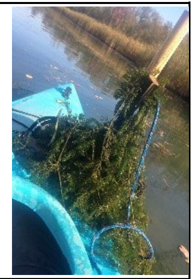
Lake Floor & Macrophyte Surveys: Macrophyte community data was collected in 2021 and 2022 through a companion Early Detection Rapid Response (EDRR) Aquatic Invasive Species project funded by the US Fish and Wildlife Service project administered by the Finger Lakes Lake Ontario Watershed Protection Alliance. This project focused on locating new instances of invasive plants and provides a much more comprehensive assessment of macrophyte communities compared to previous plant and mussel surveys conducted as part of the Emerson efforts. The leverage of the EDRR project enabled the completion of more sediment core experiments incorporating new sites across Owasco Lake at more times of the year (see sediment core section for more information.)

In 2021 and 2022, macrophyte communities were surveyed in multiple locations of Owasco Lake on predetermined transects generated using ArcGIS based on 100m x 100m grid size. The primary areas of the lake surveyed include the north end, which was primarily close to Emerson Park and the south end, which is near the Owasco Inlet.

In the field, handheld GPS devices were used to record precise locations during sampling. For plant collection, double-headed metal rakes tied to ~10m of rope were tossed from the sampling vessel and allowed to sink to the bottom before retrieval; the maximum water depth sampled was ~10m since sampling experience shows very few macrophytes present below this depth due to light limitations. Macrophytes recovered from the rake tosses were identified to species, and the dominant species and estimated total abundance were recorded in the field. Density rankings were based on the number of plants on each rake toss as picture in Table 3.

In addition to plant sampling, hydroacoustic data were collected using the FLI's Boston Whaler, equipped with a Lowrance HDS Live with Active-Imaging 3-in-1 Transducer to investigate bottom "hardness". Three sites on Owasco Lake, Emerson Park, Owasco Yacht Club and Burtis Point, were surveyed for this pilot phase based on the presence of marinas or boat launches, which are locations with higher risks for new plant invasions (Fig. 4c). Sonar logs were recorded along six transects on either side of a site point, for a total of 12 transects per site. Sonar logs were then uploaded to and processed by BioBase. Data were exported and mapped using ESRI ArcGIS Pro.

Table 3. Macrophyte density categories.

Images					
Macrophyte Density Rating Scale	0	1	2	3	4
Density Categories	No Plants	Trace Plants	Sparse Plants	Medium Plants	Dense Plants

SENECA AND OWASCO LAKES

Seneca and Owasco Lakes are two of the eleven Finger Lakes in central New York State (Fig. 1). Both are elongated, north-south orientated, borderline oligotrophic (low productivity) – mesotrophic (medium productivity) lakes, i.e., experience moderate algal productivity and oxygenated bottom waters. However, important differences exist. For example, Seneca Lake is much larger, deeper, and has a much longer water retention (residence) time than Owasco Lake (Table 4). 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 (lake volume) ratio in Seneca Lake makes it less susceptible to activities within the watershed like nutrient and sediment loading than Owasco Lake. Both rural areas surrounding the lakes are dependent on the agri-tourism economy with internationally known wineries. The lakes also supply municipal drinking water to nearby communities. Many lakeshore residents, however still use private systems to draw drinking water directly from the lake (or shore wells) in this rural region. Finally, both lakes experienced HABs events (e.g., Fig. 7).

Table 4. Physical & Other Characteristics of Seneca and Owasco Watersheds[5].

Characteristic	Seneca Lake	Owasco Lake
Maximum Length (km)	57	18
Maximum Width (km)	5.2	2.1
Shoreline Length (km)	123.6	41.3
Lake 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
Permitted Drinking Water Withdrawals (MGD)	9	16

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

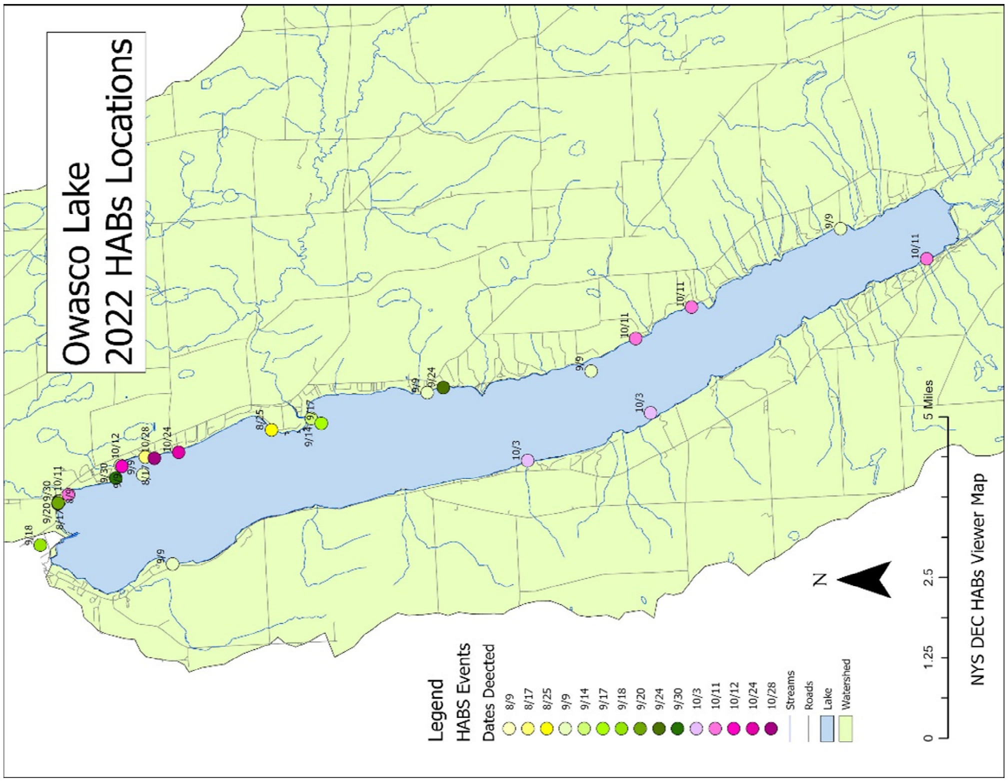
CYANOBACTERIA AND HARMFUL ALGAL BLOOMS BACKGROUND

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” atmospheric 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 phosphorus and nitrogen dynamics, especially the different types of nitrogen, are not very well understood. Both *Dolichospermum* and *Microcystis* were the cyanobacteria genera most often detected in Seneca and Owasco Lakes. *Dolichospermum* species typically preceded *Microcystis* in a given HABs season, but *Microcystis* soon thereafter dominated the cyanobacteria population.

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, threaten 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 BGA genera are common in NY lakes, total microcystin is commonly measured using EPA Method 546 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*. The presence of toxins cannot be determined visually but instead require a complex analytical procedure.

The concentrations, e.g., maximum contaminant levels (MCL), when these toxins impact human health 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 less than 24 hours, which makes detection in the water column difficult. The NYSDEC defined a cyanobacteria bloom when the cyanobacteria chlorophyll 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.

[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



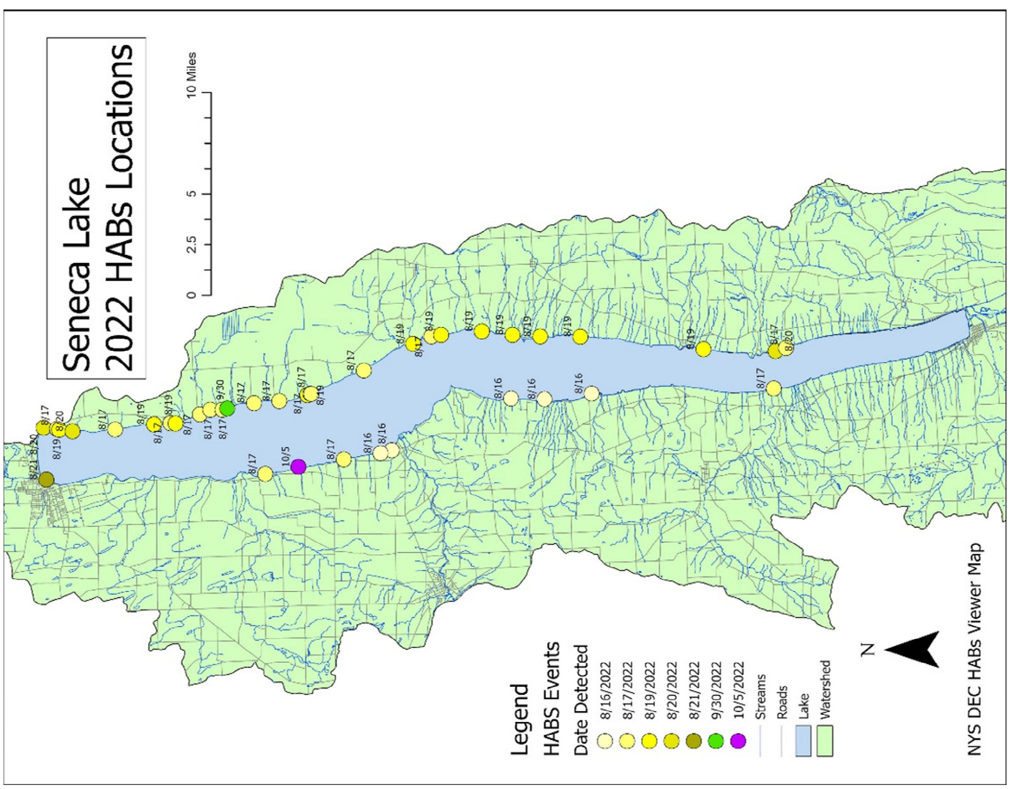
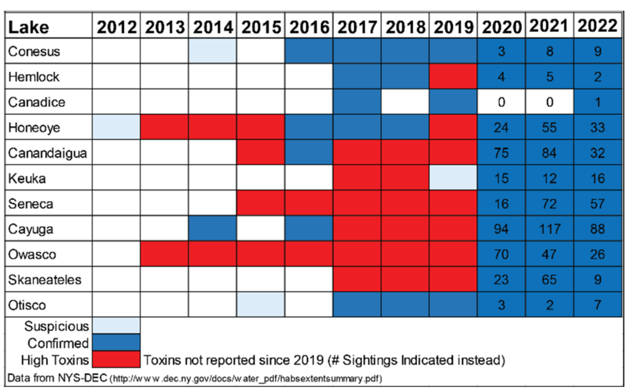


Fig. 7. Confirmed cyanobacteria bloom locations in Seneca and Owasco Lakes during 2017-2021 (in appendix) and 2022 (above). Data are from the NYS-DEC HABs Map website.

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. Like previous years, nearly two hundred lakes in New York State (198) officially reported cyanobacteria blooms in 2022 out of the 7,849 lakes in the state (all identified lakes and ponds with or without monitoring programs, Rebecca Gorney, NYSDEC, pers. comm.).

Lakeshore residents with private water systems should use bottled water during cyanobacteria outbreaks along their shoreline because their private water supplies are challenged to remove cyanobacteria from the water without bursting the organism's cell walls[8]. For example, filtration used by many private systems can easily compromise the cell wall integrity. Cell wall integrity is critical, because once 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 private drinking supplies used by lakeshore residents.

Seneca and Owasco Lakes have experienced numerous surface-water, primarily nearshore, cyanobacteria (cyanobacteria) blooms, many with toxic levels of microcystin and other toxins (Fig. 7). In Seneca Lake, blooms were first detected in 2015 (Fig. 8). Since then, 2017 – 2019 annual mean cyanobacteria concentrations ranged from 3,600 to 6,700 µg/L (Max: 59,000 to 118,000 µg/L) and 2017 – 2018 microcystin toxin concentration ranged from 47 to 290 µg/L (Max: 670 to 2,100 µg/L; Fig. 8). In Owasco Lake, blooms were first detected in 2012, and 2017 – 2019 annual mean cyanobacteria concentrations ranged from 140 to 4,960 µg/L (Max: 1,100 to 45,500 µg/L) and microcystin toxin concentration ranged from 240 to 750 µg/L (Max: 1,100 to 45,500 µg/L). The DEC measured cyanobacteria and toxin concentrations from 2012 through 2019. Since then, the DEC has only tallied confirmed bloom sightings, first and last detection dates, and published it with photographs and pinpointed locations on the NY HABS mapping website (Fig. 8).[9]



Cyanobacteria & Microcystin Concentrations

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

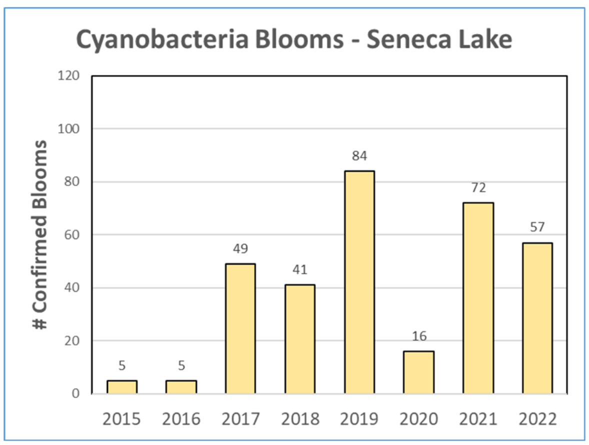
Fig. 8. The number of Finger Lakes with suspicious bloom activity, confirmed blooms and confirmed blooms with high toxins from 2012 - 2019 (left, by permission DEC), and the 2017 – 2019 cyanobacteria and toxin results (right).

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

[9] NY HABs Map.

The number of DEC confirmed blooms were slightly different between Seneca and Owasco Lakes (Fig. 9). Both lakes experienced a small number of blooms during the first few years since the initial detection. Counts then increased from 2017 through 2019. More blooms were detected in Seneca Lake (41 to 84 each year) than Owasco Lake (11 to 23). Lake size explains some of these apparent differences. Normalizing the bloom counts to length of shoreline, the Seneca Lake volunteers detected 0.4 to 0.7 blooms/km of shoreline compared to a similar 0.3 to 0.6 blooms/km of shoreline in Owasco Lake.

The number of bloom sightings changed drastically in 2020. It decreased to 16 confirmed blooms in Seneca (0.1 blooms/km) and increased to a record high 70 blooms in Owasco (1.8 blooms/km). These changes were probably real despite other potential factors that influenced bloom counts 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 in 2020 to determine potential water quality and/or meteorological variables that influenced this change.



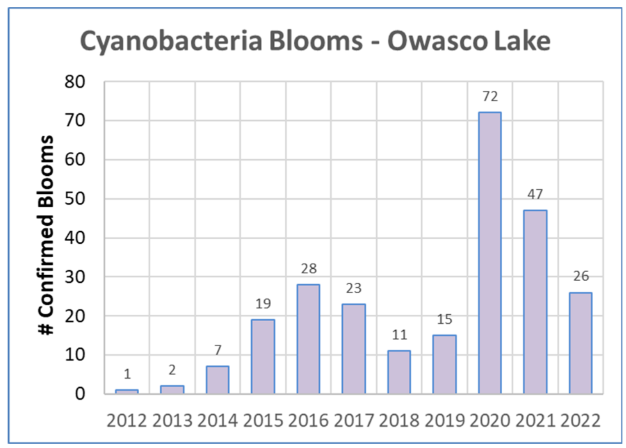
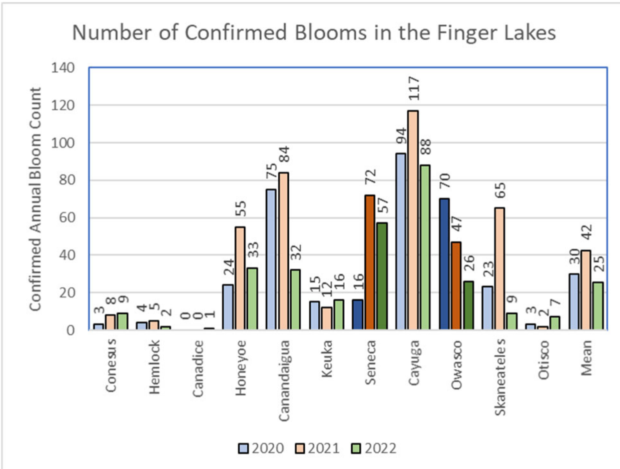


Fig. 9. Annual numbers of confirmed cyanobacteria blooms detected by the volunteers and compiled by DEC (NYS HABs Maps), Seneca (above left), Owasco (above right).

From 2021, bloom counts decreased from 72 to 57 in Seneca Lake (3rd largest, 0.6 blooms/km) and decreased from 47 to 26 in Owasco Lake (4th largest, 0.7 blooms/km). However, the number of confirmed counts in 2022 remained one of the largest since their official appearance in both lakes (Fig. 9). Conditions in 2021 were prime for bloom activity in both lakes, and slightly less ideal in 2022. As a comparison, Canandaigua reported 32 confirmed blooms in 2022, whereas Cayuga had 88 blooms, or 0.6 blooms/km and 0.6 blooms/km, respectively. Bloom counts and first and last seasonal sightings from 2020 – 2022 in all the Finger Lakes are reproduced below (Fig. 10; Table 5).



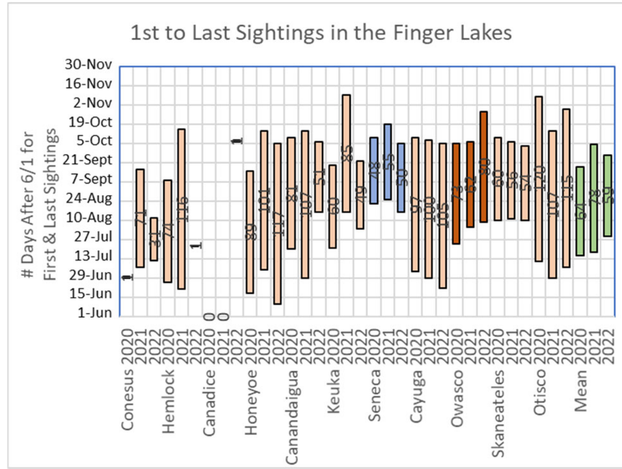


Fig. 10. The number confirmed blooms and dates for first and last sightings in the Finger Lakes form 2020 through 2022. Data from DEC's HABs mapper website.

Table 5. Bloom Counts and Blooms/km of Shoreline in the Finger Lakes

Lake	2020	2021	2022	Shoreline (km)
Conesus	3 (0.1)	8 (0.3)	9 (0.3)	29.8
Hemlock	4 (0.1)	5 (0.2)	2 (0.1)	27.5
Canadice	0 (0.0)	0 (0.0)	1 (0.1)	10.0
Honeoye	24 (1.6)	55 (3.6)	33 (2.1)	15.4
Canandaigua	75 (1.3)	84 (1.5)	32 (0.6)	57.8
Keuka	15 (0.2)	12 (0.1)	16 (0.2)	96.0
Seneca	16 (0.1)	72 (0.6)	57 (0.5)	121.3
Cayuga	94 (0.6)	117 (0.8)	88 (0.6)	153.4
Owasco	70 (1.8)	47 (1.2)	26 (0.7)	39.8
Skaneateles	23 (0.4)	65 (1.2)	9 (0.2)	54.7
Otisco	3 (0.1)	2 (0.1)	7 (0.3)	24.9

Bloom Counts by NYS-DEC (Blooms/km Shoreline)

OFFSHORE WATER QUALITY

The following section compared the open-lake water quality data with the following "ideal/preferred" cyanobacteria water quality conditions gleaned from the scientific literature:

- 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,
- an alkaline pH.

This section focuses on potential meteorological and water quality "triggers" for cyanobacteria blooms in these two lakes. Keep in mind, predicting their occurrence remains a challenge due to the large number of cyanobacteria species and the diversity of their habitats, and significantly more challenging in these two lakes, because they are oligotrophic to mesotrophic systems, and not the nutrient-rich, eutrophic lakes, where cyanobacteria blooms were more common in the past.

Algal Populations: Before 2018, mean daily cyanobacteria concentrations were small, < 2 μg/L in Seneca and < 8 μg/L in Owasco (Fig. 11). Diatoms dominated the communities in both lakes in the early spring and fall; diatoms, green algae and cryptophytes in mid-summer; and, cyanobacteria in the late summer and early fall. The mean annual concentration of cyanobacteria in Owasco Lake increased from 0.01 μg/L in 2017 to 3.2 μg/L in 2020, then decreased to 2019 values in 2021, and 2018 concentrations in 2022 (< 0.1 μg/L). This was consistent with visual observations at Owasco Lake that noted an increased presence of cyanobacteria in the surface water throughout the lake in 2020 compared to years before or after. Similar fluctuations in cyanobacteria were not observed in Seneca Lake. Instead, cyanobacteria were never prevalent in the offshore FluoroProbe data of Seneca Lake (< 2 μg/L).

Mean annual plankton enumerations paralleled the FluoroProbe results (Fig. 12). *Diatoma* (spring), *Asterionella* (spring) and *Fragilaria* (fall) were the three most common species of diatoms, and diatoms dominated the plankton communities. *Dolichospermum* (formerly *Anabaena*) and *Microcystis* were the two common forms of cyanobacteria. Low counts of *Dolichospermum* appeared before and was quickly followed by much larger counts of *Microcystis* during the HABs season. Varieties of green algae and dinoflagellates make up the rest of the community. The plankton net mesh is too coarse (80 μm mesh) to collect most Cryptophyte species.

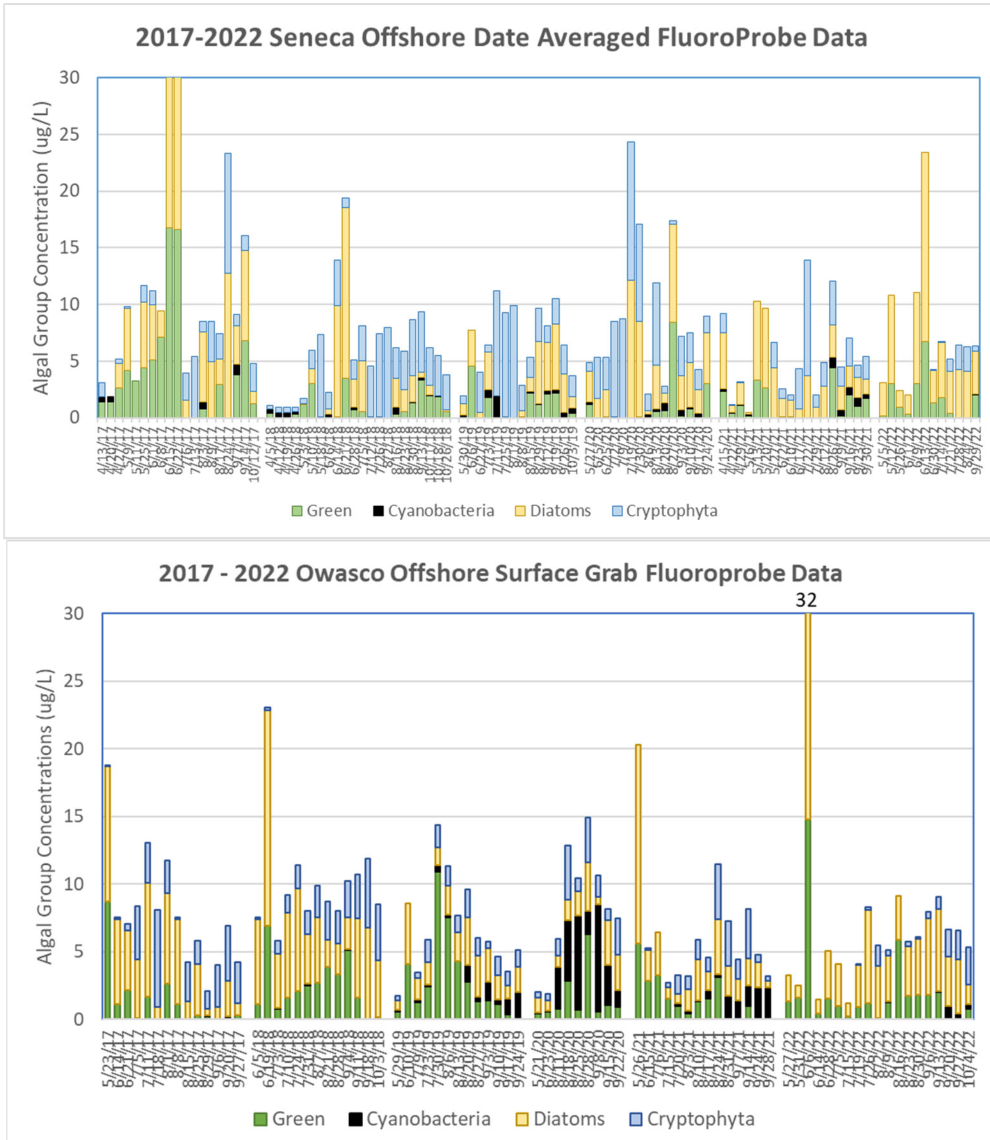
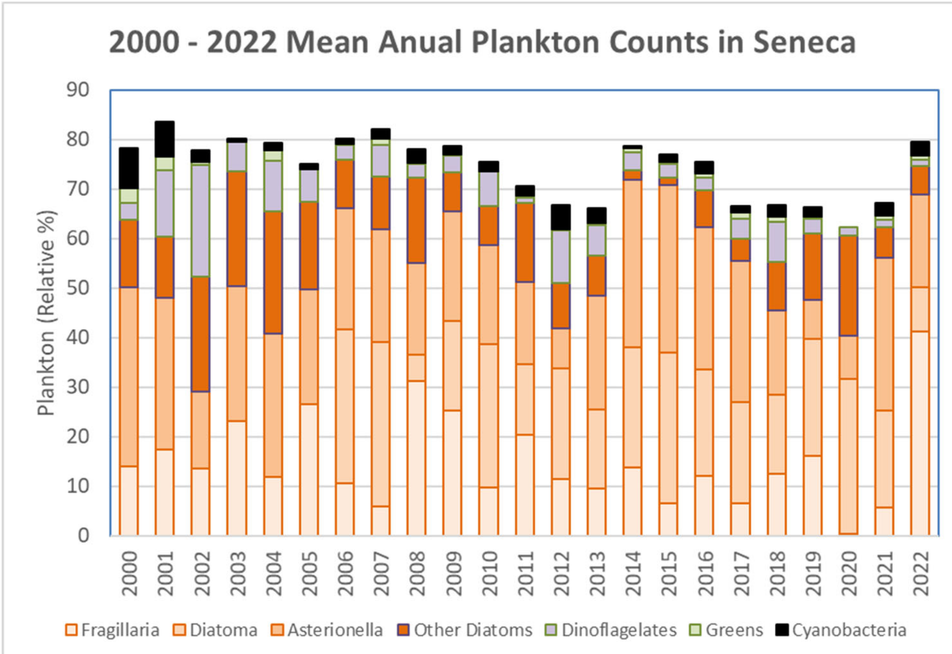


Fig. 11. Offshore, surface grab, date averaged, bbe FluoroProbe concentrations of the four algal groups from 2017 through 2022 in Seneca (above) and Owasco (below) Lakes.



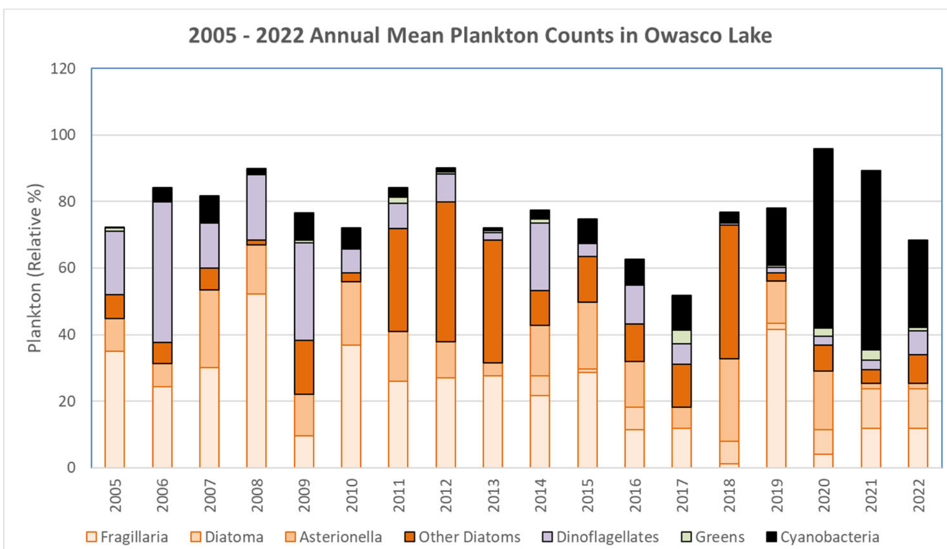
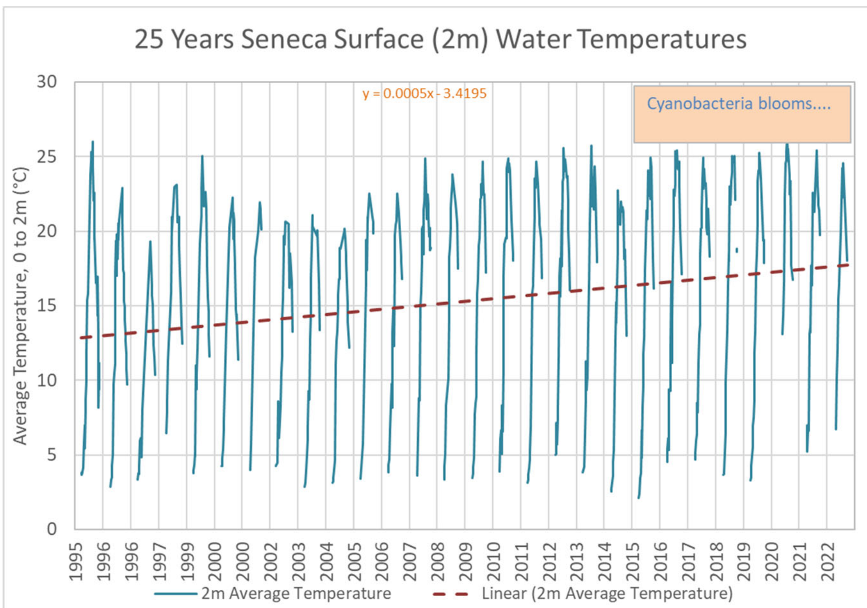


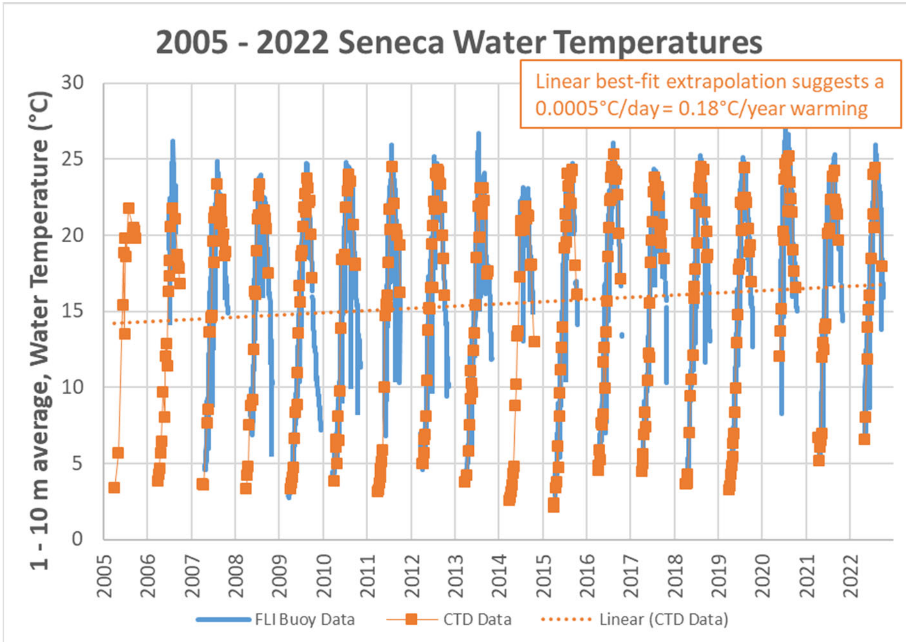
Fig. 12. Mean annual plankton counts from offshore vertically integrating (15m deep) plankton tows (80 µm mesh) in Seneca (above) and Owasco (below) Lakes.

Cyanobacteria dominated the plankton counts (40 to 95%, annual mean 38 & 54%) in Owasco Lake during the 2020 and 2021 HABs season but not Seneca Lake. Their dominance in Owasco declined substantially in 2022 (6 – 68%, annual mean 26%) but was still larger then Seneca's algal community (< 5%). Perhaps the earlier appearance of cyanobacteria (2012 vs 2015) in Owasco than Seneca enabled more time for them to become more firmly established in Owasco. Alternatively, nutrient sources were more ideal for cyanobacteria proliferation in Owasco than Seneca, but these differences diminished in 2022.

Surface Water Temperatures by CTD: Surface water temperatures measured by CTD since 1995 in Seneca Lake indicate a warming trend over the past two decades (Fig. 13). Water temperatures detected in 2020 were the warmest in this dataset, and the 2021 and 2022 maximum temperatures were similar to those over the past decade. A linear, best-fit line suggests that Seneca Lake has warmed approximately 0.18°C/year since 1995, presumably due to climate change. The warming was not uniform but instead occurred in a step function with a few years occasionally deviating above or below the linear warming trend. More importantly, the water temperatures over the recent decade were the warmest than earlier years in the 30-year dataset, and the warmest waters were coincident with the proliferation of cyanobacteria blooms. A similar warming trend was detected in Owasco Lake (0.21°C/year). Since the first detection of cyanobacteria in Owasco Lake (2012), the surface water was at its warmest, compared to the earlier years in the dataset. Warmer water probably helped initiate blooms in these two lakes as the HABs season surface water temperatures became firmly established in the preferred range for cyanobacteria blooms, and more importantly, warmer water stimulates faster bacterial activity, thus releasing more nutrients to support HABs events.

The observed surface water warming trend helped trigger HABs events.





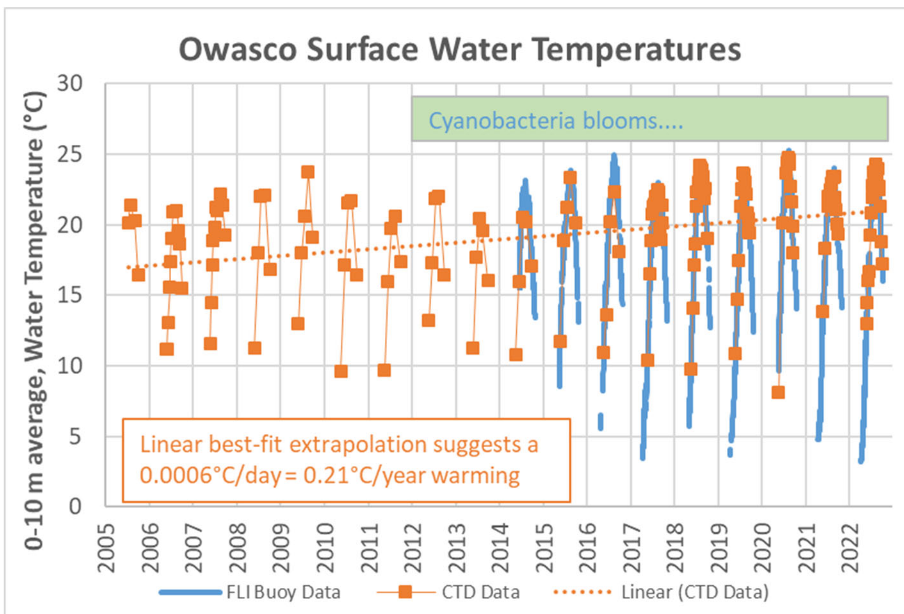


Fig. 13. Surface water temperatures from Seneca (above 1995 to 2022 and 2005 to 2022 datasets) and Owasco (below) Lakes measured by CTD and FLI Buoy. Years with reported cyanobacteria blooms are shown.

Secchi Disk, Nutrient, Turbidity & Chlorophyll-a Data: Offshore Secchi depths, total phosphorus, soluble reactive phosphate, nitrate, total suspended solids and chlorophyll-a concentrations have also changed over time (Fig. 14). 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[10]. During the past decade and coincident with detected cyanobacteria blooms, larger concentrations and larger variability in

[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.

each year's nutrient data were observed, especially the largest values in each year, i.e., the upper whisker of the box and whisker plots. The decade-long increase in algal productivity, i.e., lower Secchi depths, larger TSS, TP and chlorophyll concentrations, is attributed to nutrient loading in both watersheds.[11] Superimposed on this long-term trend, were larger concentrations of TP and SRP in 2014, and shallower Secchi depths, and larger TSS and chlorophyll concentrations in 2015 were detected in Seneca Lake. These changes are interpreted to reflect significant additions of phosphorus and sediment from flood-scale storms and associated runoff events in 2014. The timing also corresponded to the initial detection of cyanobacteria blooms in the lake. The historical data suggest that the injection of phosphorus, the limiting nutrient in the lake, and the onset of warmer water pushed Seneca Lake over a tipping point in 2015, and triggered cyanobacteria blooms. Similar flood-scale loading events were noted at the start of cyanobacteria blooms in Owasco Lake, especially in 2014. These limnological precursors to the onset of cyanobacteria blooms are also observed in the water quality data from neighboring Finger Lakes.[12]

Phosphorus loading in 2014 helped trigger HABs events in these lakes.

Nitrate concentrations followed a unique trend, and steadily declined in Seneca since 2015. The decline was minor until 2017 when it declined at a faster rate. Increased productivity most likely caused the decline in nitrogen from the lake. In contrast, nitrate concentrations fluctuated up and down in Owasco Lake until 2018, then like Seneca, concentrations declined. The decline is interpreted as the utilized of the lake's supply by increased algal populations/productivity and a larger presence of cyanobacteria from phosphorus loading in the watershed. The decline was more noticeable in Owasco than Seneca due to Owasco's smaller volume (easier to impact nitrogen concentrations in the lake). Similar nitrate trends are observed in the neighboring Finger Lakes.

Shallower Secchi disk depths and slightly larger chlorophyll-a concentrations were observed a few years earlier in Owasco than Seneca. Owasco was also slightly more turbid, experienced lower maximum total phosphate and soluble reactive phosphate concentrations, and slightly higher nitrate concentrations. These differences indicate that Owasco is slightly more productive, i.e., more mesotrophic than Seneca, and reflects its smaller surface area, smaller volume, shallower depths, larger watershed to lake surface area ratio, and slightly more agricultural land use / land cover in its watershed. The increased productivity at Owasco Lake may have promoted the earlier detection (2012 vs 2015) of bloomsn any individual HABs seasons than Seneca Lake.

One additional change in 2022 is also noteworthy. Larger total phosphorus (TP) concentrations were detected in both lakes in 2021 and 2022 compared to 2020. It suggests that an increase in TP concentrations should increase the number of blooms in both lakes. The increase can be attributed to significant rainfall events in 2021, especially in Owasco Lake, and 2020 was a relatively dry year. However, TP does not consistently covary with bloom counts from year to year in either lake. The best example is from 2020 to 2021 where TP increased in both lakes;

[11] 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.
[12] 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.

whereas, bloom counts increased in Seneca but not Owasco Lake. The decline in 2020 at Seneca is more likely from the intense winds during the HABs season. Multiple stressors reaffirm the intertwined and complex drivers for HABs events in these lakes. This nutrient-bloom inconsistency reaffirms that open water nutrients were not the primary nutrient source for the cyanobacteria blooms and stimulated the search for nutrients in the nearshore sediments and lake-floor biota (e.g., macrophytes, *Cladophora* and mussels).

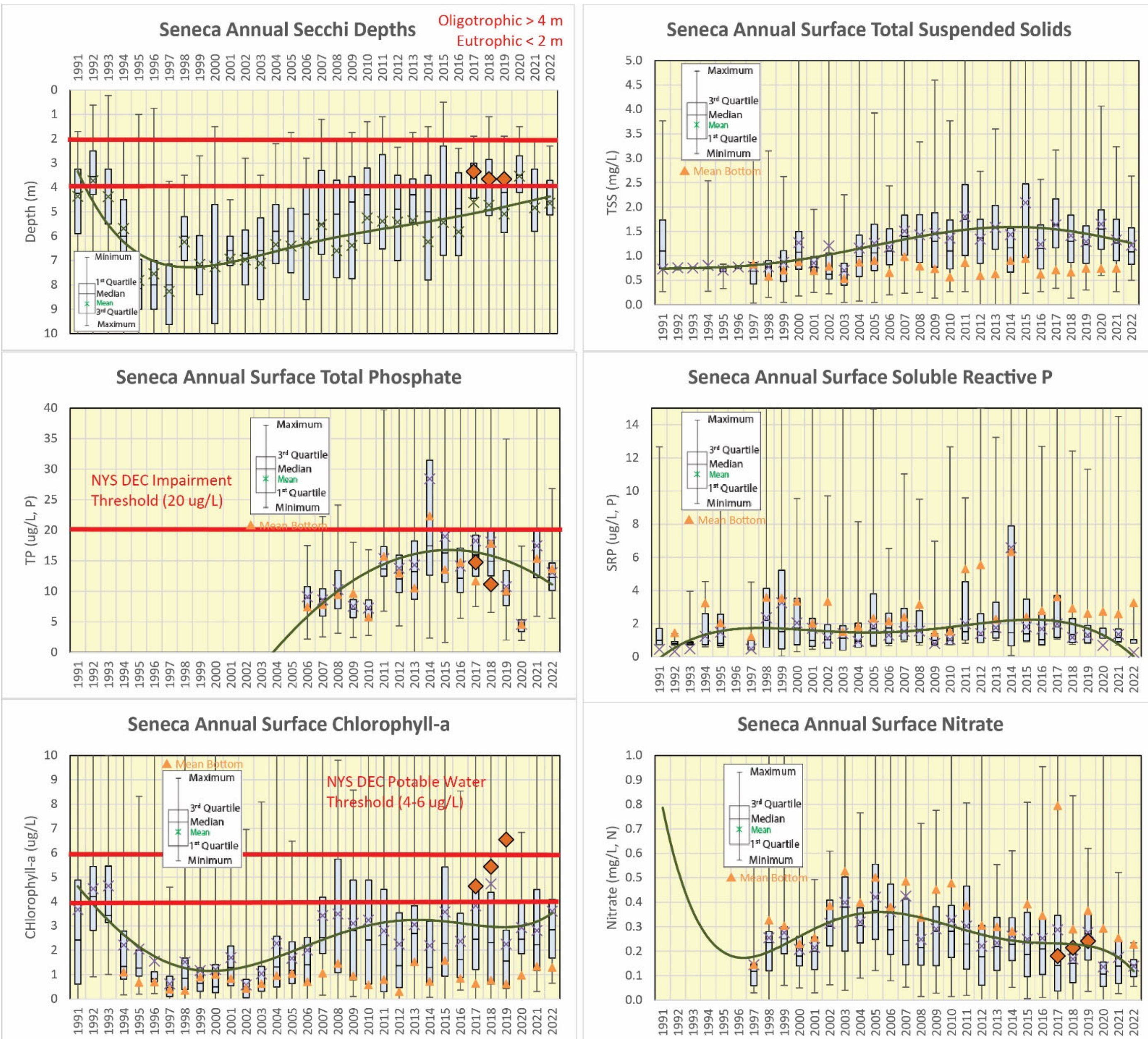


Fig. 14. Historical Secchi depths, nutrient and chlorophyll data from the Seneca Lake monitoring program. The box in the box and whisker plots contain 50% of the available annual data. The lower and upper whiskers correspond to the minimum and maximum values of the available annual data. The orange triangles plot annual mean bottom water data. The orange diamonds plot annual mean CSLAP data when available.

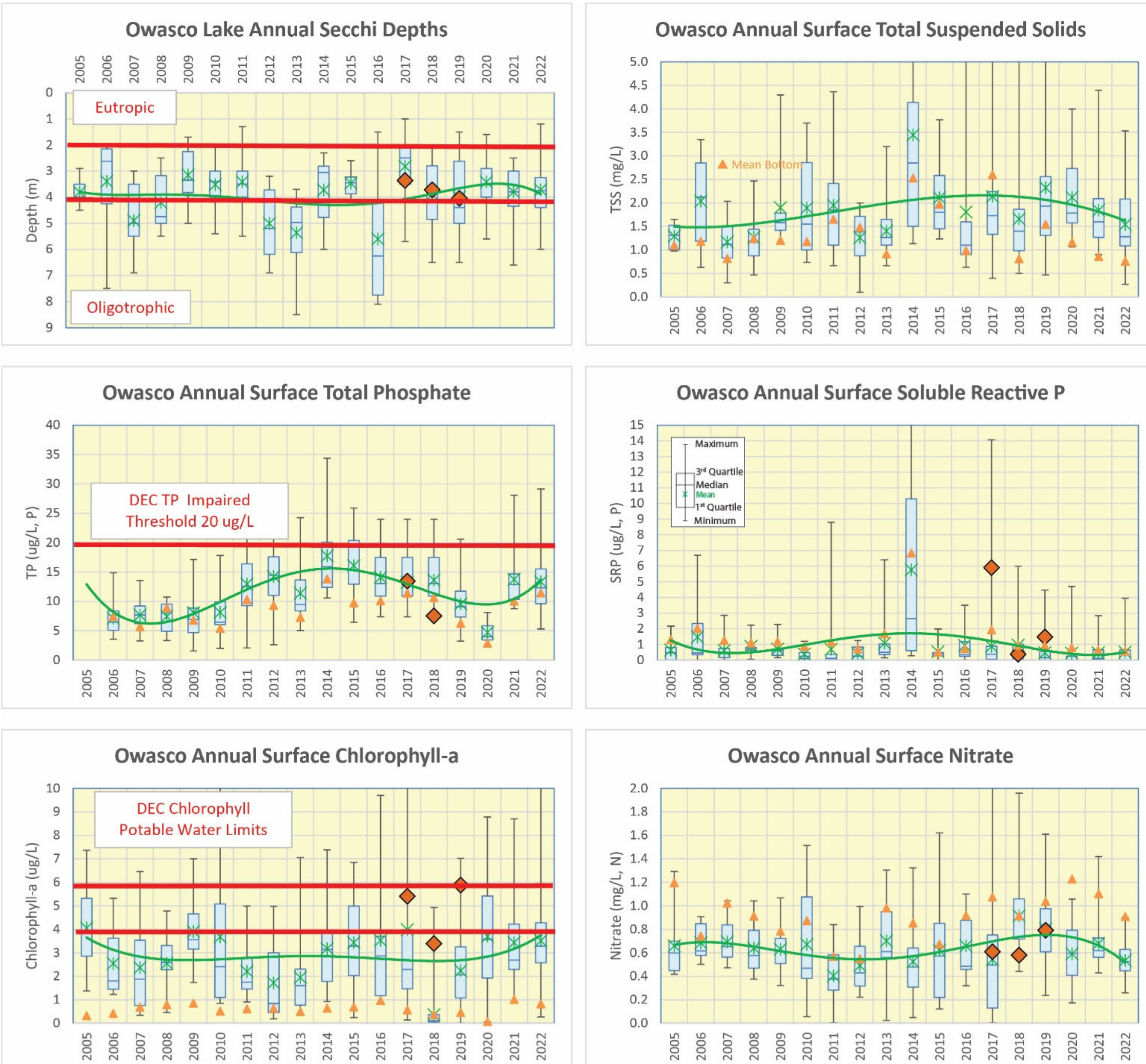
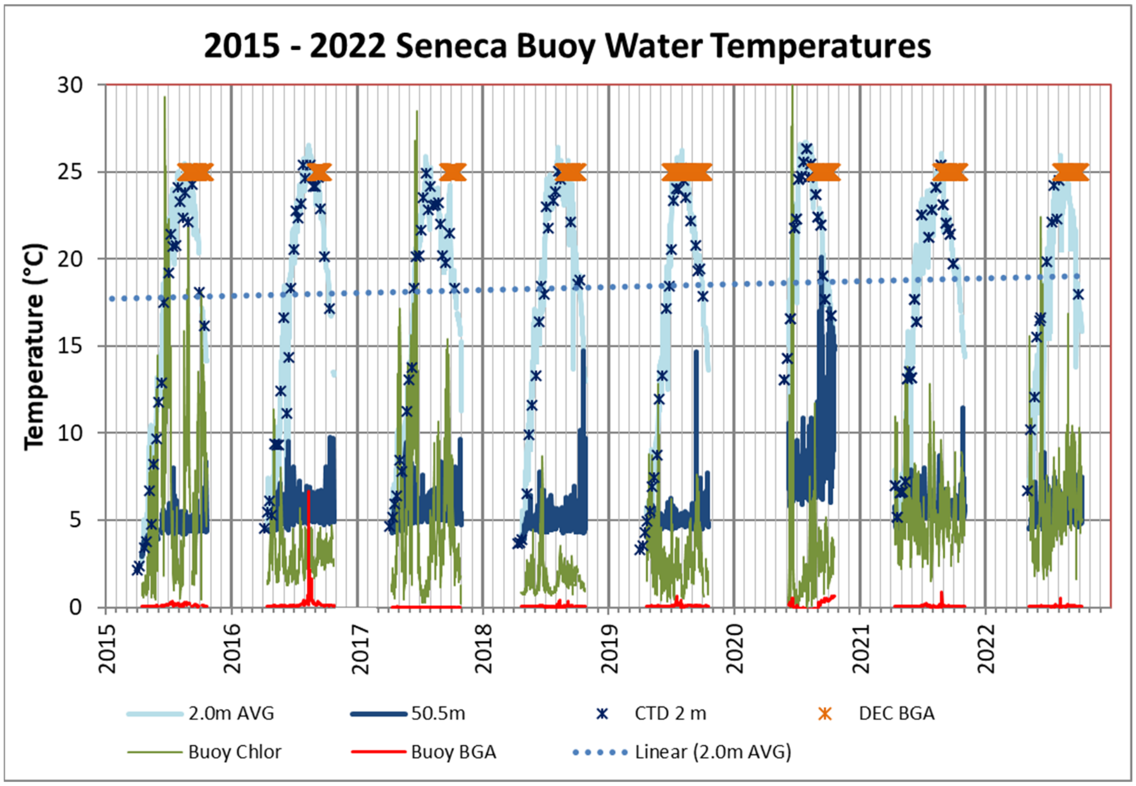


Fig. 14 continued. Historical Secchi depths, nutrient and chlorophyll data from the Owasco Lake monitoring program. The box in the box and whisker plots contain 50% of the available annual data. The lower and upper whiskers correspond to the minimum and maximum values of the available annual data. The orange triangles plot annual mean bottom water data. The orange diamonds plot annual mean CSLAP data.

FLI Buoy Data

Lake Temperatures by Buoy: The FLI Monitoring buoys provided higher resolution water quality data than the weekly (to monthly) limnological surveys. In 2020, the USGS buoy[13] was used in Seneca Lake because the FLI buoy was inoperative. Since the USGS buoy was deployed in shallower water north of the FLI buoy site and the lowest thermistors sampled the lower epilimnion / upper hypolimnion instead of the hypolimnion at the FLI buoy site, it influenced an "apparent" warming of the bottom water temperatures in 2020. In other respects, the USGS buoy temperature data were consistent with previous FLI buoy results[14].



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

[14] 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.

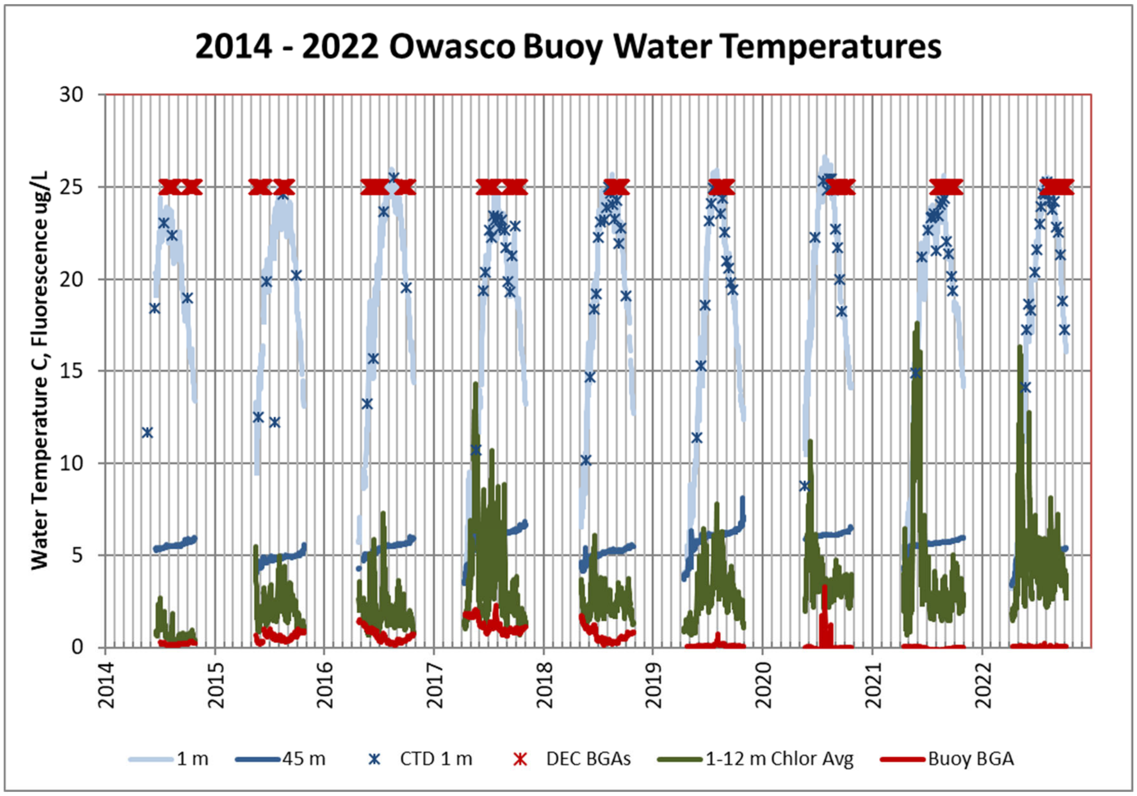


Fig. 15. Field season surface and bottom water temperatures at the Seneca (above) & Owasco (below) buoys. Surface water (1-2m) CTD data were superimposed onto the buoy temperatures. The USGS buoy on Seneca Lake was used for its 2020 data. The weeks these lakes were on DEC's HABs Notification Page are also shown.

Shoreline cyanobacteria blooms were detected when the surface water was warm, 18 to 26°C (65 – 80°F, Fig. 15). However, blooms typically did not appear until a week or two after the warmest water temperatures of the summer season. An exception was during 2019 in Seneca, and during 2015, 2016, 2017 and 2021 in Owasco. The delay indicates that warm water by itself does not directly trigger bloom activity. However, the delay provided time for more bacterial decomposition of organic matter in the nearshore sediments (and accumulation of nutrients) of these lakes potentially 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, and/or Owasco's larger watershed to lake surface area ratio and its nutrient loading issues, to jumpstart the blooms. Alternatively, bloom watch volunteers were better at detecting blooms in those years, although the HABs database revealed consistent first detection dates from 2020 through 2022 in these two lakes, except for a July sighting in 2020 in Owasco. Cyanobacteria blooms were not detected after the surface water cooled below 15°C (60°F) in the fall.

Since 2014, the buoy data indicate that Owasco Lake warmed more quickly in the early spring (0.6°C, May – June) and cooled more quickly in the fall (0.1°C, August – October) than Seneca Lake (Fig. 16). The difference was calculated by subtracting each Seneca buoy surface water temperature from the Owasco Buoy surface water temperature (Owasco – Seneca) for each profile in the record. Owasco Lake's smaller volume and shallower depths allows it to warm and cool more quickly, all other drivers like solar intensity, wind speeds/directions and ice cover being equal. For example, the springtime warming in Owasco Lake would be delayed if it had a thick cover of ice in the previous winter. In contrast, Seneca has not frozen completely in many decades. The implication, warmer water in the spring would enable earlier biological activity in the spring, i.e., earlier activity by bacteria and the associated release of nutrients, thus earlier shoreline blooms. The earlier warming helps explain why blooms were detected earlier in the summer at Owasco Lake than Seneca Lake, although this difference may instead reflect the respective bloom watch volunteer protocols and procedures at each lake.

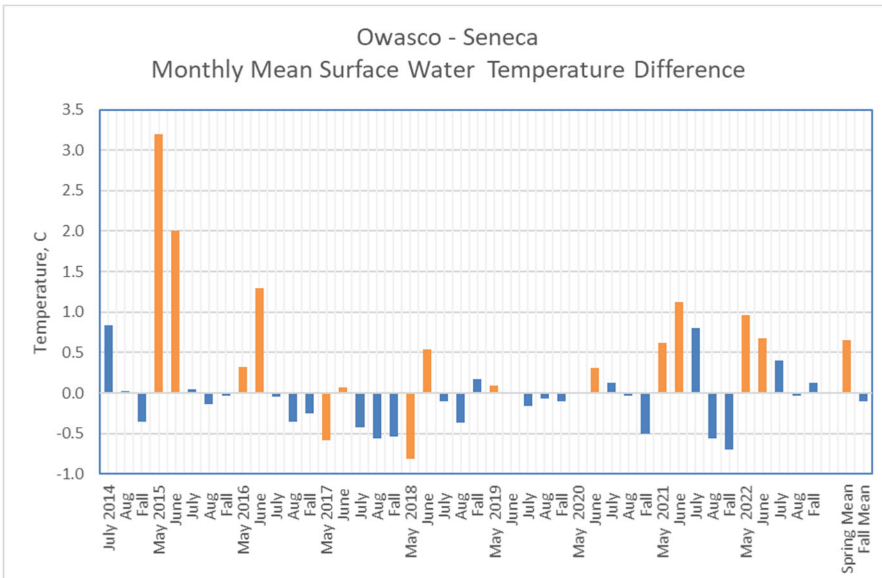


Fig. 16. Differences in surface water temperatures in the two lakes, averaged by season (seasonal average of daily differences = Owasco temperature – Seneca temperature).

Recent water temperatures were warm enough for cyanobacteria blooms in these two lakes. However, blooms were more often detected after the warmest water of the year. The warm season occurred earlier in the year at Owasco than Seneca Lake, and helped jumpstart biological activity and the HABs season in Owasco Lake.

Buoy Total and Cyanobacteria-PC Fluorescence: Minimal correlations were observed between the buoy total fluorescence and buoy cyanobacteria-PC, or between the buoy total fluorescence and recorded shoreline cyanobacteria blooms (Figs. 15, 17 - 20). It indicates that the open water productivity utilizes a unique source of nutrients than the bulk of the shoreline cyanobacteria blooms. The buoy detected larger algal concentrations and more frequent offshore algal blooms in 2015, 2017, 2021 and 2022 compared to 2016, 2018, 2019 and 2020. More rain fell in 2015, 2017 and 2021, and the associated increased nutrient loads from its runoff probably stimulated more algal growth during these impacted years. More importantly, 2015, 2017, 2021 and 2022 had larger daily rainfall events. Large events deliver significantly more nutrients to the lake and were correlated to annual mean chlorophyll concentrations in the lake.[15]

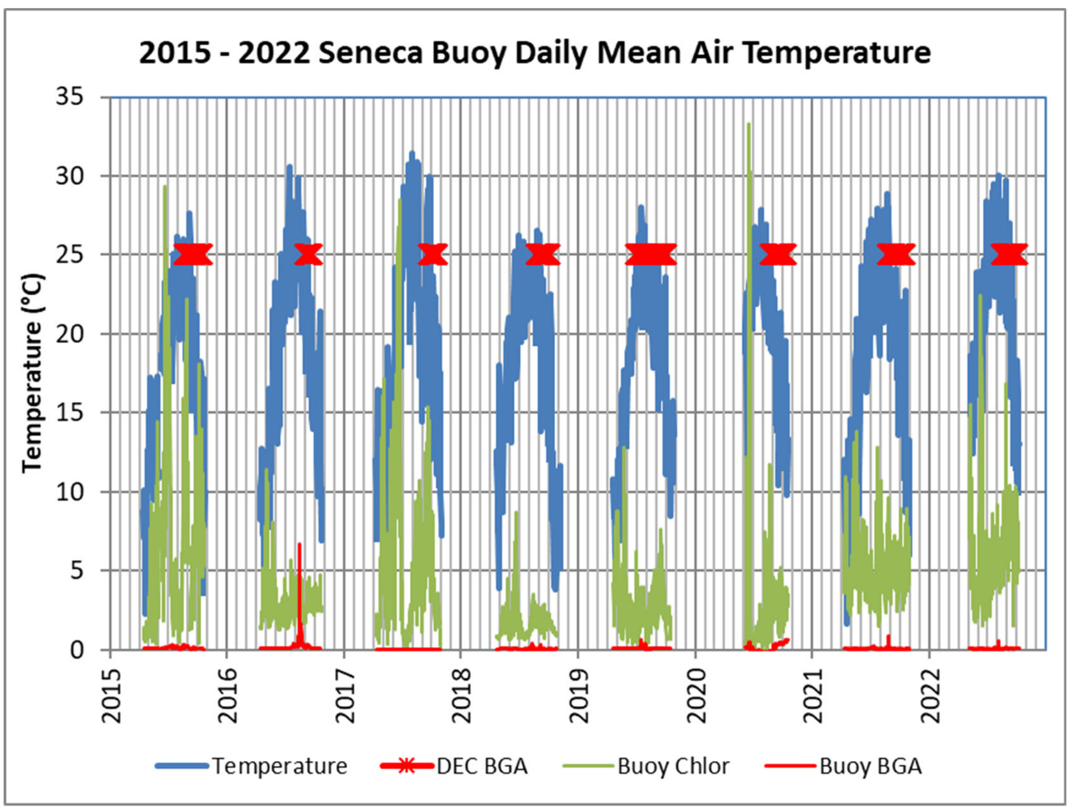
[15]Halfman, J.D., et al., 2023. The 2022 Water Quality Monitoring Report, Owasco Lake, NY. Finger Lakes Institute, Hobart and William Smith Colleges. 53 pg.

Cyanobacteria blooms were rarely detected at the buoy sites and paralleled smaller and/or less frequent bloom reports from offshore compared to nearshore locations. The absence may also reflect the 1-m shallowest depth for the buoy measurements, a depth below the surface hugging cyanobacteria blooms. Perhaps an automated camera should be deployed on the buoy to monitor the presence or absence of cyanobacteria at this offshore site.

Offshore total and PC fluorescence data did not parallel cyanobacteria bloom counts at the shoreline.

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) during the summer season, but still warm enough for bloom development (Fig. 17). Colder air temperatures in the fall, i.e., 10°C (50°F), coincided with the 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. Annual fluctuations in air temperature did not parallel blooms counts.

Offshore air temperature data was warm enough to support blooms. Fluctuations in air temperature from one year to the next did not parallel the annual cyanobacteria bloom counts at the shoreline.



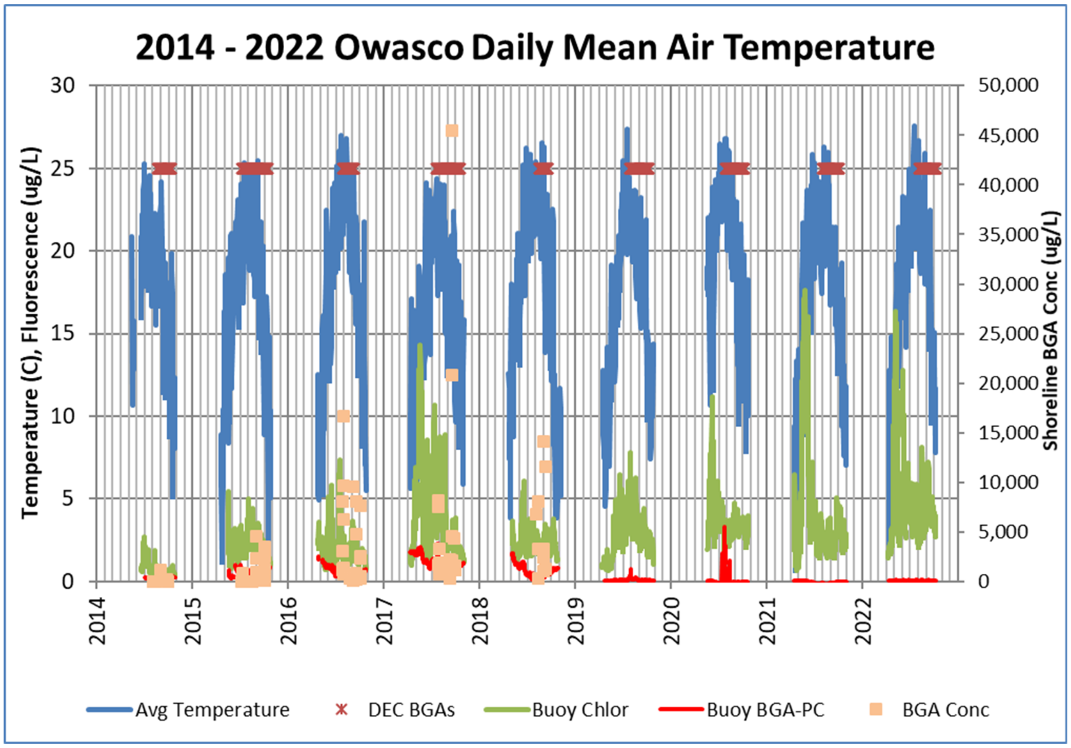


Fig. 17. Field season air temperatures at the Seneca (above) & Owasco (below) FLI Buoys. The 2020 Seneca data used the USGS buoy, anchored farther north and in shallower water than the FLI site. The weeks these lakes were on DEC's HABs Notification Page are also shown.

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 when mean daily insolation (sunlight) decreased from just above 340 $\mu E/cm^2$ in mid-June (suitable) to below 150 $\mu E/cm^2$ by mid to late October (less suitable) in both lakes (Fig. 18). The 2020 Seneca insolation data used the USGS buoy data. The USGS light sensor inexplicitly yielded slightly larger values in 2020 than the other years measured by the FLI buoy and at the dock sites. Warmest water and air temperatures also peaked after summer solstice noting that water takes time to warm, and warms more slowly than air. All three typically peaked before the cyanobacteria blooms. Lower light levels experienced in the early fall might favor cyanobacteria blooms because cyanobacteria can migrate to water depths with optimum light and nutrient concentrations. Thus, blooms were favored when the air and water were warmer but typically waited until after summer solstice and peaks in air and water temperatures. However, blooms were NOT detected on every warm and sunny day. In conclusion, solar intensity, air and water temperatures were favorable for bloom development but changes in these parameters from one HABs season to the next did not parallel, and thus, did not by themselves trigger the nearshore blooms.

The sunlight intensity was favorable for blooms, but did not parallel the annual cyanobacteria bloom counts at the shoreline.

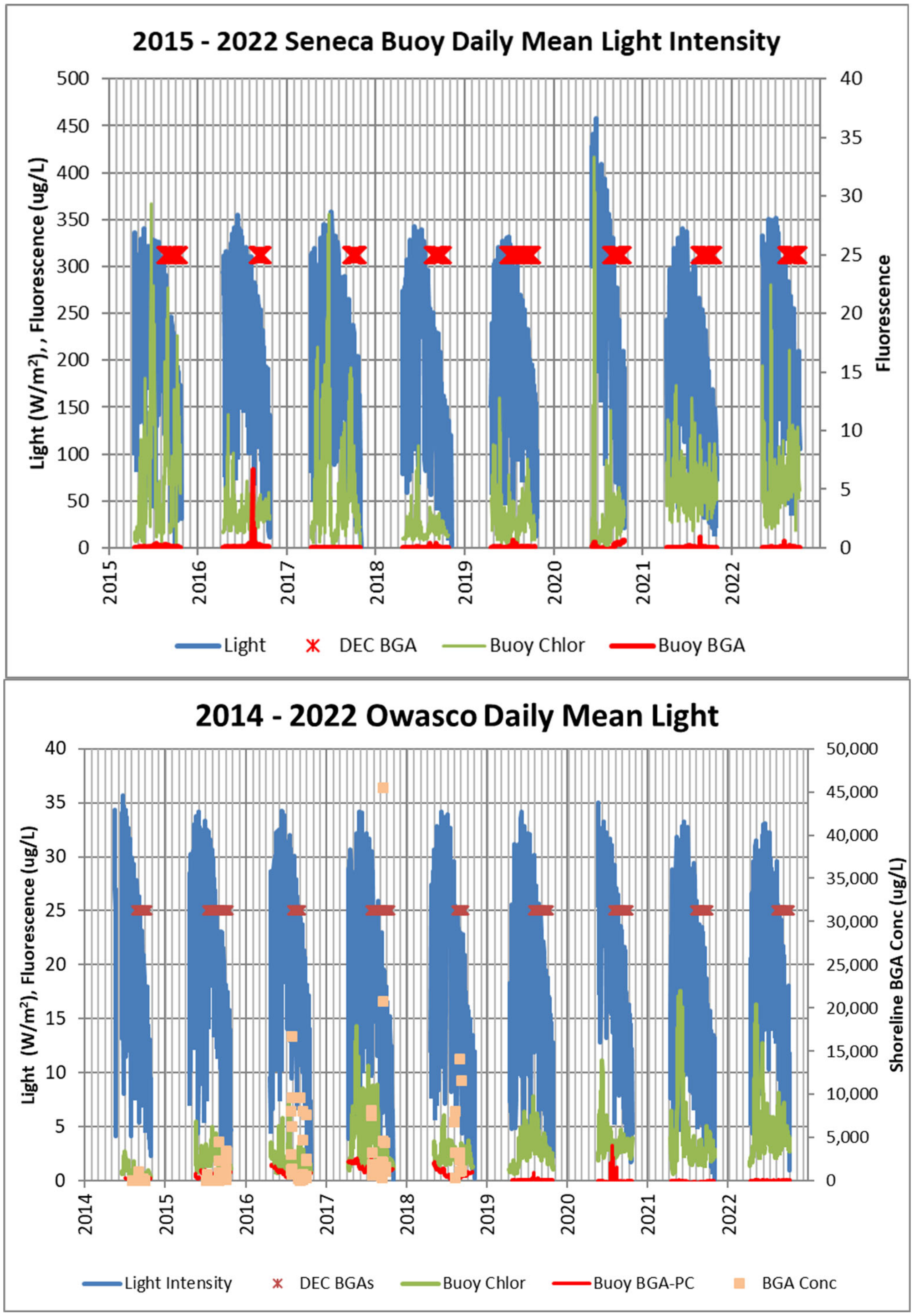


Fig. 18. Field season light intensity data at the Seneca & Owasco FLI Buoys. The 2020 Seneca data used the USGS buoy that used a different sensor thus different slightly results. The weeks these lakes were on DEC's HABs Notification Page are also shown.

Buoy Wind Speed & Direction: The mean, HABs season, daily wind speeds in 2015, 2017, 2021 and 2022 were at or below 9 mph (4 m/s, small waves) with only a few days with wind speeds above 15 mph (7 m/s, large waves with white caps, whereas they were above 9.5 mph (4.3 m/s) in the other years (Fig. 19 & 20). Except in 2020, the annual variability in wind velocities did not impact the bloom counts. In 2020, Seneca Lake experienced many more days with wind speeds above 15 mph and fewer calm days than Owasco Lake. Combined with a much larger fetch in Seneca than Owasco, it generated larger waves, that would more severely impact the exposed shorelines. Perhaps the faster wind speeds in 2020 mixed any nearshore cyanobacteria and their nutrient sources throughout the entire epilimnion away from the shore, decreasing nearshore blooms in Seneca Lake. The more frequent calm periods at Owasco Lake during 2020 allowed for more shoreline blooms, that took advantage of the nutrients released from the nearshore sediments by the winds and associated waves (both were larger in 2020 compared to other years at Owasco Lake). Thus, wind speeds and lake size may help explain the large difference in bloom counts in 2020 between the two lakes.

A decrease in wind speeds and more frequent calm periods from 2020 to 2021 and 2022 probably enabled the large nearshore bloom counts in both lakes. Winds above 20 mph (8.9 m/s, very large waves with white caps) coincided with the end of the bloom activity in most years.

Turbulence from faster and more persistent winds probably contributed to the smaller number of blooms in Seneca than Owasco Lake in 2020, and slower winds and more calm episodes probably contributed to some of the largest annual bloom counts in both lakes in 2021 and 2022.

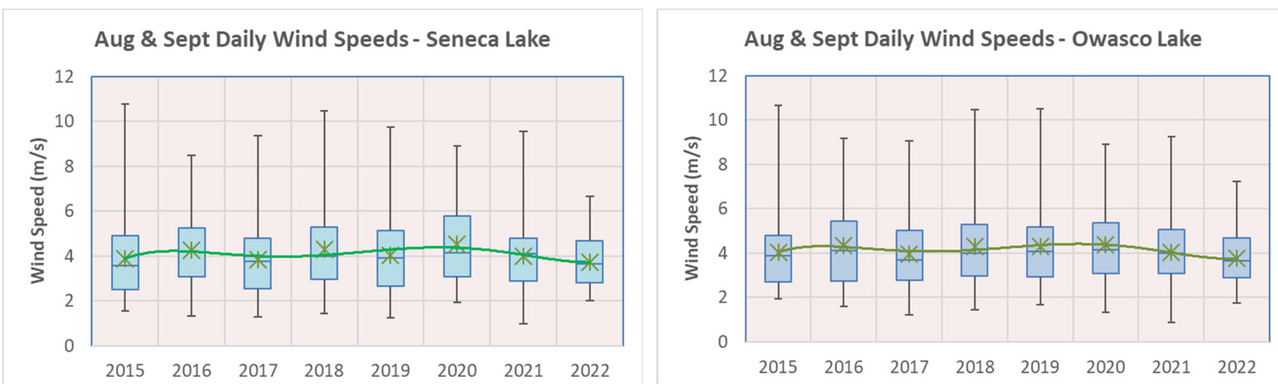


Fig. 19. The 2015 - 2022 HABs season wind speeds at the FLI buoy in Seneca (left) and Owasco (right) Lakes.

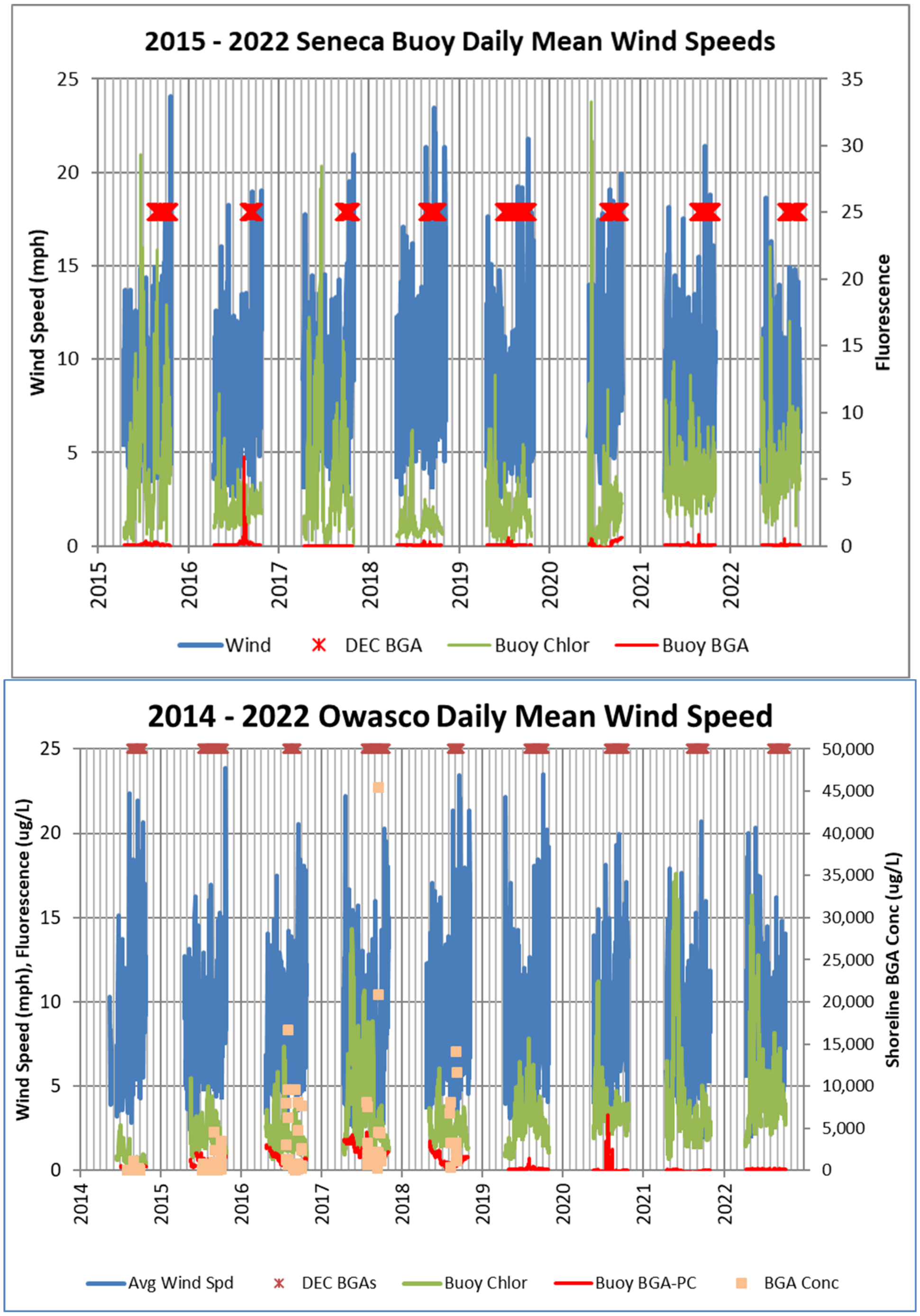
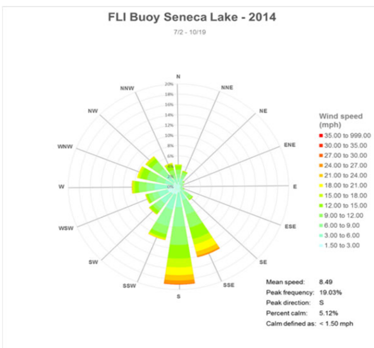


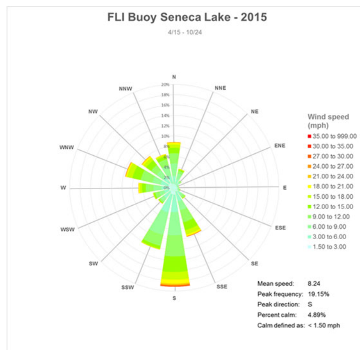
Fig. 20. Wind speeds at the Seneca & Owasco FLI Buoys. The 2020 Seneca data used the USGS buoy, anchored farther north and in shallower water than the FLI site. The weeks these lakes were on DEC's HABs Notification Page are also shown.

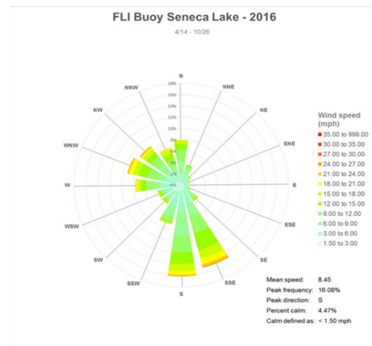
The dominant wind direction each year measured at the buoys was typically from the south (S), and to a lesser extent from just east of south (SSE), consistent with the North/South elongation of both lakes (Fig. 21). Slight differences exist. SSE winds were dominant during 2018, 2020, 2021 and 2022 in Owasco Lake. This shift in dominance was not observed in Seneca Lake. Instead, SSE winds were the 2nd most common direction after the southerly winds during 2014, 2016, 2017, 2018 and 2019, whereas SSW winds were 2nd most common in 2021 and 2022. Seneca, more so than Owasco Lake, also experienced winds from the west and less frequently, from the northwest and north. These changes though do not parallel changes in bloom counts in the entire lake, although they may influence the occurrence and frequency of blooms along specific shorelines.

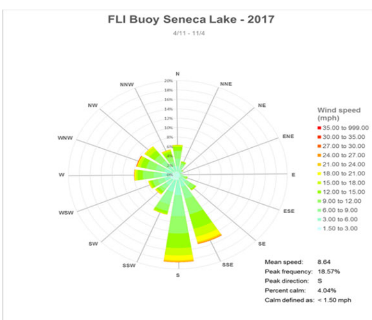
A slight shift in the dominant wind direction in Owasco Lake to the SSE in 2020 and 2021 potentially fostered significantly more blooms detected along the more protected, eastern shoreline than the exposed western shoreline (Fig. 7).

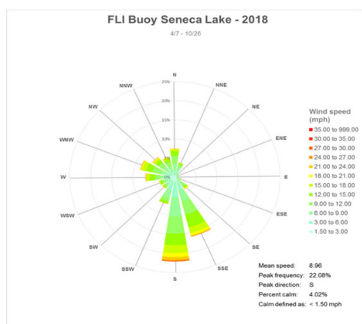
Slight shifts in the open-water annual and seasonal wind directions may impact the detection of blooms at the shoreline.

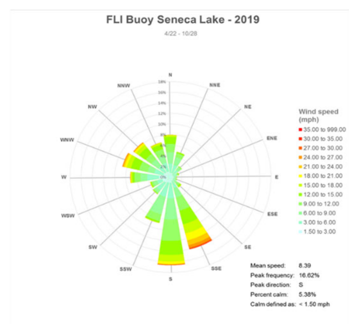




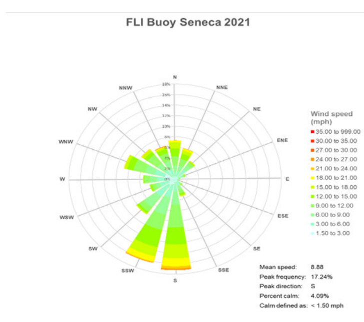


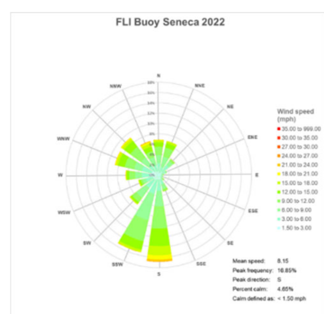






No wind direction data measured at the USGS buoy.





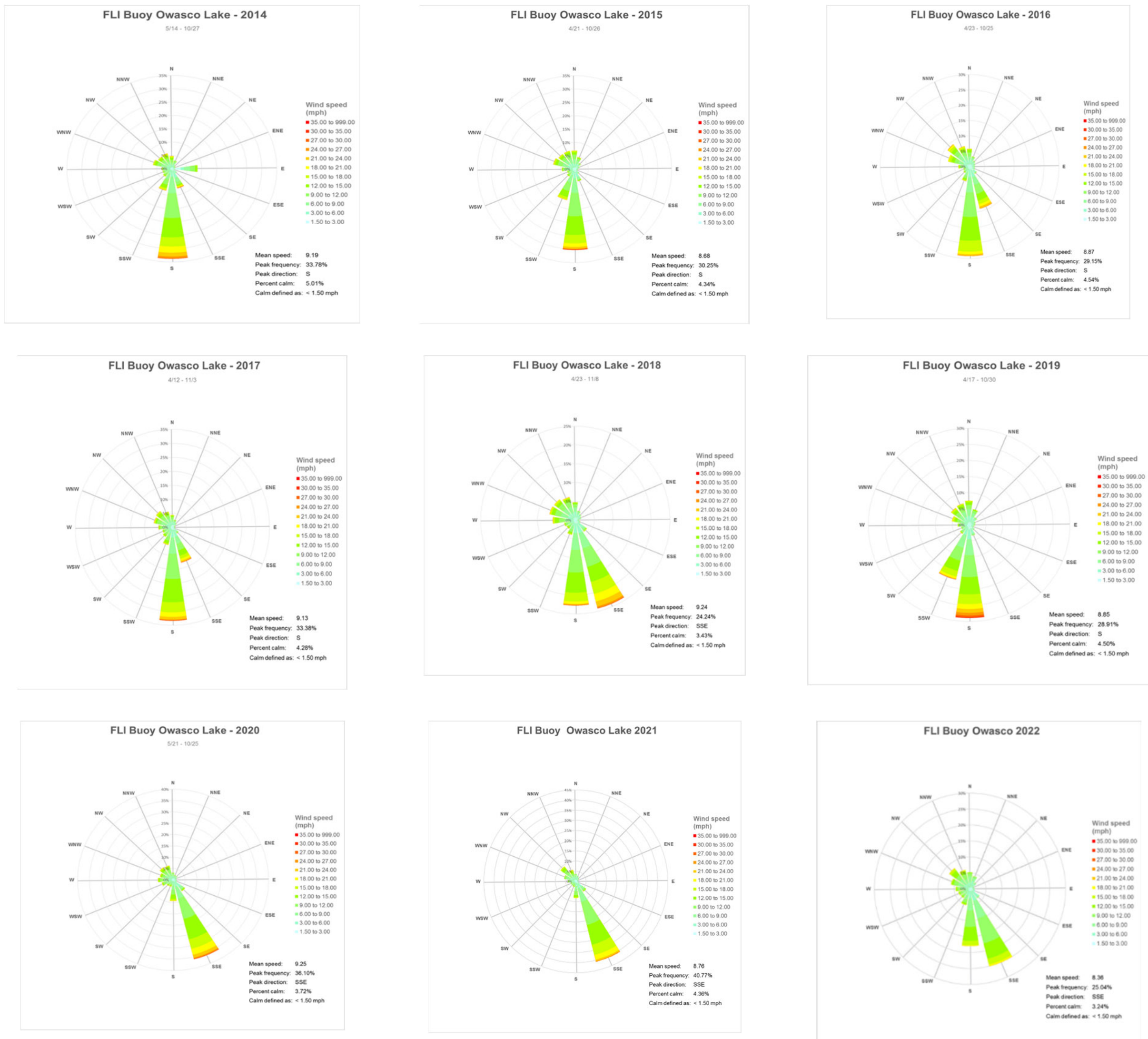


Fig. 21. Wind rose diagrams showing frequency of wind direction and speed during 2014 – 2022 at the Seneca Lake buoy (top three rows) and Owasco buoy (bottom three rows). Unfortunately, the USGS buoy did not record wind directions, and wind data from onshore meteorological stations do not mimic the lake buoy data.

The dominant southerly directions were consistent with the majority of the cyanobacteria blooms located along the northern and northeastern margins of both lakes (Fig. 7). Previously, some scientists suggested that strong winds might push surface-floating, open-water, cyanobacteria towards the downwind shore inducing a shoreline bloom. However, our direct observations noted the disruption of cyanobacteria blooms that formed on calm days after the development of even a light breeze. Apparently, wind and its vertical mixing of the water column by waves (gravity not capillary waves) were sufficient to overcome the buoyancy provided by the cyanobacteria gas vacuoles. Annual and seasonal wind directions might still play a role in bloom genesis. Winds could push and concentrate dead macrophytes, *Cladophora* and other decaying organic matter towards and along the downwind shoreline. The nutrients released by bacterial decomposition of the accumulated organics could be an important nutrient source for cyanobacteria blooms. Shallower water depths, extensive nearshore shelves (<4 m) before the steep drop off to deeper water, and more agricultural land in the northern portion of these watersheds could also foster more blooms in the northern portion of the lakes.

Winds accumulate dead organic matter along the downwind shoreline and after its bacterial decay, provide a source of nutrients for the cyanobacteria blooms.

Wind direction changed seasonally at the Seneca Buoy in 2022 (Fig. 22). In late July, August, and the first part of September, winds were primarily from the south. Subsequently, winds increasingly came from the NW or the NNE. Wind direction changed from the S or SSE in July through September to the NNE at the Owasco Buoy during October in 2022 as well. These annual and seasonal changes in wind direction did not correlate to bloom count variability or bloom locations.

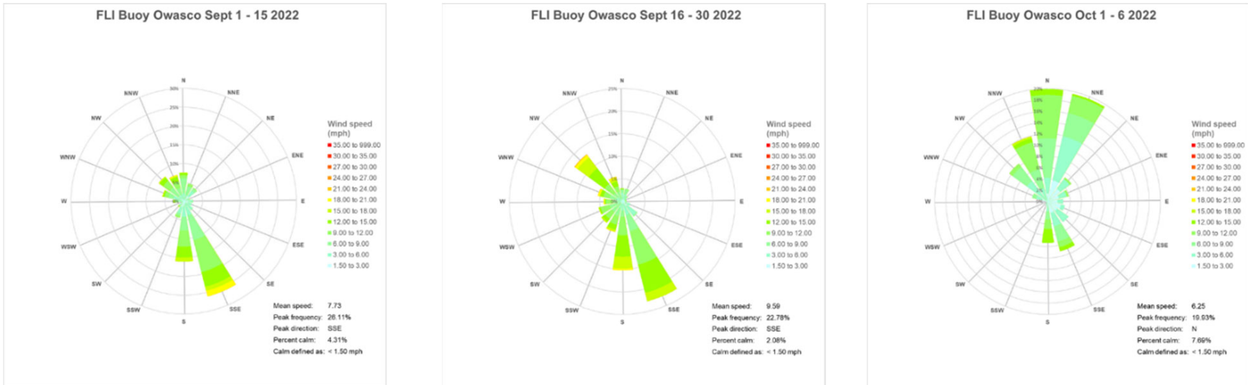


Fig. 22. Seasonal wind roses during 2022 at Seneca and Owasco Lakes recorded by the FLI buoys.

DOCK SITE RESULTS

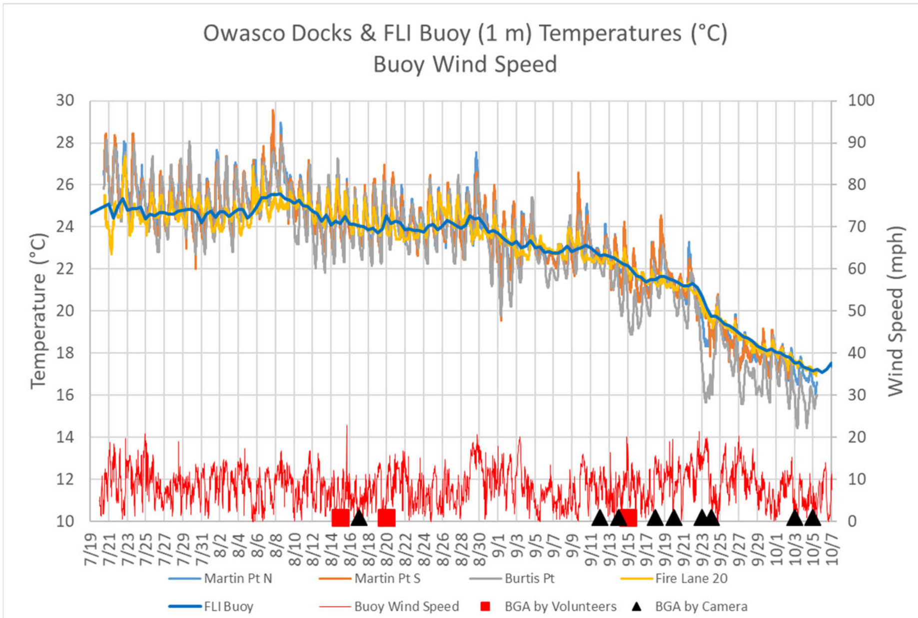
Unlike previous years, dockside measurements were only collected from Owasco Lake in 2022.

Water Temperatures: Owasco surface water temperatures revealed nearly consistent fluctuations in temperature across each lake even between the nearshore temperature loggers (deployed at 1-m depth) and offshore surface water (1 m) temperatures at the buoy (Fig. 23). Daily cycles in surface water temperature were once again detected in the dockside data, and ranged from 0.1 to 5°C. The largest fluctuations were detected at Burtis Pt and Martin S (mean amplitude of 5.0°C and 5.2°C, respectively), smallest at Fire Lane 20 (mean amplitude 3.6°C) and declined in amplitude through the HABs season. Burtis Pt site is more protected from mixing events by an extensive point of land and has a broad, shallow shelf that extends a few 100 meters offshore, whereas the Fire Lane 20 site lacks similar shoreline protection, and the lake floor quickly descends to very deep water at the end of the dock. The lake floor and shoreline geometry enabled more intense daily warming and cooling at the northern sites. The FLI buoy on Owasco Lake did not detect daily oscillations. Yet, it would be challenging to detect with only two samples / day. Similar fluctuations were observed in previous years at Seneca Lake.

The 2022 August and early September shoreline cyanobacteria blooms were typically preceded by a lake-wide decrease (a few °C) in surface water temperature like previous years. The 2022 dips in temperature were not as pronounced as those detected earlier. Lake-wide temperature declines in the surface water may reflect cooler air, cloudier conditions, and/or wind/storm events that generated surface waves and internal seiche activity and ultimately mixed some colder rain water and/or colder hypolimnetic water into the epilimnion. These same events could have also introduced nutrient-rich hypolimnetic waters to the nearshore areas and released nutrients buried in nearshore sediments from decaying organic matter. This suggests that wave events and internal seiche activity might be important mechanisms to deliver and/or release nutrients in nearshore areas and propagate cyanobacteria blooms along the shoreline.

Like previous years, dips in temperature observed in earlier, i.e., July and early August, did not result in cyanobacteria blooms. The delay to late summer probably reflected the time required for bacteria to increase the nutrient concentrations in the hypolimnion and nearshore sediments to promote cyanobacteria blooms. The bacteria in turn must wait for the macrophytes and other attached plants like *Cladophora* to grow, mature and die. Once dead or uprooted by wind events, their biomass, once decayed, probably contributed to the nutrient pool along the shoreline and in nearshore sediments for HAB events.

Lake-wide surface water temperature dips preceded many blooms, and the associated waves perhaps released nutrients stored along the shoreline. But every dip did not generate a bloom, and some blooms were not preceded by a dip in water temperature.



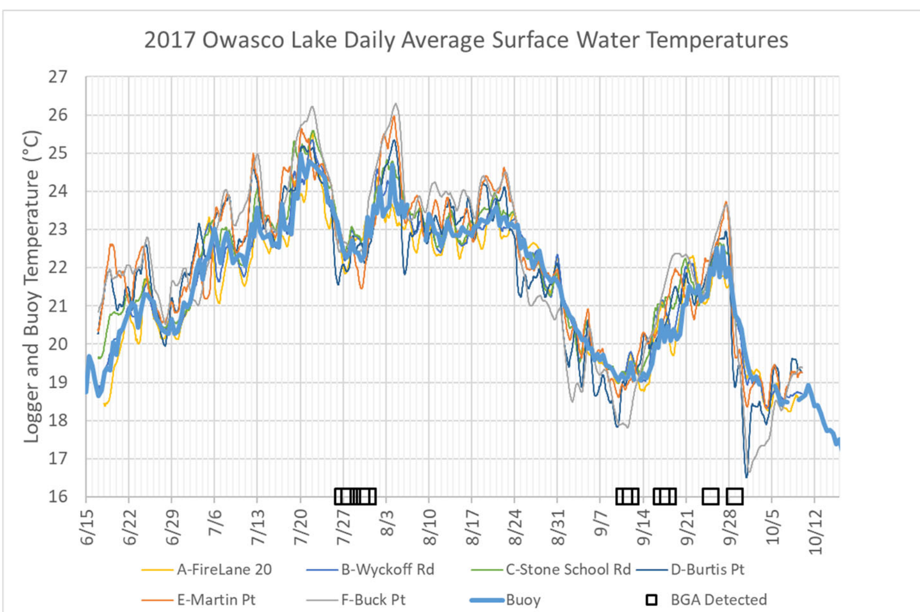


Fig. 23. Dock and buoy surface water temperatures, nearshore cyanobacteria blooms and mean daily wind speeds measured in Owasco Lake in 2022 above and 2017 below. See below for dock site water temperature plots measured by the WQ sondes.

Automated Cameras: The Brinno cameras recorded ~2 x 3 meter images of the lake's surface from 7/20 through 10/5, a 77 day deployment at Owasco Lake in 2022 (Fig. 24). Positioning the camera closer to shore since 2019 detected blooms within a meter of the shoreline that would have been missed in 2019. Consistently positioning the camera to collect images towards the north since 2019 minimized glare from the sun, and indicated that careful camera orientation corrected a glare issue that hampered image analysis in 2019. Camera power or memory issues in 2022 hampered image recovery at the Martin Pt S (17 days). Unfortunately, blooms may have been missed at this site because blooms were detected elsewhere in the lake during the malfunctioning episode. Moisture occasionally found its way into the camera's weather tight (?) housing and slowly degraded the electronics over time. It suggests that these cameras have a short useful lifetime in harsh environments.

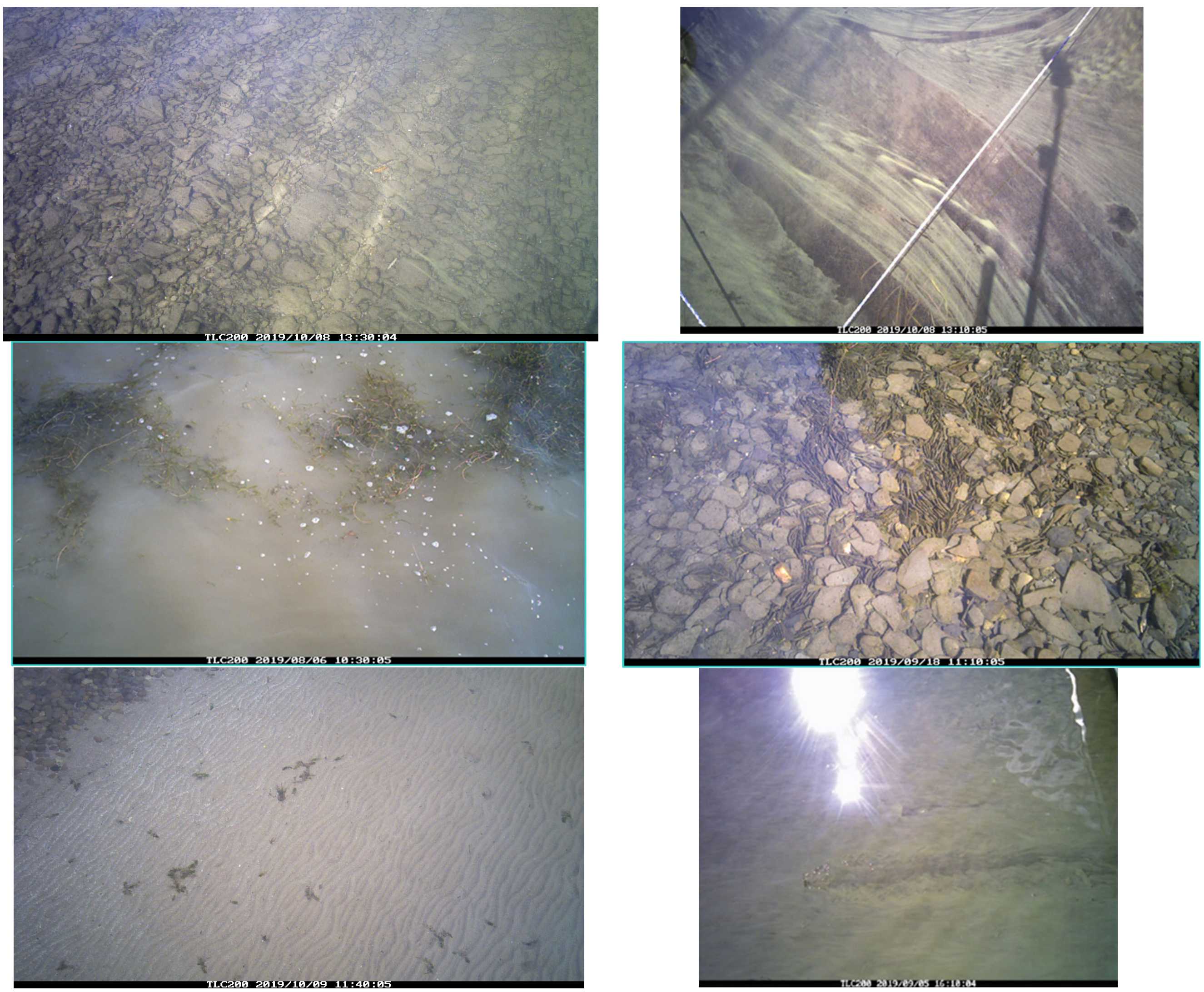


Fig. 24. Camera images from 2019 revealing bloom (top), turbid and clear conditions (2nd row), a sandy bottom subsequently covered by leaves and organic debris (3rd row). Similar images were collected in subsequent years.

The cameras detected from 1 to 3 blooms at the Owasco Lake sites in 2022, fewer than previous years in the study (Fig. 25, Table 6). Blooms were primarily detected in the afternoon just like previous years (Fig. 25). Each bloom lasted from 0.5 to 1.7 hours and averaged 0.9 hours in

2022. The durations were shorter than previous years paralleling the 2022 decline in bloom counts. Over the entire multiyear study, blooms were typically detected at only one site (76%) during the same 10-minute interval recorded by the cameras, and rarely detected at 3 or more sites (<4%) of the 12 sites at the same time (Fig. 25). This highlights the temporal and spatial variability of blooms in these lakes. Dockside cyanobacteria concentrations were measured by FluoroProbe during the dock visits. One visit sampled a dense algal cloud at Martin N and revealed a total fluorescence of 25 μg/L and a phycocyanin concentration 13 μg/L (by FluoroProbe), insufficient to be classified as a cyanobacteria bloom. At every other dock site visit, total fluorescence was small, between 1.2 to 10 μg/L, and similar to the offshore sites. Even though the imaged blooms lacked concurrent water samples, the images revealed similar surface appearances/algal densities to those at or above the 25 μg/L cyanobacteria concentration threshold for blooms in previous years, and thus suggests that the imaged cyanobacteria blooms were concentrated enough to be a confirmed bloom.

Table 6. Brinno Automated Camera Results Owasco Lake

Camera Results (in days)	Martin Pt N	Martin Pt S	Burtis Pt	Fire Lane 20
Blooms Detected (unknown conc.)	3	1	3	2
Turbid Water (lake floor invisible)	21	7	3	7
Clear Water (lake floor visible)	55	52	72	69
Camera Malfunctioned*	0	17	0	0
OWLA Volunteers (#Blooms)	2	1	0	0
Calm Winds (<1 mph average)	19	5	10	20
Rainy Days (> 0 in)	36	34	21	34
Sunny Skies (> 130 W/m^2)	38	34	35	47

*faulty camera or power issues. Moisture may have penetrated the Cameras early in the field season.

The bloom events in 2022, like previous years, were random in both space and time. However, two dates in 2021 were noteworthy exceptions. Blooms were detected at 3 of 4 sites, and elsewhere around the lake, on August 20 – 22 in the northern end of Owasco Lake. This timing was just after the heaviest rainfall of the season, when a single, multiday, event dumped 10" of rain over the northeastern corner of the Owasco watershed, and lake levels rose a few feet to near flood stage. This event also added over 50% of the annual total phosphorus load from the watershed to Owasco Lake.[16] It suggests that blooms occur after a major rain/wind event on the next calm and sunny day, stimulated by the introduced nutrients. Interestingly, more blooms were not detected at Seneca Lake on this date but the rain event dumped much less water in the Seneca watershed. Rainfall events would also impact Owasco to a greater extent than Seneca due to its larger watershed to lake surface area (volume) ratio.

Is this a sign of the future? More intense, more localized and larger rain events are becoming the norm as we move into a global warming world[17]. Extremely large events have been observed in the Finger Lakes region in the recent past. For example, extremely large events have already

[16] Halfman, J.D., et al., 2022. The 2021 water quality monitoring report Owasco Lake, NY. Finger Lakes Institute, Hobart and William Smith Colleges. 54 pg.

[17] Easterling, D., et al., 2017. Precipitation change in the United States. In: Climate Science Special Report: A Sustained Assessment Activity of the U.S. Global Change Research Program [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA (2017), pp. 301-335.

been experienced over the southern end of nearby Skaneateles Lake (2017), and over Lodi and the southeastern edge of Seneca Lake (2018).

Cyanobacteria blooms were typically localized in space and time. An exception was noted in 2021 after a flood localized to the Owasco watershed preceded numerous blooms around the perimeter of the lake, presumably stimulated by the significant nutrient loads.

Fig. 25. Concurrent blooms as detected by the camera at the 12 sites over the course of the study (above left). Number of days with a bloom detected by the cameras at the 12 sites over the course of the study (above right). Bloom time of day for 2022 (middle left), duration in 2022 (middle right), and duration in previous years (bottom right) in Owasco. The frequency of turbid days and bloom duration in 2019 through 2022 at Owasco Lake (bottom left).

Owasco HABs volunteers detected slightly fewer blooms than the cameras at the dock sites in 2022. Perhaps the volunteers missed blooms that happened 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), and occasionally detected fish, ducks, waders, swimmers, kayakers, and other animals. 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 in 2019 (Fig. 24). Migrating blooms were also noted by the authors and 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 in 2022 remained the same or decreased from 2021 at the Owasco sites (Fig. 25). The decrease reflected the decreased time winds blew onshore.

Histograms of bloom events by date reveal that blooms were most frequent in August followed by late September through early August at both lakes (Fig. 26). The early October peak in Seneca Lake was one exception, but this was during a calm spell after a very windy HABs season in 2020. The mid to late August start lags the supposedly ideal warm air temperatures, calm winds, sunny skies, and warm water temperatures. The delay once again suggests that bloom genesis requires nutrients in these nutrient-poor lakes, and the delay might reflect the time required for bacteria to decompose organic matter, which in turn must wait for the growth and subsequent death of macrophytes, mussels and other organic matter along the shoreline to release sufficient nutrients for a HABs event.

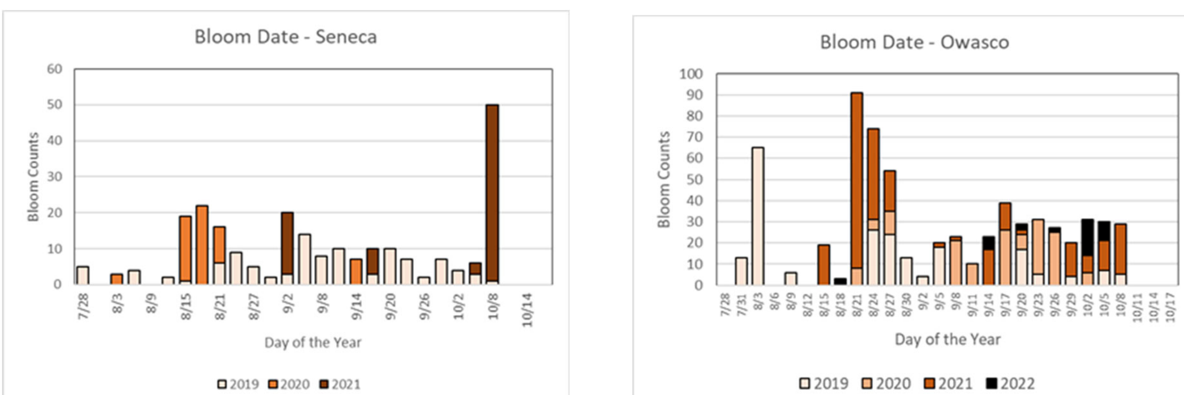


Fig. 26. Bloom date detected by camera in Seneca (bottom left) and Owasco (bottom right) over the course of the study.

One set of images collected in 2020 from the Martin N site were informative on bloom development (Fig. 27). As small, cm-high, waves with relatively clear water lapped onto the organic debris littering the 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 9/9/20, revealed more cyanobacteria adjacent to larger piles of accumulating organic debris along the shoreline than those shorelines with smaller piles or no macrophytes. It suggests that rotting macrophytes along the shoreline could supply nutrients for HABs events. The authors have also observed cyanobacteria oozing out of floating rafts of decaying macrophytes (e.g., Eurasian milfoil) in the middle of the lake. The macrophytes also slow the waves and water movement making the physical condition of the water more amenable for floating cyanobacteria.

This indicates a simple remediation practice to reduce HABs events in these lakes. Harvest the growing macrophytes before they die and decompose, and/or remove the piles of macrophytes and other organic matter decomposing along the shoreline, before the released nutrients stimulate the next bloom. Cyanobacteria resting cells are present in the sediments from previous blooms and background concentrations of live cells in the water exist both waiting for sufficient nutrient and other ideal conditions to bloom. Thus, nutrient availability is probably key for bloom development.

Decaying organic matter along the shoreline provided nutrients for nearshore cyanobacteria blooms. It suggests that a simple remediation practice to reduce HABs events is to harvest the macrophytes along the shoreline before they die and remove the pile of macrophytes and other organic matter along the shoreline before they decompose. The availability of these nutrients, or not, also helps explain the seemingly random nature of blooms in both space and time.

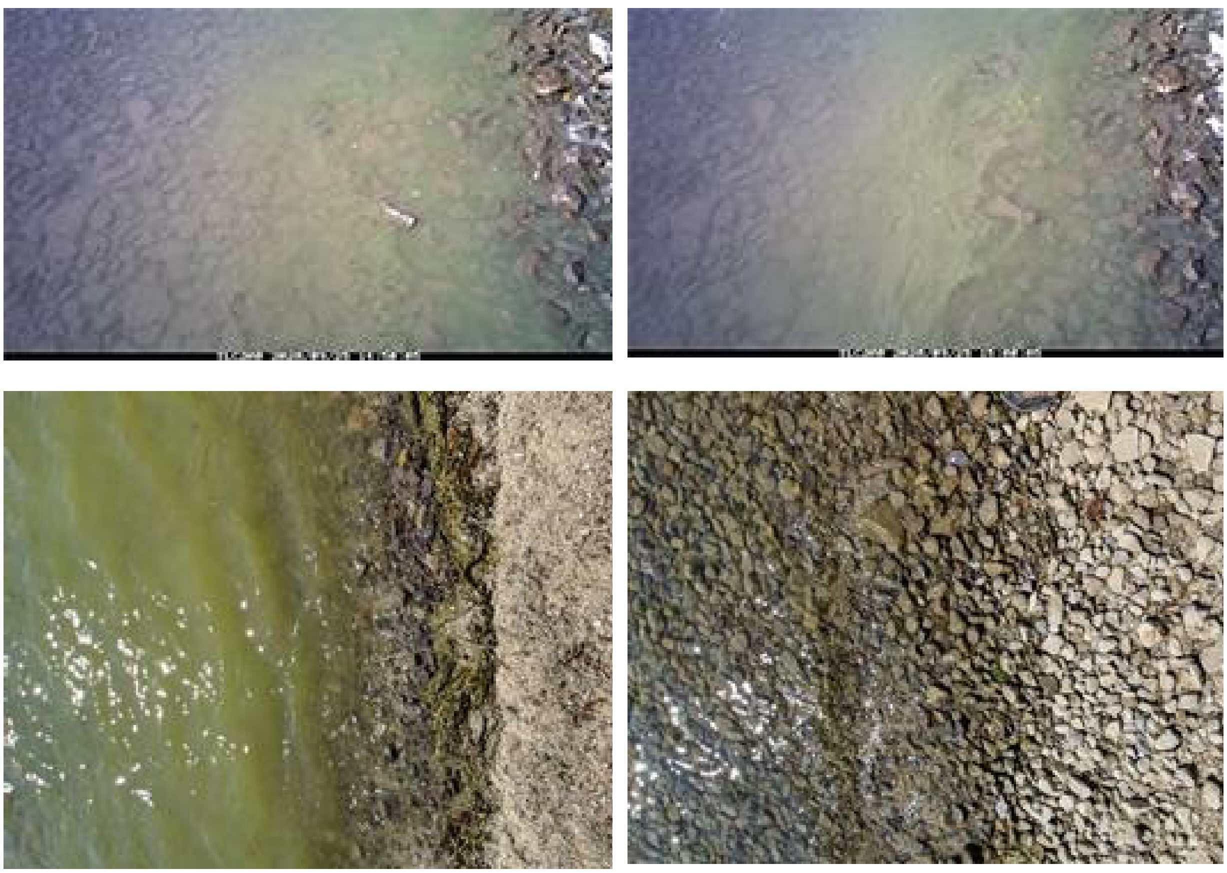
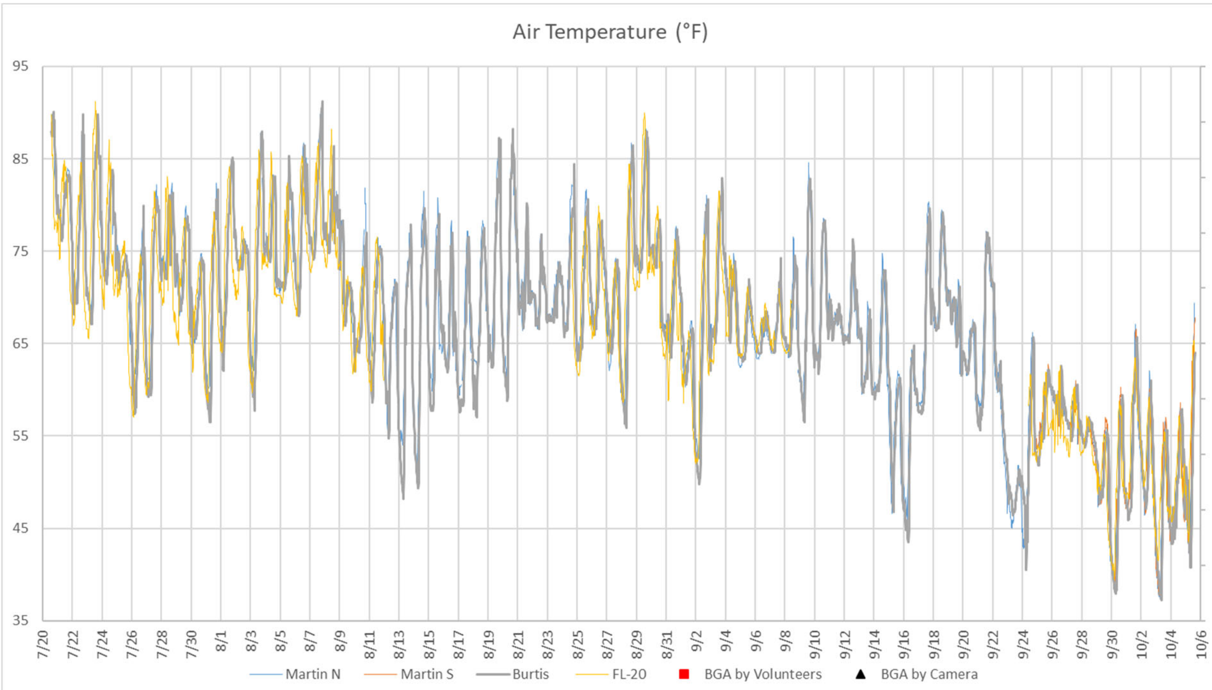
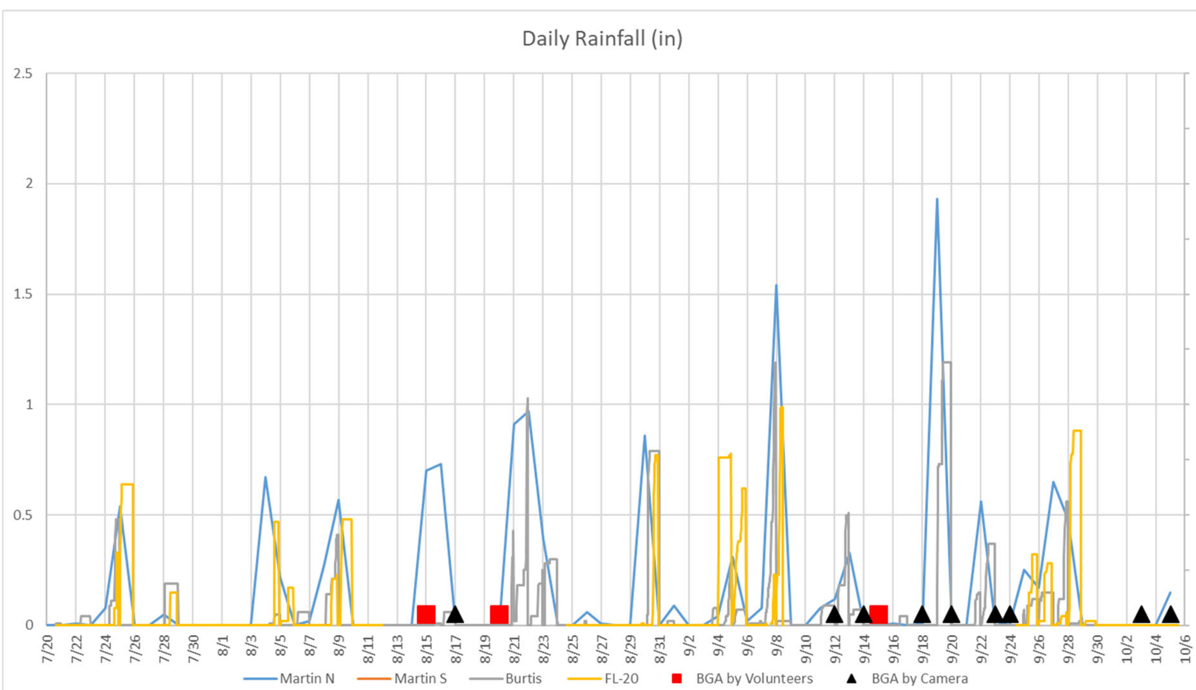
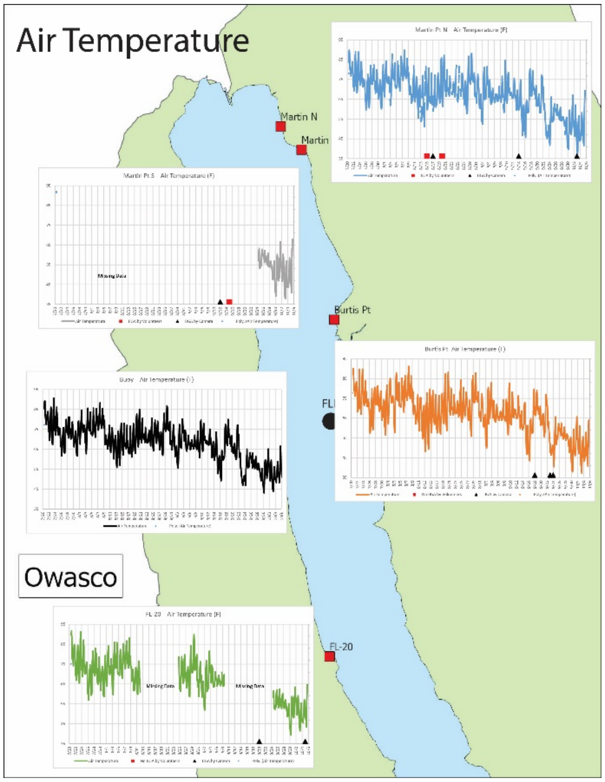


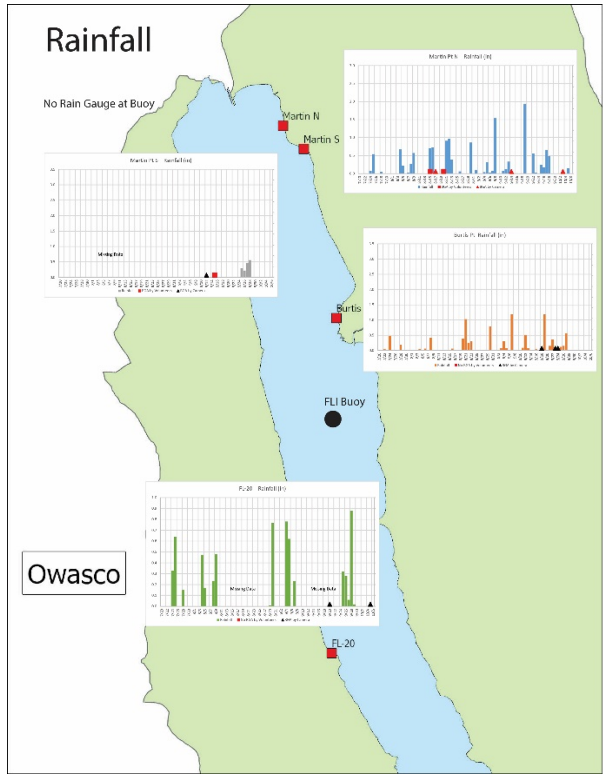
Fig. 27. Cyanobacteria were more abundant in the back wash moving away from shore (above left) than waves lapping onto (above right) a macrophyte covered shoreline. Larger cyanobacteria concentrations (below right) were detected adjacent to larger piles of macrophytes than smaller piles or no macrophytes (below left) along the shoreline.

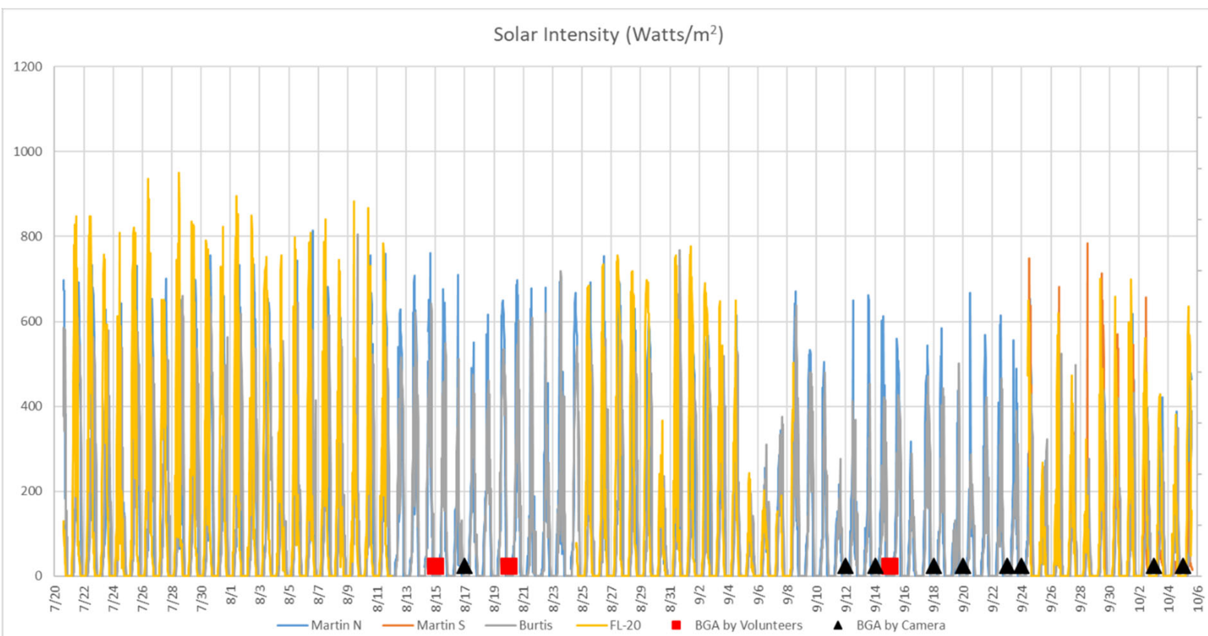
Nearshore Weather: In both lakes, warmer air temperatures, cloudier skies, windier conditions and rain preceded many cyanobacteria appearances at the sites (Fig. 28). The blooms typically occurred on the next calm or nearly calm day with important caveats (see below). Power issues prevented weather data collection at the Martin S site from 7/20 to 9/24, and from the FL-20 site from 8/12 to 8/24 and 9/7 to 9/24.






Air Temperature
Martin N
Martin
Burtis Pt
FL-20
Owasco
Missing Data


Rainfall
No Rain Gauge at Buoy
Martin N
Martin S
Burtis
FLI Buoy
FL-20
Owasco


Solar Intensity (Watts/m2)
1200
1000
800
600
400
200
0
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
Martin N
Martin S
Burtis
FL-20
BGA by Volunteers
BGA by Camera

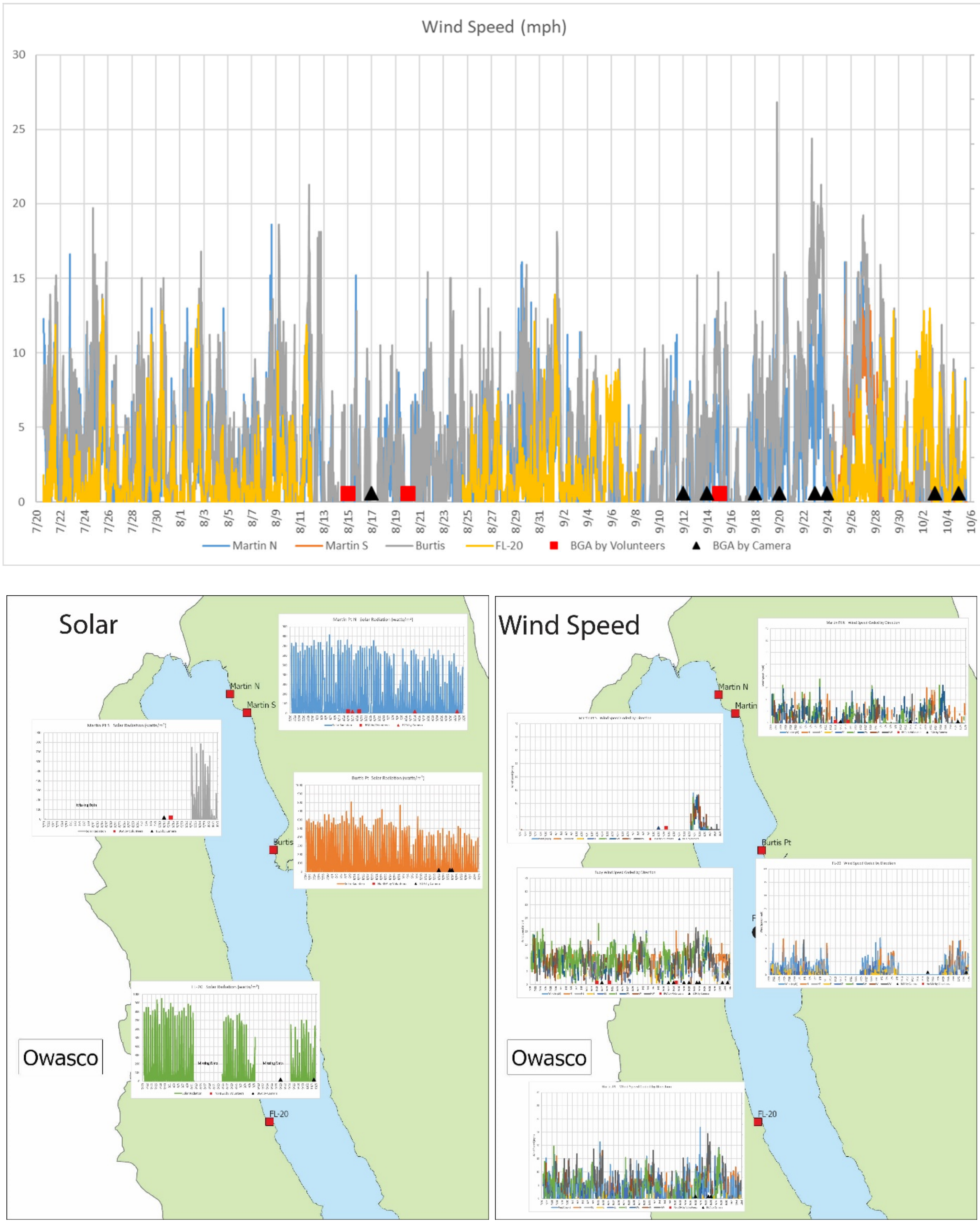
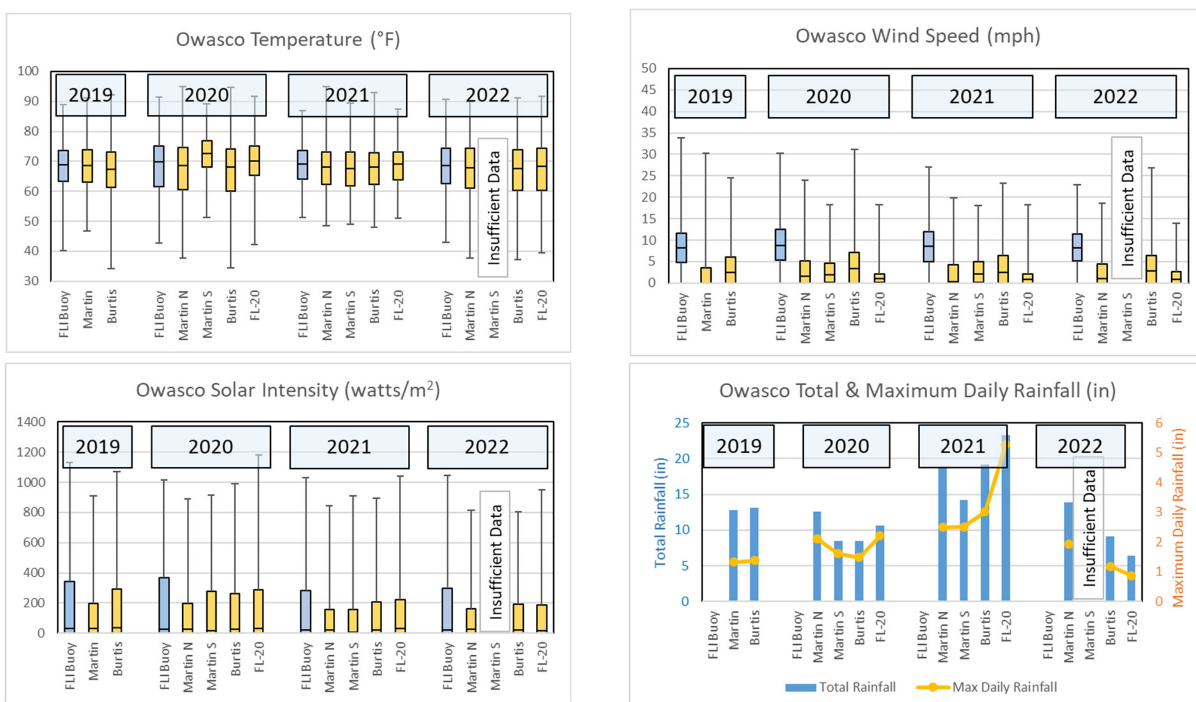


Fig. 28. Dockside air temperature, daily rainfall, solar intensity and wind speed data. Wind speed is color coded by its direction. The red squares mark dates when cyanobacteria were observed by the HABs volunteers at each site, the black triangles mark dates when cyanobacteria were imaged by the camera.

Wind Speed & Direction: Like previous years, the mean wind velocities were significantly slower at most of the dock sites than the mid-lake buoy site (Fig 29, Table 7). The shoreline provides some protection from the winds, especially winds not blowing directly onto shore. Wind speeds (and their associated waves) were also typically slower (smaller) during bloom events at these sites (Fig. 30). Protection from waves is maximized at the Burtis Pt site by a prominent but low lying point of land near the dock. Thus, blooms were present on windier days because the dock area was protected from and lacked significant waves but was still influenced by the stronger winds. It is not totally clear why blooms happened on windy days at the FL-20 site. Perhaps the bloom originated somewhere else and migrated to this site. Seasonal variability was also detected in wind speed at each dock site in both lakes with faster winds during late September and slower winds during July, early September and early October (Fig. 31). The majority of the blooms occurred in September and early October. Apparently, when wind speeds decreased long enough and/or were slow enough during the September – October HABs season, blooms were detected during calm or nearly calm days, but not every calm day experienced a bloom.

Calm or nearly calm days favored blooms but not every calm day experienced a bloom.



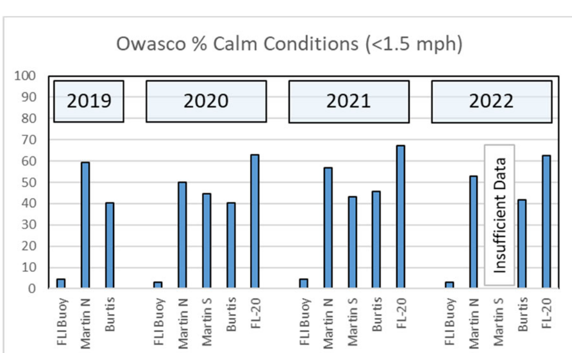


Fig. 29. Box and whisker or bar/line plots of air temperature (top), wind speed (top), solar intensity (middle), rainfall (middle), and % calm (<1.5 mph) conditions (bottom left) at the four Owasco sites in 2019 through 2022. The buoy data are included for comparison, the buoy did not measure rainfall.

Table 7. Mean wind speeds (mph) during cyanobacteria blooms and over the entire field season.

Site	Cyanobacteria Blooms	Season	Site	Cyanobacteria Blooms	Season
Martin N	1.6	2.6	Burtis Pt	3.4	3.9
Martin S	0.0	2.3	Fire Lane 20	3.5	1.9

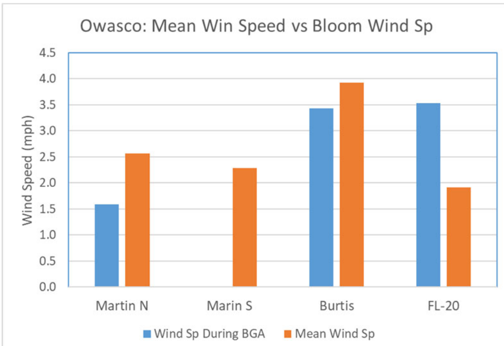


Fig. 30. Mean wind speed during blooms and through the entire 2022 field season at each site in Owasco Lake.

The dominant wind direction detected at each dock site consistently varied between sites and between each site and the regional wind field detected by the FLI buoy (Fig. 32). Even sites in close proximity, e.g., North and South Martin Point, revealed significantly different wind speeds and directions over the course of the study. The unique shoreline orientations modified wind directions and wind speeds in different ways, and dictated which shoreline locations experienced onshore winds and which were protected and experienced calm conditions. More importantly, if one shoreline experienced calm and sunny conditions, a bloom was more likely appear. The shorelines with onshore winds were less likely to develop a bloom. Winds and nutrient availability helped explain why cyanobacteria blooms appear along different segments of shoreline on different days. Onshore winds also impacted water clarity, i.e., turbid *vs.* clear water, as mentioned above. The local variability in winds dictate why the water column can be turbid (windy) at some sites but clear (calm) at other sites on the same day. An occasional light breeze originated from land during the early evening hours at sites with agricultural or grassy fields inland. The timing and speed suggest that these breezes originate from the differential heating and cooling of land/water surfaces.

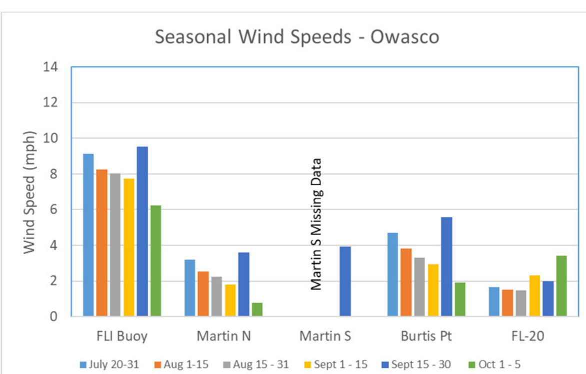


Fig. 31. The 2022 seasonal mean wind speeds at the buoy and dock sites in Owasco Lake.

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

Fig. 32. Seasonal rose diagrams of wind speed and direction at the Owasco dock sites, and the offshore buoy.

Some seasonal variability in wind direction was detected at the dock sites (not shown) just like some seasonal variability was detected at the FLI Buoy site in both lakes.

Rainfall: Like previous years, rainfall totals, both seasonal and daily accumulations, varied from site to site (Fig. 33). Daily variability was significant, e.g., from no rain to ~2 inches of rain between sites on the same day. More sites detected rainfall when daily rain accumulations were largest. More importantly, rainfall totals during the HABs season were significantly larger in 2021 than previous years, primarily due to the flood event in 2021 (Fig. 34).

The largest rainfall events and their associated runoff provided a source of nutrients to the shoreline and stimulated bloom development. For example, the Owasco watershed experienced a number of significant intense storm events in 2021. The Aug 18 event dumped over 10" of rain in the northeastern part of the watershed over a 3-day period, and contributed over 50% of the nutrient loads from fluvial sources to Owasco Lake.[18] It preceded a record number of blooms around the shoreline over the next few days. This rain event was significantly less severe over Seneca Lake, and it experienced fewer blooms. Unfortunately, only the largest rainfall events reliably stimulated blooms, and some blooms lacked a preceding rain event.

Rainfall and its associated runoff of nonpoint source nutrients from very large rain events was an important source of nutrients for bloom development.

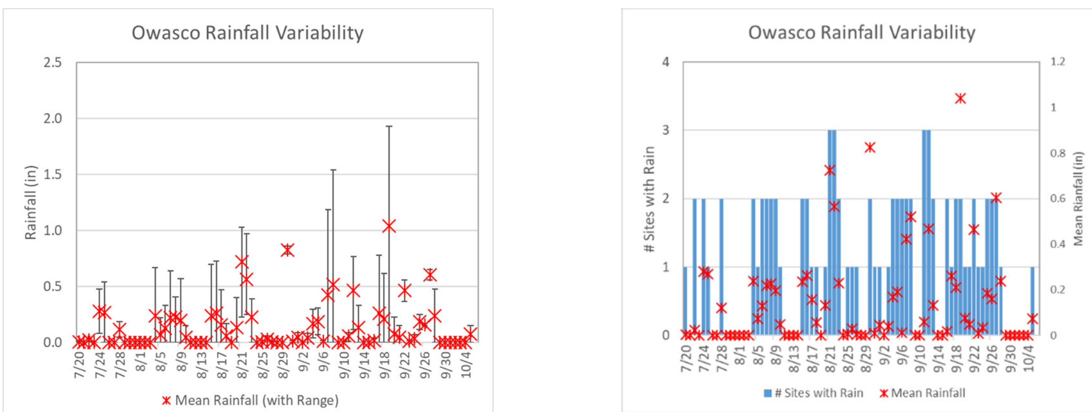


Fig. 33. Rainfall variability between sites. The mean, and minimum and maximum range for rainfall on any given day (left), and the mean rainfall and number of sites with any rain on any given day (right)

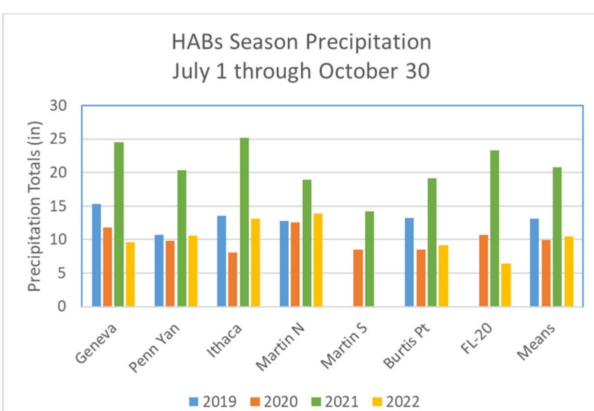


Fig. 34. HABs season precipitation totals for the Geneva Ag Station, Penn Yan Airport, Cornell University and the Owasco docks sites. Their mean is shown for comparison.

[18] Halfman, J.D., et al., 2022. The 2021 water quality monitoring report Owasco Lake, NY. Finger Lakes Institute, Hobart and William Smith Colleges. 54 pg.

Meteorological & Water Temperature Histograms: Histograms were created to determine the most common meteorological and water temperatures during blooms and non-bloom times (Figs. 35 – 38). The histograms utilized every 30-minute data point from 7 am to 6 pm (daylight), and combined data from every year and every site. Separate histograms were plotted for each lake to note lake to lake consistencies and/or inconsistencies, but inconsistences were not observed.

As expected, blooms were more frequent during calm, < 0.5 mph, conditions in both lakes (48% in Owasco, 45% in Seneca, Fig. 35). Yet, over 52% of the blooms were detected at wind speeds from 1 to 15 mph, that were more often blowing onshore. The onshore direction was unexpected because waves associated with faster winds typically retard cyanobacteria buoyancy. However, it is consistent with small waves oozing cyanobacteria from rotten macrophytes along the shoreline noted earlier.

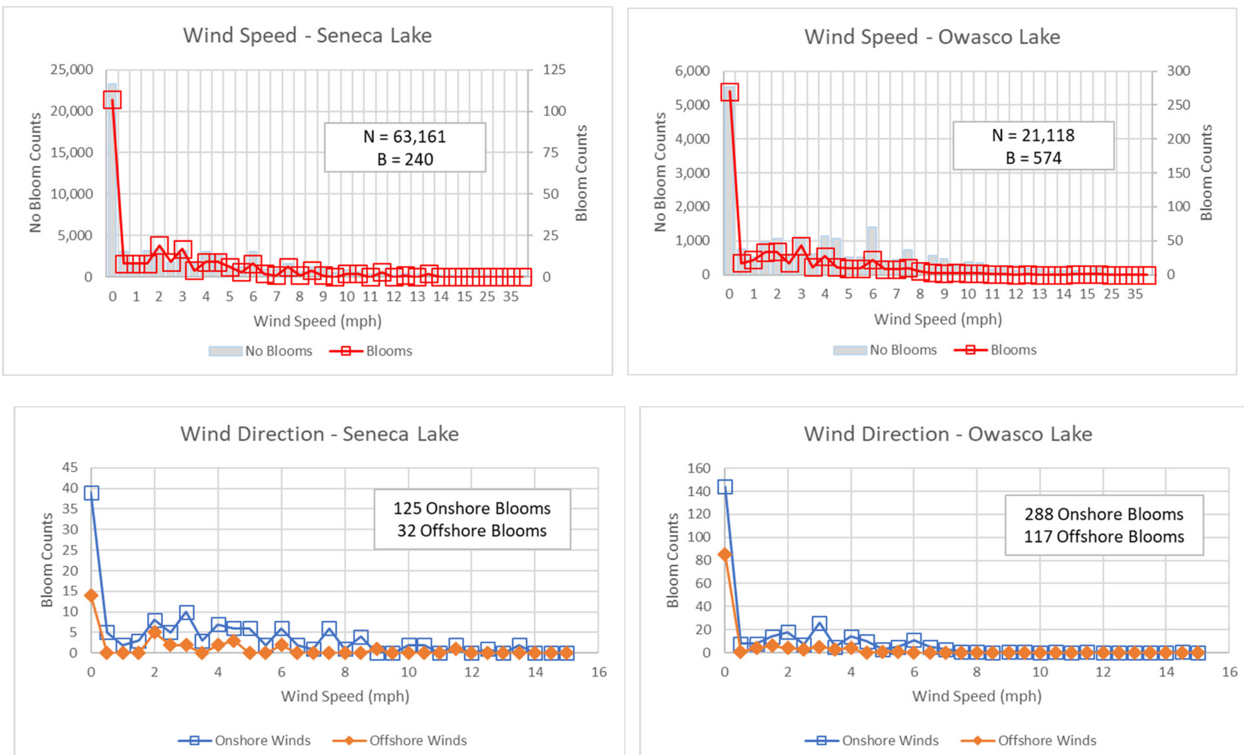


Fig. 35. Bloom – no-bloom histograms of the 30-minute wind speed and direction data for Seneca (left) and Owasco (right) Lakes differentiating conditions during blooms and no blooms.

Blooms were rarely detected (< 0.5%) during rain events defined as no accumulation of rain during the previous 30 minutes of a bloom (Fig. 36).

The bloom – no bloom histograms of air temperature revealed similar bell-shaped curves (Fig. 36). The most frequent (74%) air temperatures during blooms were from 18 to 27°C (65 to 80°F).

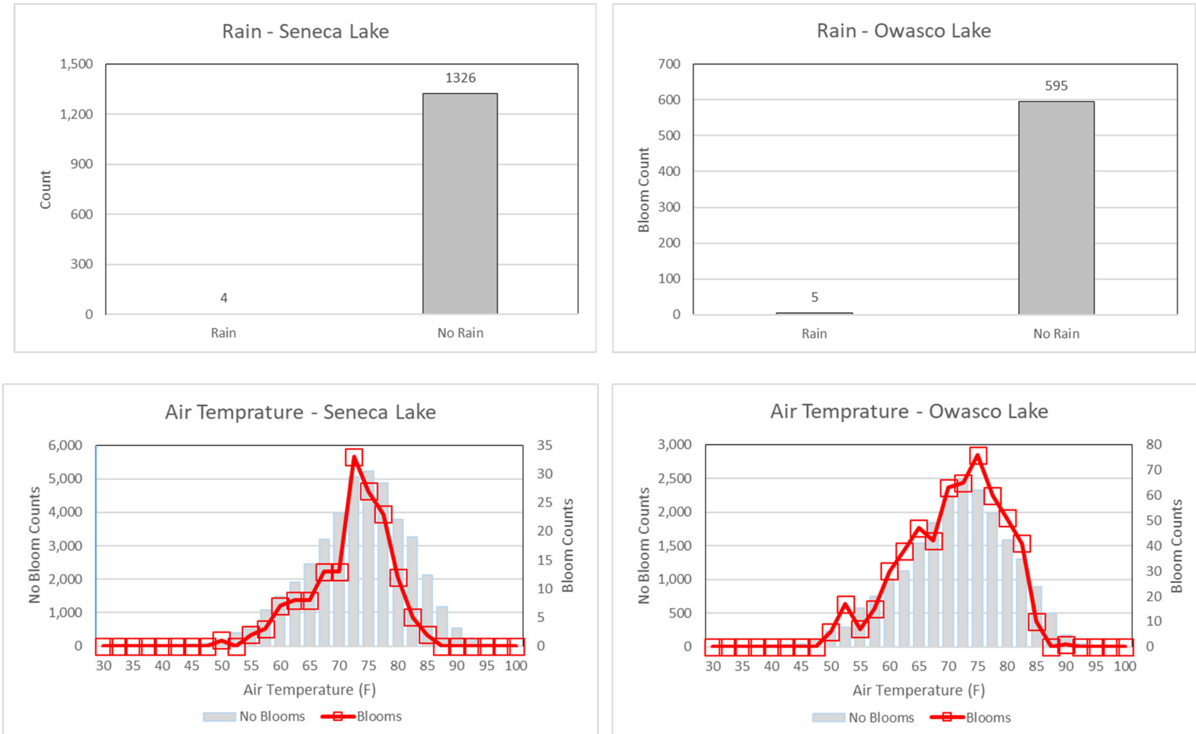


Fig. 36. Bloom – no-bloom histograms of the 30-minute rainfall and air temperature data.

Many blooms were detected when the water was warm, from 23 to 25°C (44% of the blooms in Owasco, 33% in Seneca, Fig. 37). However, an unexpected peak in blooms was detected in cooler water, from 16 to 21°C (23% of the blooms in Owasco, 33% in Seneca). The cooler peak is consistent with blooms occurring after a dip in water temperatures. Overall, water temperatures during blooms ranged from 16 to 29°C, the latter temperature was the maximum water temperature in this study. At this range of surface water temperatures, both lakes were stratified, as bottom water temperatures were within a degree of 4°C year-round. The warm peak was observed in the no-bloom histogram, but the second cooler peak was not obvious in the no-bloom histogram.

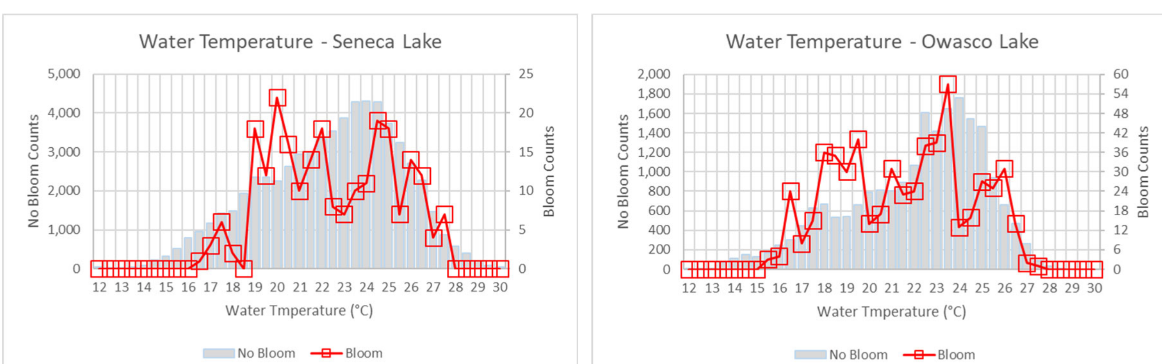


Fig. 37. Bloom – no-bloom histograms of the 30-minute water temperature data.

Finally, bloom counts unexpectantly peaked at low light intensities, i.e., from 100 to 200 W/m^2 (25% in Owasco, 35% in Seneca) with a secondary peak at the expected larger light intensities, i.e., sunny conditions, from 600 to 900 W/m^2 (25% in Owasco, 23% in Seneca, Fig. 38). For reference, light intensities peak just above 1,100 W/m^2 from August through October. Some of the low light episodes reflected cloudy weather but others reflected shading of the dockside weather station by nearby trees, buildings, and steep shorelines. Open water solar intensities were typically larger at the offshore buoy site than the dock sites. The dock sensors were occasionally in the shade of nearby buildings, steep topography and trees.

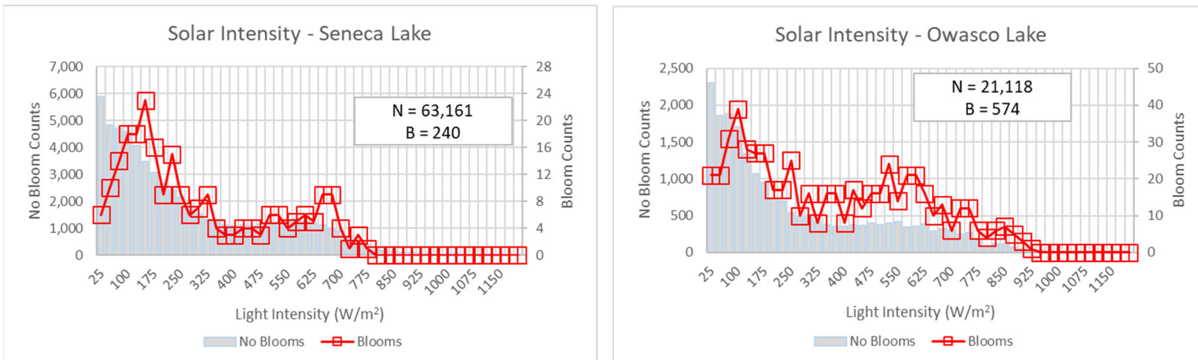


Fig. 38. Bloom – no-bloom histograms of the 30-minute solar intensity data.

The bloom histogram paralleled the no-bloom histogram shape, except for the lowlight levels but always had significantly fewer counts. In fact, 99% of the "Ideal" calm, sunny, warm water, warm air, and rain free episodes did not experience a bloom (Fig. 35 – 38). Thus, the dogma, blooms on the next sunny, warm and calm day is **NOT** a reliable predictor for blooms. Instead, blooms occurred when it was sunny, warm, or calm, but not on every sunny, warm or calm day. For example, blooms are more likely during calm days BUT the majority (>99%) of the calm days did not experience a bloom.

Furthermore, the observed blooms did not require all four "Ideal" conditions to bloom, i.e., warm air and water temperatures, calm winds, and sunny skies (Fig. 39). Ideal is defined as ½ standard deviations from the mode (the histogram peak). Typically, only one or two of these parameters fell within their "ideal" conditions during each bloom, rarely all four. Out of these four parameters, calm winds were the most important criteria for a bloom, and bright sunlight and warm water temperatures the least important. Thus, and unfortunately, no one "ideal" meteorological or water quality parameters, or any series of events, was the unique trigger for blooms. The dichotomy once again indicates that nutrient availability must be critical in these nutrient-poor lakes. It indicates that another facet of bloom genesis, i.e., nutrient availability, must be critical in these nutrient-poor lakes.

Blooms were detected during calm, warm and/or sunny days, but a calm, warm or sunny day will not always foster a bloom.

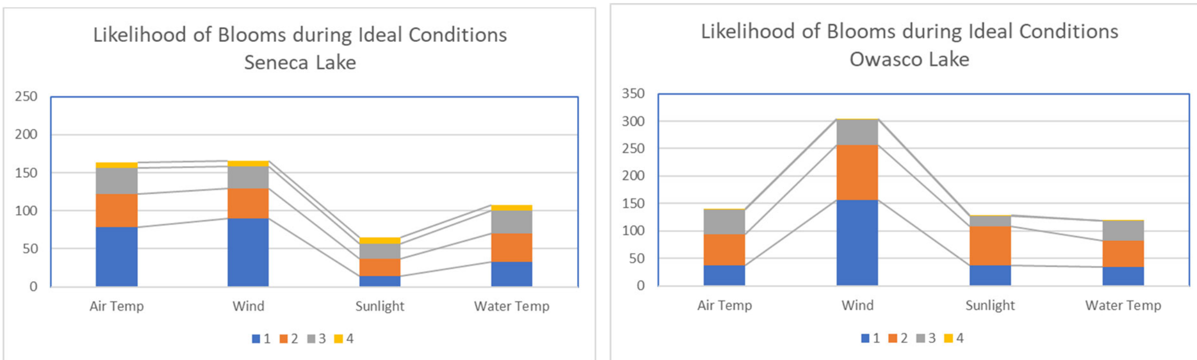
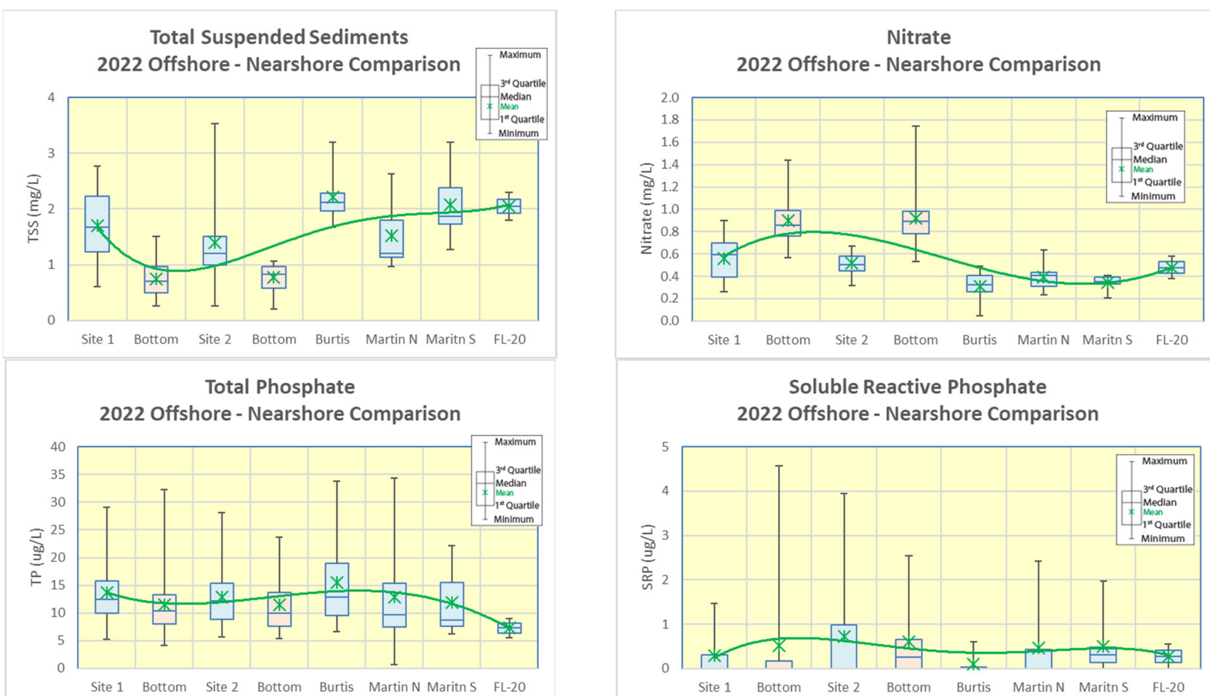


Fig. 39. The number of ideal conditions during each bloom.

Dockside Nutrients: The 2022 dockside, water column, nutrient data were very similar to the offshore results just like previous years (Fig. 40). More importantly, the nutrient concentrations available in the water column at the offshore and nearshore sites in in Owasco Lake are, by an order or magnitude (or more), insufficient to support the amount of phosphorus and nitrogen in a typical cyanobacteria bloom biomass.[19] It indicates a unique source of nutrients is required to trigger a cyanobacteria bloom in these borderline oligotrophic-mesotrophic, i.e., nutrient-poor lakes.

The nearshore water column typically lacked sufficient nutrients to foster a bloom.



[19] 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. 36 pg

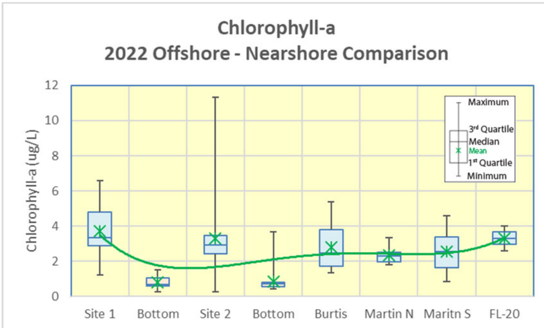
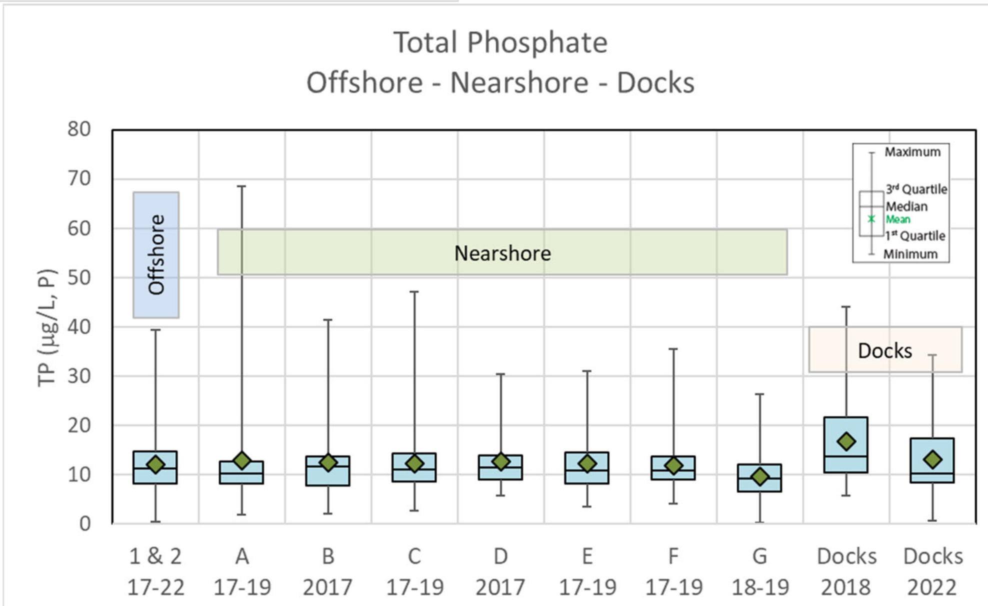


Fig. 40. Surface water offshore and dockside nutrient concentration box and whisker plots in 2022 (above and left). Surface water offshore, nearshore and dock total phosphorus concentrations over the course of the study below. The years samples were collected is include in the captions.



Water Quality Sonde Data (Owasco Only): Water quality (WQ) sondes were redeployed at the four Owasco dock sites to measure 30-minute temperature, salinity, and fluorescence (both total fluorescence and cyanobacteria-PC fluorescence) data at approximately 1-m below the lake's surface.

The sonde temperatures revealed similar seasonal and daily oscillations in temperature as the 1-m temperature loggers at each site (Fig. 41). The salinity (reported as specific conductance) data was also uneventful and paralleled open water concentrations. Like earlier years, it decreased by ~10 µS/cm each night of the observed daily oscillations at Burtis Pt. The reasons for these daily changes are unclear and may reflect the sensor's temperature sensitivity. Salinity increased by 50 to 100 µS/cm on a few occasions at Martin S and Martin N for unknown reasons as well. Perhaps the sensor was temporarily fouled with organic matter or mussels. None of the deployment pipes were clogged with decaying macrophytes like previous years.

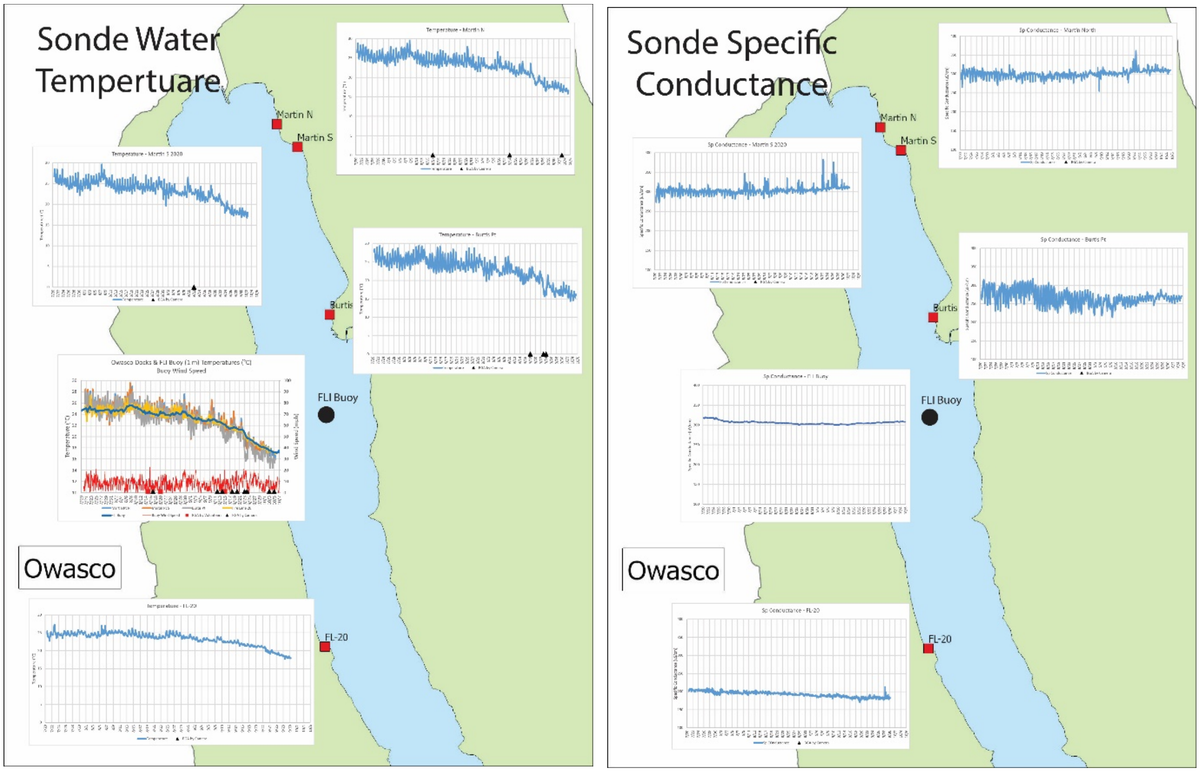


Fig. 41. Surface water temperatures and salinity measured by the WQ sondes at the dock sites and FLI Buoy in Owasco Lake. The long-term and daily temperature oscillations were identical to the temperature loggers, and the salinity trends similar to the offshore data.

The dissolved oxygen (DO) concentrations again revealed daily oscillations (Fig. 42). They were again largest at Burtis Pt and smallest at Fire Lane 20 and the FLI Buoy. 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, available plants/algae and other organisms affected the DO concentrations. When biological activity is intense enough, oxygen is produced during the daylight hours through photosynthesis; and, 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 temperature and DO fluctuations indicates that biological activity had a major impact on daily nearshore dissolved oxygen concentrations.

The magnitude of the daily oscillations parallels the amount of macrophyte biomass at its site, as visual inspections (and macrophyte data presented below) indicated that Burtis Pt had the most and Fire Lane 20 had the least biomass. Martin N and Martin S have rocky lake floors but still experienced DO fluctuations. It highlights the importance of biological activity by microorganisms 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, *macroalgae* and other organics might provide a viable source of nutrients for cyanobacteria blooms.

None of the sondes recorded near anoxic dissolved oxygen conditions as in past years. It suggests that none of the deployment pipes were clogged with decaying macrophytes and other organic debris in 2022 (Fig. 42). The sonde at S Martin in 2021 revealed anoxic DO conditions and concurrent increased fluorescence after the deployment pipe was presumably clogged with macrophytes (Fig. 22). Bacteria decay of the macrophytes released sufficient nutrients to promote a cyanobacteria bloom inside the deployment pipe. Cyanobacteria were not observed in the camera at this site on these dates. It suggests that rotting macrophytes and other organic matter is a viable source of nutrients for localized blooms.

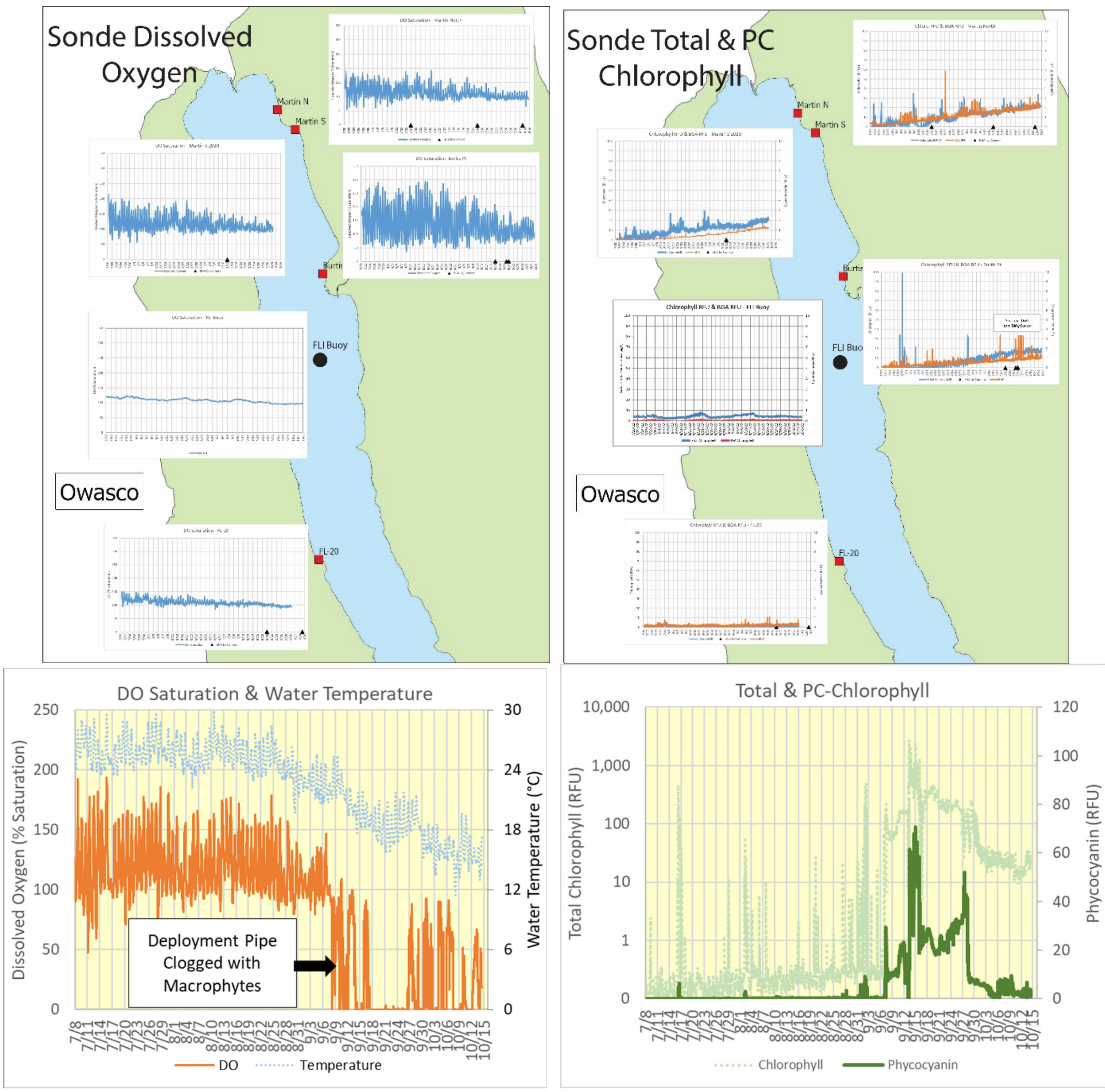


Fig. 42. WQ sonde dissolved oxygen, total chlorophyll and cyanobacteria-PC-chlorophyll concentrations. Non-synchronous blooms were detected at all the sites (above). The baseline sensor increase at Martin S, Martin N and Burtis Pt sites is interpreted to reflect the decreased effectiveness of the sensor wiper to clean biofouling organic films off of the In Situ Aqua Troll 600 sensor over time and/or sensor drift. Sonde DO and chlorophyll data from the Martin S site in 2021 (below).

Fluorescence was uneventful (Fig. 42). Rising above the baseline trend were hour long, and seemingly random spikes of increases in fluorescence at all four sites. They were more frequent and spiked to larger concentrations at the northern sites. Like previous years, these brief spikes in fluorescence were not synchronous in time between sites, nor synchronous with peaks in the cyanobacteria-PC fluorescence. Algal or cyanobacteria blooms were not imaged at the site during these spikes in fluorescence as well. The spikes were synchronous with increased water turbidity (detected by the camera). Wave action that induced the nearshore turbidity probably also suspended benthic (lake floor) algae into the water column and were detected by the sondes. It highlights a robust algal community at 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.

Finally, the WQ sonde fluorescence sensors revealed a baseline increase over time at Martin S, Martin N, and Burtis Pt (Fig. 42). It is again interpreted to reflect the decreased effectiveness of the sonde's wiper to clean organic films off of the In Situ Aqua Troll 600 sensor, and/or sensor drift over the deployment. It appears that the wiper on the YSI/Xylem EXO2 sonde kept its sensors clean, and/or the EXO2 was less prone to instrument drift (Fire Lane 20 & Buoy sites).

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 ~1.0 m below the surface.

The nearshore region has a robust benthic plant community, and once decayed may provide a critical nutrient source for cyanobacteria blooms.

NUTRIENTS, SEDIMENTS, LAKE FLOOR HARDNESS & MACROPHYTES

Mesocosm Experiments: For the June incubations, the mean chlorophyll concentration for the three controls was ~1.5 µg/L (Fig. 43). The after-incubation chlorophyll concentration for the nitrogen-only and phosphorus-only treatments were not statistically different than the control. However, the nitrogen plus phosphorus treatment was significantly higher than the control treatments. This is a different result than previous years and shows a co-limitation of nitrogen and phosphorus although the phosphorus only treatment did show higher chlorophyll concentrations compared to the controls and nitrogen only.

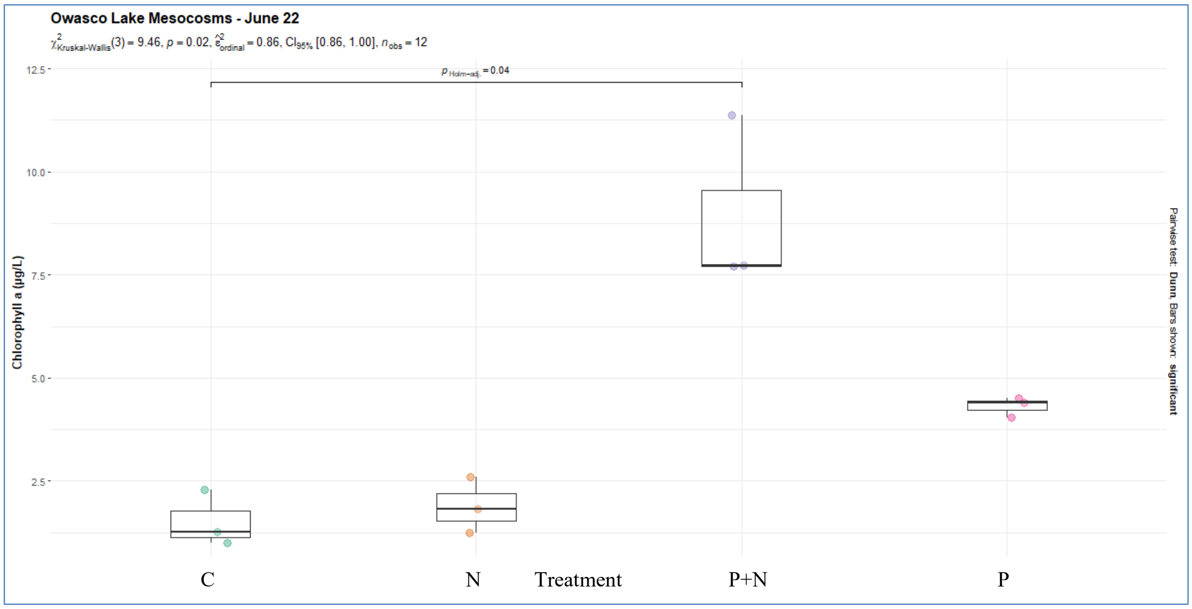


Fig. 43. Results from June mesocosm experiments. The P as well as the N+P treatments resulted in higher Chl. a concentrations at the end of the experiments. The N+P treatment showed statistically higher concentrations compared to the controls.

In July, a similar finding was observed but with higher overall chlorophyll concentrations likely due to the warmer temperatures observed in July (Fig. 44). All treatments showed higher chlorophyll concentrations relative to the control but the P only and N+P increased by about 4x and 5x, respectively.

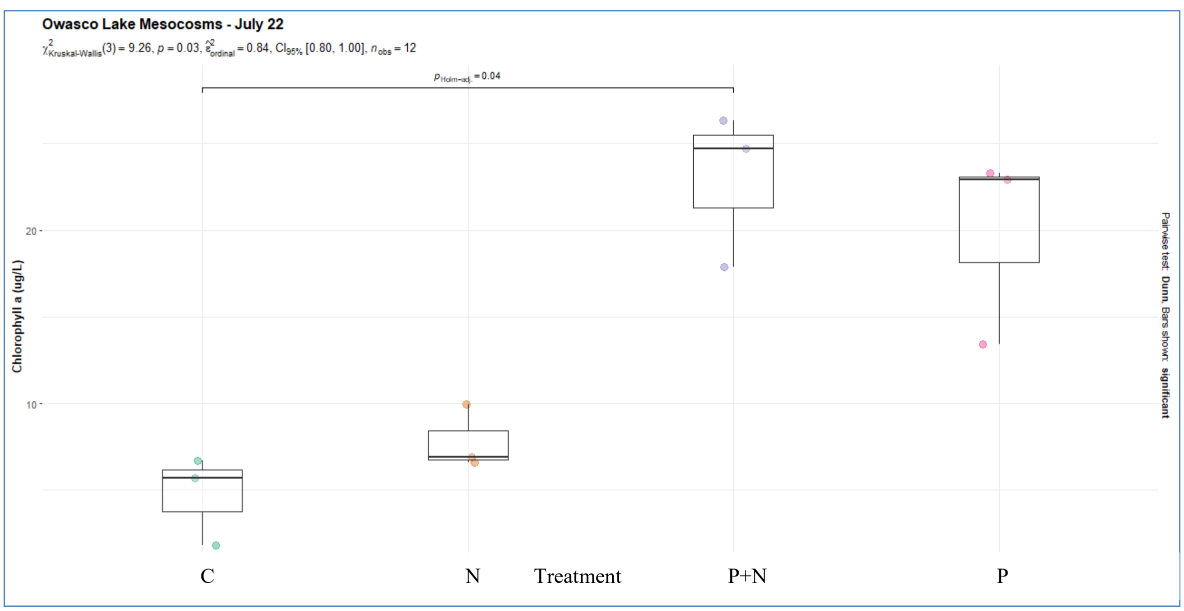


Fig. 44. Results from July mesocosm experiments. The P as well as the N+P treatments resulted in higher Chl. a concentrations at the end of the experiments. The N+P treatment showed statistically higher concentrations compared to the controls.

For August, a comparison of the response of nearshore vs. offshore phytoplankton to nutrients was tested in two separate experiments. Water was collected on the same day at the nearshore and offshore sites. The nearshore phytoplankton had slightly higher chlorophyll concentrations than the offshore phytoplankton in the controls (Figs. 45 and 46). However, the magnitude of the differences in response to nutrient additions varied between nearshore and offshore experiments. The nearshore N treatment showed almost 50% increase of chlorophyll while the P treatment almost doubled the chlorophyll concentration. The N+P chlorophyll was the only treatment that was statistically higher than the controls with an increase of almost 300%. For the offshore phytoplankton, the N only treatment did not increase the chlorophyll much, but the P only and the N+P treatments did. These results show that nearshore phytoplankton and offshore phytoplankton may have different starting nutrient conditions and responses that should be explore in more detail.

Further work: Compared to other years (2020-2021), Owasco Lake phytoplankton showed more N+P co-limitation for phytoplankton growth rather than P-only or serial limitation. More experiments should be conducted on phytoplankton conducted from locations across the lake and across seasons to determine if nearshore and offshore phytoplankton respond differently to added nutrients. Also, since these experiments are primarily completed by students, we would like to test more replicates for each treatment to help resolve some of the large differences we observed in chlorophyll concentrations within treatment groups. More replicates will also help with having more robust statistical analyses to detect differences among treatments. Finally, we will explore time series experiments where we will test the results of chlorophyll changes after 2-day, 3-day, and 5-day incubations to help determine how quickly the phytoplankton respond to nutrient additions.

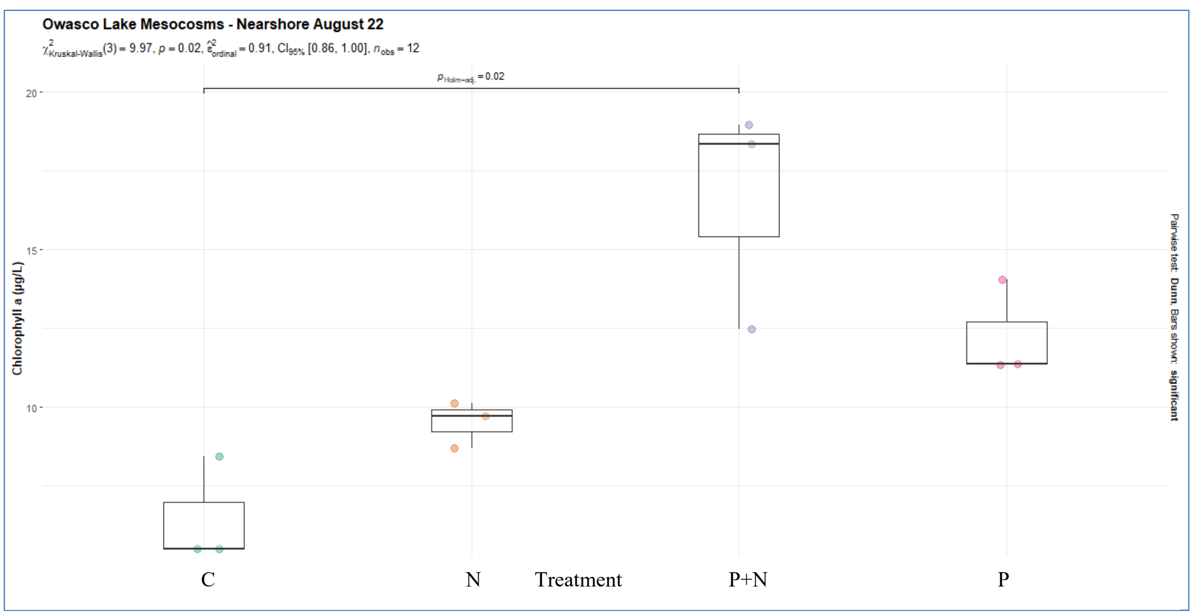


Fig. 45. Results from August nearshore phytoplankton mesocosm experiments showing increase in chlorophyll for all treatment groups. From a statistical perspective, there is co-limitation by N+P.

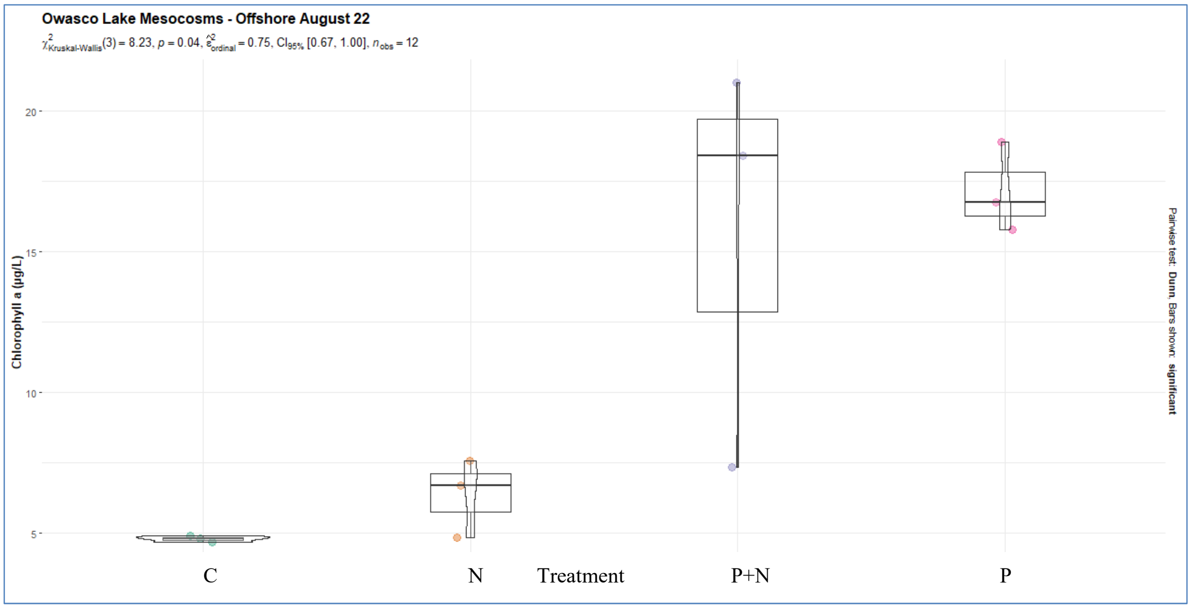


Fig. 46. Results from August offshore phytoplankton mesocosm experiments showing that P as well as N+P treatments resulted in higher chlorophyll concentrations at the end of the experiments. This is mostly likely showing serial P limitation, but the results were not statistically significant.

Sediment Flux Experiments: Results from the sediment incubations show that the uptake and efflux of nutrients from sediments vary in magnitude among sites and over time for the same sites (Fig. 47).

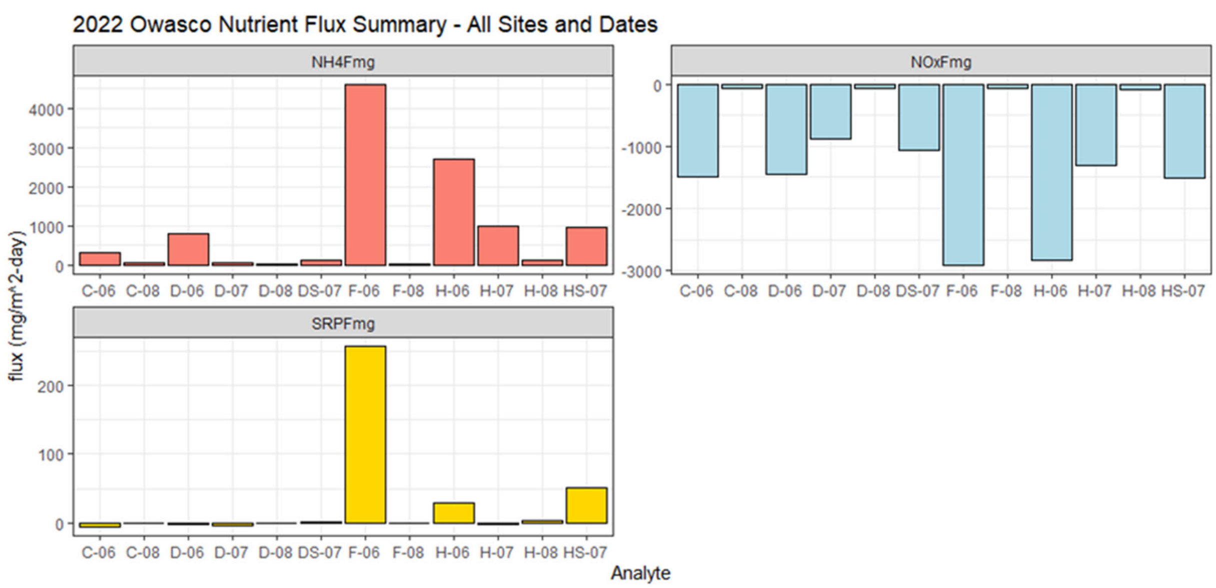


Fig. 47. Fluxes (F) of nutrients (NH_4 F = Ammonium, NO_x F = Nitrate + Nitrite, SRP F = Soluble Reactive Phosphorus for all 2022 experiments. The letter identifies the site and the number represents the month (06 = June, 07 = July, 08 = August). For July cores, sediments with a biofilm are identified with "S" after the site. Please note differing scales based on the analyte. Individual month data and experiments are discussed in more detail below.

June: Summaries of the flux of SRP in June from the beginning of the incubation period (T_0) through 72-hrs by site are illustrated in Fig. 48. This shows large differences among the sites. First, cores from Site F had the highest flux of SRP with Site H having the second highest flux. Sites C and D had a negative flux of SRP, meaning that P was removed from the water and taken up by the sediments.

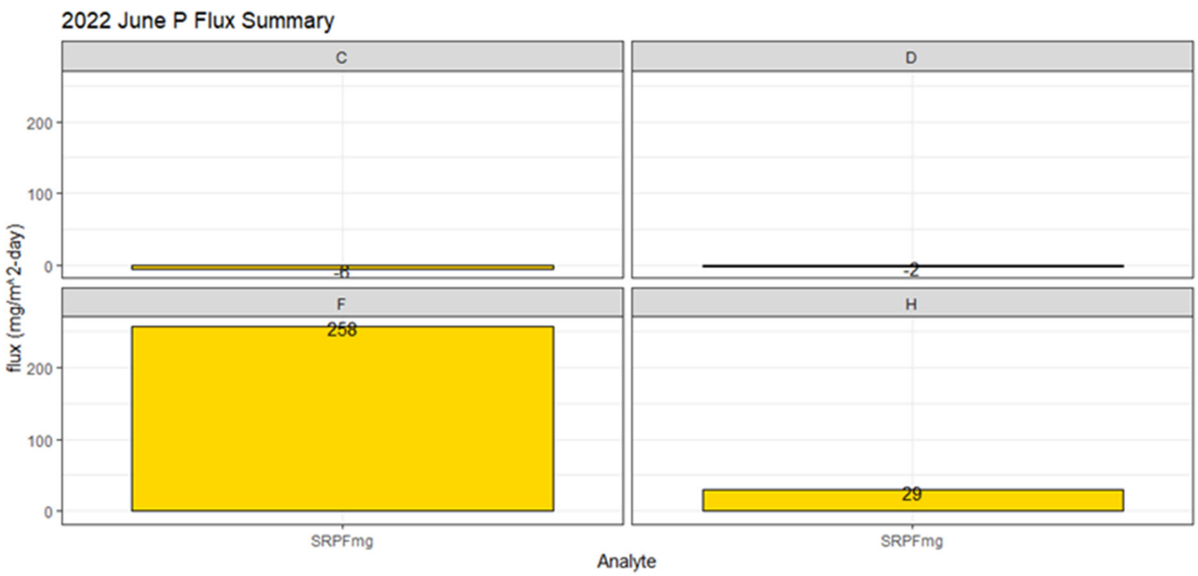


Fig. 48. Site F has the highest flux of both SRP and TP with Site H having the second highest P release into overlying water. Sites C and D had a negative flux of SRP, meaning that the microbes and physical properties of the sediments were removing SRP and TP from the water.

July: For the biofilm experiments, the presence of the biofilm resulted in positive fluxes of both SRP and TP from the sediment cores at both sites (Fig. 49). Similar to June, cores with no biofilm from Site D showed a negative SRP flux, meaning that the microbial community of the sediment core was removing SRP from the water column. In contrast to June, cores from Site H had a negative flux of SRP in July. The presence of the biofilm at Site H greatly enhanced the flux of SRP from sediment to the water. The magnitude of SRP flux from the Site H core with biofilm was higher than the June Site H cores with no biofilm.

For August, cores from all sites except Site H had a slightly negative SRP flux (Fig. 50). Based on the magnitude, little SRP is moving from the sediments to the water column at this time of year. The annual suggests that the sediments are a small annual source of SRP to the water column.

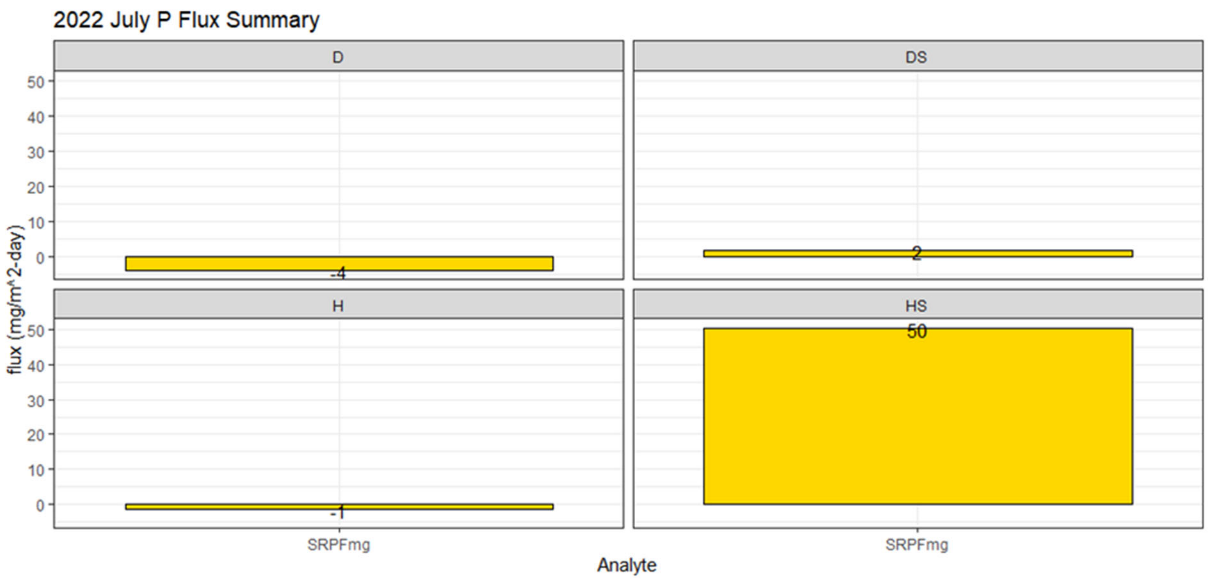


Fig. 49. July SRP flux results (Site name with S denotes biofilm on sediment core).

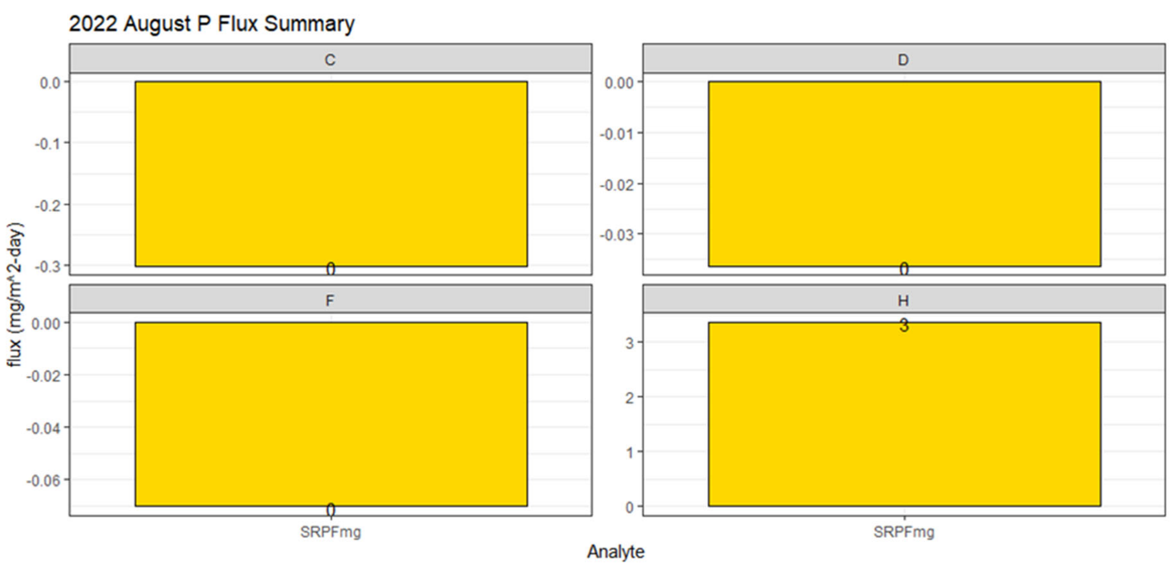


Fig. 50. August SRP flux results.

For nitrogen species, results were less variable. As a reminder, nitrogen cycling is complex and mediated by microorganisms while phosphorus flux is mediated more by particles and release during low oxygen conditions.

Sediment-water interfaces are locations of both nitrification (conversion of NH_4 to NO_3) and denitrification (NO_3 to N_2), often in close proximity and over short-time spans. Dissimilatory nitrate reduction to ammonium (DNRA) is another process that could result in the loss or conversion of NO_3 in aquatic ecosystem.

The ultimate source of nutrients in the sediments is the decay of settling organic material often composed of detritus, particulate matter, plankton and other biota, which are recycled at the bottom of the water column. Thus, nutrients are either buried deeper into the sediment or become available for uptake by aquatic organisms when the water and/or particles at the sediment water interface are mixed from internal waves, large wind events, or lake turnover. Since we focused on nearshore sediments for this project, all mechanisms for moving nutrients from the sediments to the water column and vice-versa are possible.

For all sites and all sampling times, NH_4 had a positive flux from sediments to water while NO_x had a negative flux. For June, Sites F and H had the most NO_x loss from the water overlying sediments with the highest positive flux of NH_4 into the water (Fig. 51).

Fig. 51. June nitrogen species flux results from Sites C, D, F, H.

For the sediment core biofilm study in July, the flux rates of both NO_x and NH_4 were similar within a site regardless of whether or not a biofilm was present (Fig. 52). Compared to June, the flux rates for NH_4 at Site D were about 10% of the July rates while the NO_x rates were roughly similar. For Site H, NH_4 fluxes from the sediments were about one third less while the NO_x flux was about half of what was measured for the June cores.

Fig. 52. July nitrogen species flux results (Site name with S denotes biofilm on sediment core).

For August, Site H cores had the highest flux rates of NH_4 and NO_x (Fig. 53). The other three sites were very similar. The flux values are lower than what was seen in June for all sites. The surface water concentrations of NO_x (T_0) were also lowest in August compared to the other months.

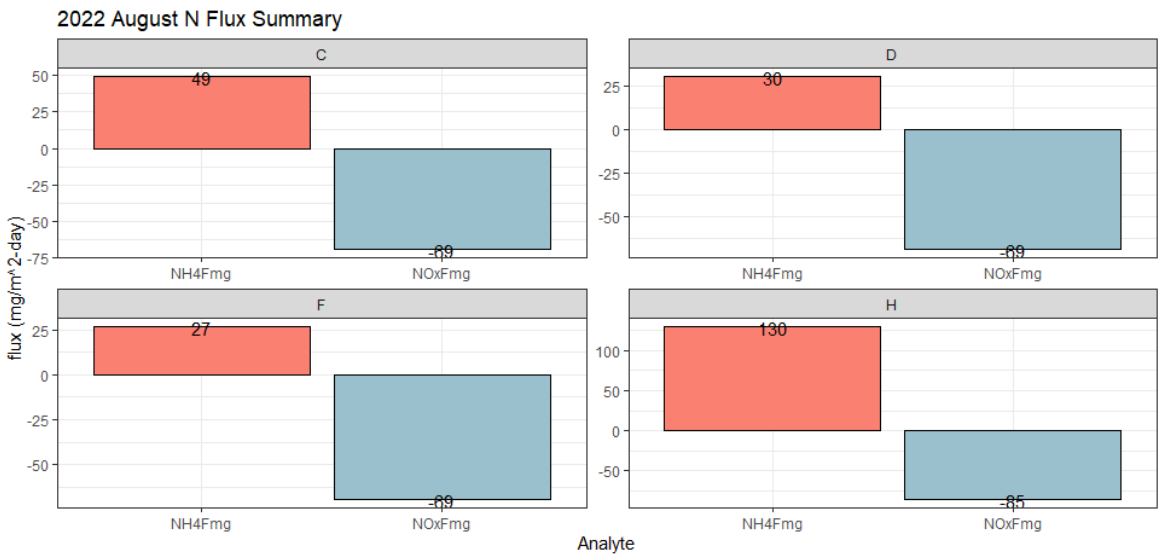


Fig. 53. August nitrogen species flux results.

Summary: The highest flux rates for all nutrients were in June. The organic content (measured as ash-free dry weight) of the sediment cores from each site except C were highest in June (Table 8). All sites had relatively consistent organic content across months except Site F, which had a much higher organic content in June than in August. Site H, located at the south end of the lake, consistently had the highest organic content of all sampled sites.

The ultimate source of nutrients in the sediments is the decay of settling organic material often composed of detritus, particulate matter, plankton and other biota, which are recycled at the bottom of the water column. Thus, nutrients are either buried deeper into the sediment or become available for uptake by aquatic organisms when the water and/or particles at the sediment water interface are mixed from internal waves, large wind events, or lake turnover. Additionally, macrophytes and macroalgae such as Chara and Starry Stonewort are able to access nutrients in the sediments. Since we focused on nearshore sediments for this project, all mechanisms for moving nutrients from the sediments to the water column and vice-versa are possible.

Table 8. Organic content of sediment cores used for incubations.

Site	June	July	August	Average Organic Content %
C	1.89	NA	2.76	2.33
D	1.01	0.62	0.90	0.84
F	3.96	NA	0.61	2.29
H	5.88	5.39	5.08	5.45
DS (+ biofilm)		1.56		
HS (+ biofilm)		6.45		

Looking across all months and all sites, a correlation matrix was prepared to look at the relationship among the fluxes of measured nutrients as well as the organic content of the sediment samples across all of the sites and months (Fig. 54). A strong positive relationship exists between the flux of SRP and NH_4 meaning when NH_4 is released from the sediments into the water from the sediments that SRP increases in the water as well. In contrast, NO_x has a negative association with the efflux of SRP and NH_4, which means that NO_x is removed from the water column through contact with the sediment. The exact NO_x removal pathway is not known at this time (e.g., denitrification, DNRA), but should be explored in future work. Also, the magnitude of the NO_x removal from water is associated with the NO_x concentrations in the surface water. In other words, the highest removal rates of NO_x from the surface water occurred in June when the highest NO_x concentrations were found in the surface water.

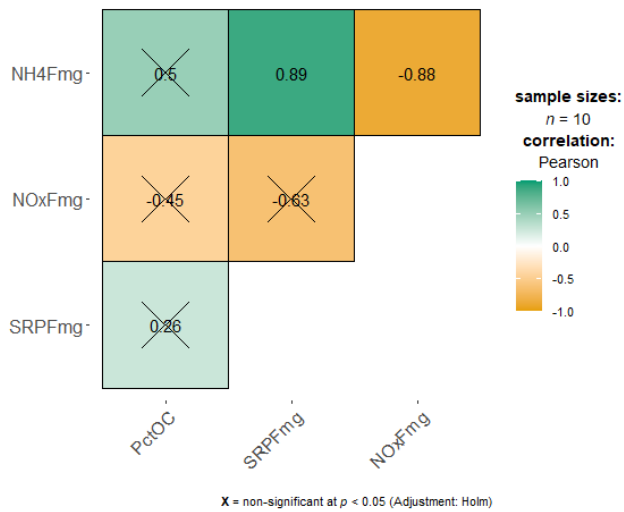


Fig. 54. Pearson correlation matrix showing relationships among the fluxes of various nutrients and % organic carbon (PctOC) from the sediment cores across all experiments (n =10). Green boxes show a positive relationship while orange indicates a negative relationship. Note that sediment cores with biofilms were excluded from this analysis.

Summary and Future Plans: Looking ahead several research items studying the flux (both positive and negative) of nutrients from sediments can be done to help us gain a better understanding of in-lake nutrient sources that could be contributing to HABs. First, to help us learn more about the transformation of various forms of nitrogen and their fate and transport, we should introduce radio-labeled N isotopes to distinguish among nitrogen removal pathways including denitrification or DNRA. Also, it would be good to have a better understanding of the reduction/oxidation conditions of the sediment-water interface and the sediment cores on a fine scale (cm) to determine if SRP and NH_4 flux rates are associated with oxygen concentrations in the sediments. This would be key in mid to late summer when primary production in the lake is at its maximum during the day (contributing oxygen to the water) with maximum respiration (removing oxygen) at night. Finally, we should investigate iron concentrations in the sediments as iron binds with phosphorus and prevents its release except for when oxygen concentrations are low. Genetic analysis of the microbial communities (e.g., 16s analysis) present in the sediments could help us determine the types of bacteria and the role they play in making nutrients bioavailable for phytoplankton and cyanobacteria in Owasco Lake.

Lake Floor "Hardness": A summary of the bottom hardness for each of the three sites selected for sonar are presented in Table 9 and Fig. 55.

Table 9. Summary of the lake floor hardness results.

Site	Min.	Max.	Mean	Std Dev.	Median	25th Percentile	75th Percentile
Emerson Park	0.120	0.395	0.265	0.034	0.259	0.241	0.289
G. Owasco Yacht Club	0.149	0.385	0.287	0.028	0.290	0.270	0.306
D. Burtis Point	0.153	0.382	0.294	0.035	0.296	0.270	0.322

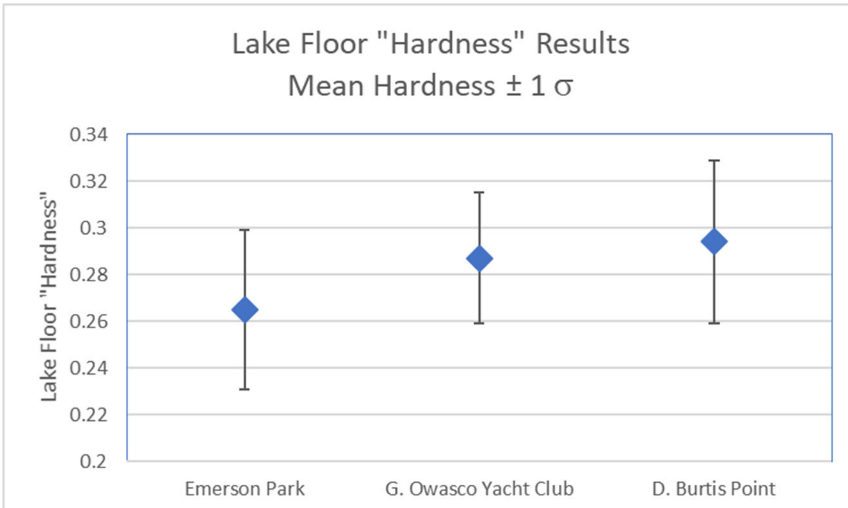


Fig. 55. Mean lake floor "hardness" at the three surveyed sites.

For the sites mapped, the nearshore areas of Emerson Park had the softest bottom as indicated by the lowest mean and median hardness values (Fig. 56). Owasco Yacht Club mainly revealed a medium bottom hardness with large patches of hard substrate located at the northern end of the transect, consistent with substrate sampling efforts from previous years (Fig. 57). Burtis Point had the hardest substrate of the surveyed sites (Fig. 58).

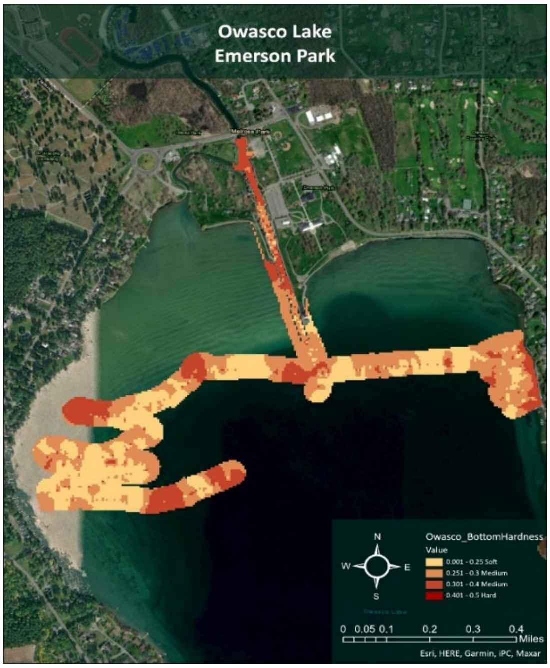
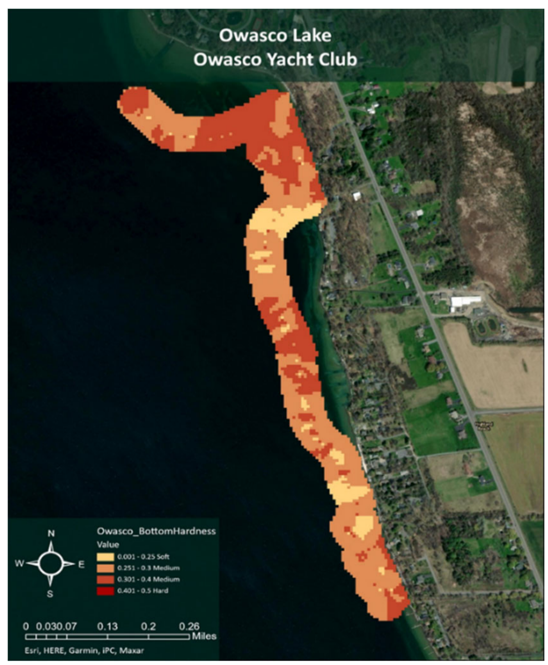


Fig. 56. Variation in bottom hardness for Emerson Park. Lighter areas are "softer" and more likely to have denser macrophyte growth. There is considerable heterogeneity but the lake bed in this area is soft with harder areas found in the Owasco Outlet.

Fig. 57. The most northern portion of the survey offshore of the Owasco Yacht Club revealed the largest bottom hardness values, compared to mostly mid-range values.



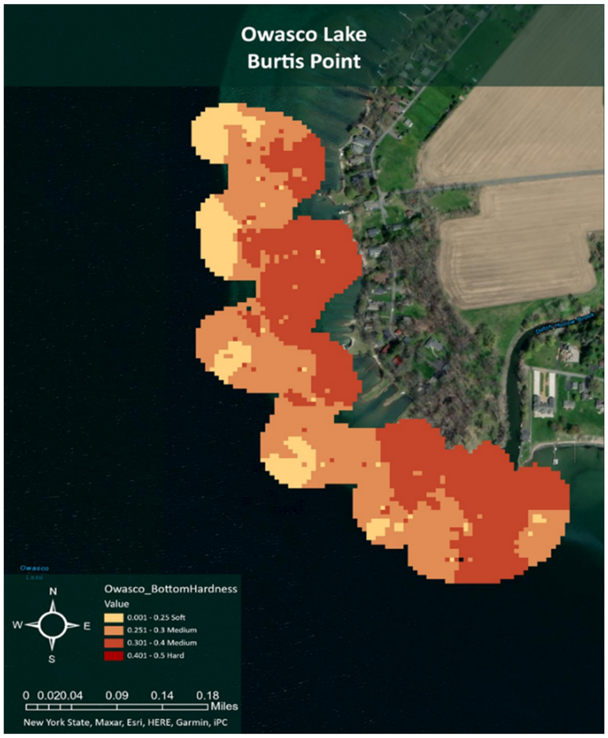


Fig. 58. The nearshore areas of Burtis Point revealed the largest bottom hardness values of the sites surveyed, especially near the mouth of Dutch Hollow Brook.

Plant Community Composition: A total of 897 rake tosses were completed over the 2021-2022 seasons with 517 rake tosses in the north end and 380 in the south end (Fig. 59). Most of the north end sampling was done in June since plants tend to be present in the north end earlier in the year while most of the south end sampling was completed in August and later.

Approximately 50% of the rake tosses from both the north and south ends resulted in no plants. For the north end, the next prevalent category was trace plants, which were 33% of all rakes tosses.

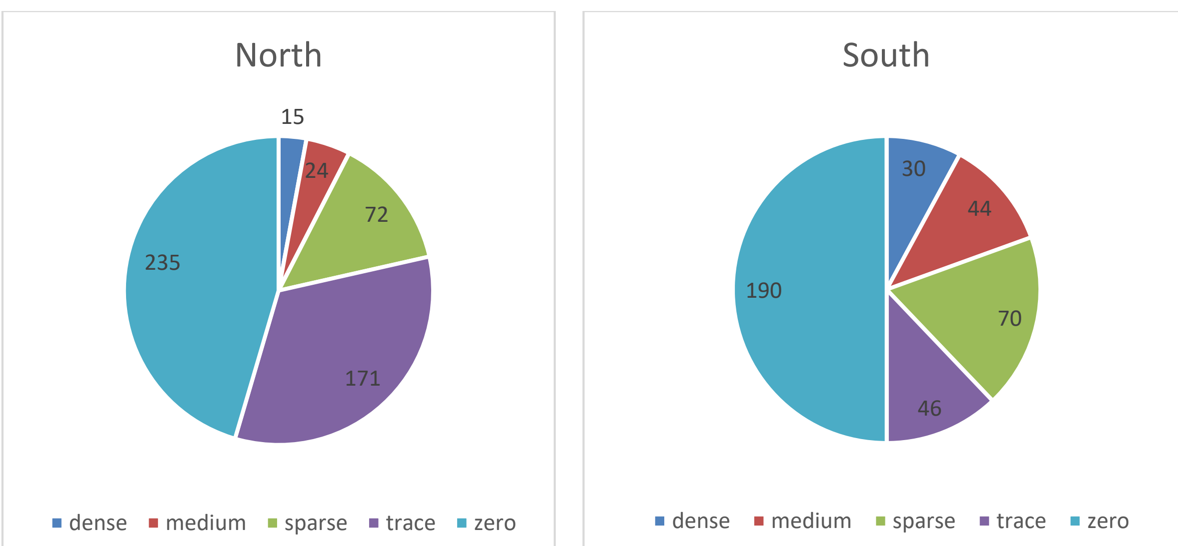


Fig. 59. Rake toss density counts for the north and south ends of Owasco Lake. On average, the northern end had less vegetation per rake toss than the southern end of the lake.

For the rake tosses with plants on the north end (n=282), the most numerous dominant macrophyte was Chara spp., a macroalgae, which was found in 34% of the rake tosses. The second most dominant macrophyte was Elodea spp while Starry Stonewort (Nitellopsis obtusa), another macroalgae, was third. Other macrophytes identified as dominant in more than 5% of the rake tosses include filamentous algae, American eelgrass (Vallisneria), curly-leaf pondweed (Potamogeton crispus), leafy pondweed (Potamogeton foliosus), and Sago pondweed (Potamogeton pectinatus).

For the rake tosses with plants on the south end (n=191), the most numerous macrophyte was Starry Stonewort, the macroalgae, which was found in 26% of the rake tosses. The second and third most dominant macrophytes were Sago pondweed and American eelgrass. Other macrophytes identified as dominant in more than 5% of the rake tosses include coontail (Ceratophyllum demersum), Elodea spp., and small pondweed (Potamogeton pusilis).

From a diversity perspective, a total of 24 different plants and algae were found in Owasco Lake (Table 10). While the average amount of plants per rake toss was lower in the north end compared to the south end, a total of 22 different species of plants and algae were found in the northern part of the lake. The southern end had 17 different species of plants and algae.

Table 10. Macrophytes and algae founds in Owasco Lake (2021-2022).

Macrophyte	Scientific name	Found in N?	Found in S?
Algae	filamentous	Y	Y
American eelgrass	Vallisneria americana	Y	Y
Chara spp	Chara	Y	Y
Coontail	Ceratophyllum demersum	Y	Y
Curly -leaf pondweed	Potmogeton crispus	Y	Y
Elodea Spp	Elodea	Y	Y
Eurasian watermilfoil	Myriophyllum spicatum	Y	Y
Flatstem pondweed	Potamogeton zosteriformis	Y	Y
Horned pondweed	Zannichellia palustris	Y	Y
Illinois pondweed	Potamogeton illinoensis	Y	N
Large leaf pondweed	Potamogeton amplifolius	Y	N
Leafy pondweed	Potamogeton foliosus	Y	Y
Long leaf pondweed	Potamogeton nodosus	Y	N
Northern watermilfoil	Myriophyllum sibiricum	N	Y
Richardson's pondweed	Potamogeton richardsonii	Y	N
Sago pondweed	Potamogeton pectinatus	Y	Y
Slender naiad	Najas flexilis	Y	N
Small pondweed	Potamogeton pusilis	Y	Y
Southern naiad	Najas guadalupensis	Y	N
Starry stonewort	Nitellopsis obtusa	Y	Y
Water buttercup	Ranunculus aquatilis	Y	Y
Water plantain	Alisma plantago-aquatica	N	Y
Water stargrass	Heteranthera dubia	Y	Y
Whitestem pondweed	Potamogeton praelongus	Y	N

Finally, filamentous algae were prevalent in the northern end of Owasco Lake during the macrophyte sampling. Pictures of green filamentous algae were sent to the FLI by Michele Wunderlich reporting that there was thick growth in the Poplar Cove area of the lake (Fig. 60). This was not reported in the previous year, but would be worth following up on in future years. Microscopic examination of the filaments at the FLI showed that the green algae were Spirogyra.

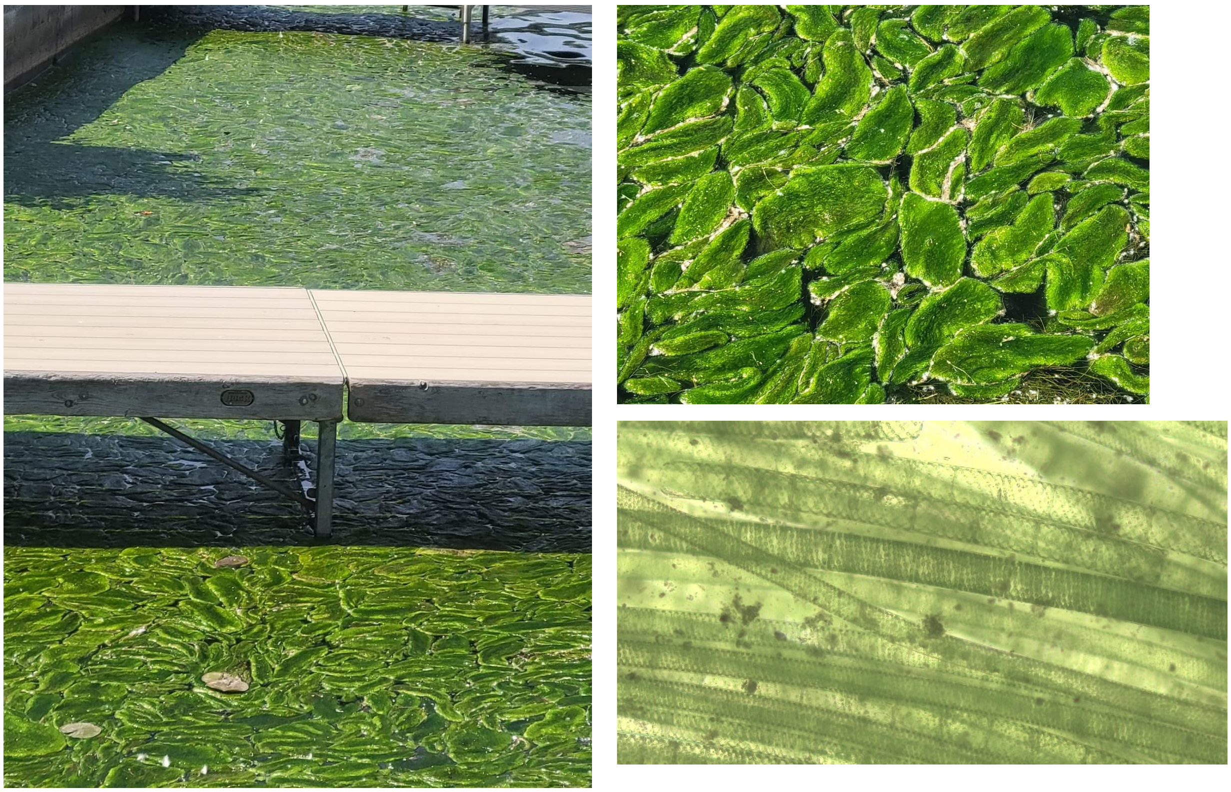


Fig. 60. Images sent to the Finger Lakes Institute showing filamentous algal mats in the Poplar Cove area of Owasco Lake from June 2022. The bottom right image on the bottom is the microscopic view of the green algae filaments showing Spirogyra spp (FLI photo).

Looking ahead: Continued macrophyte community assessment should be continued for early detection of invasive species including Hydrilla, which has been found in Cayuga Lake at numerous locations. This work will be supported by the FLI through 2023. Specifically, we plan to collect rake tosses in the shallow nearshore areas on Owasco Lake between the north and south ends of the lake. FLI also plans to continue the BioBase work on the south end of Owasco Lake to measure the bottom hardness. Based on the sediment core work and the plant sampling completed to date, we expect to find softer sediments at the south end of the lake.

ACKNOWLEDGEMENTS

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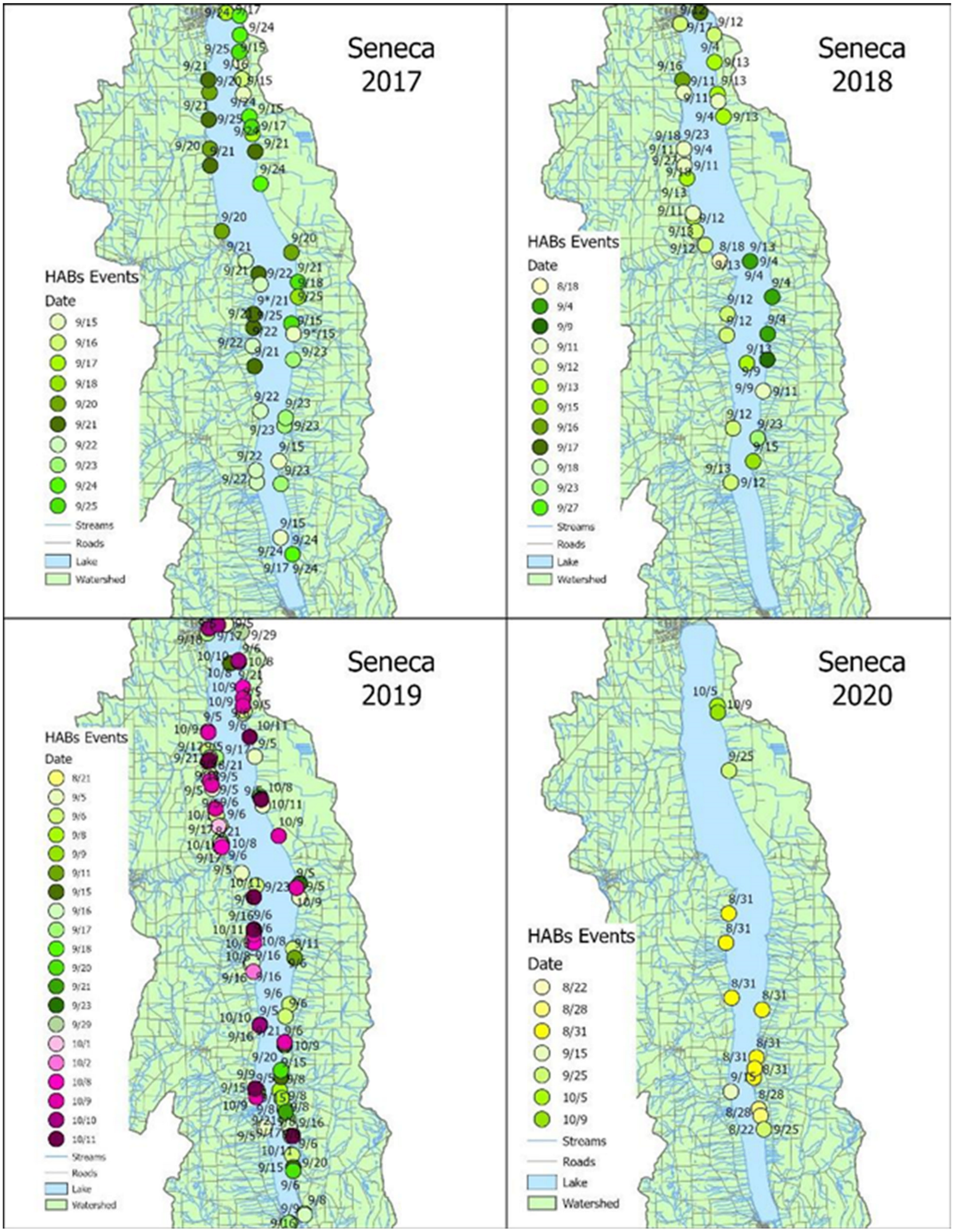
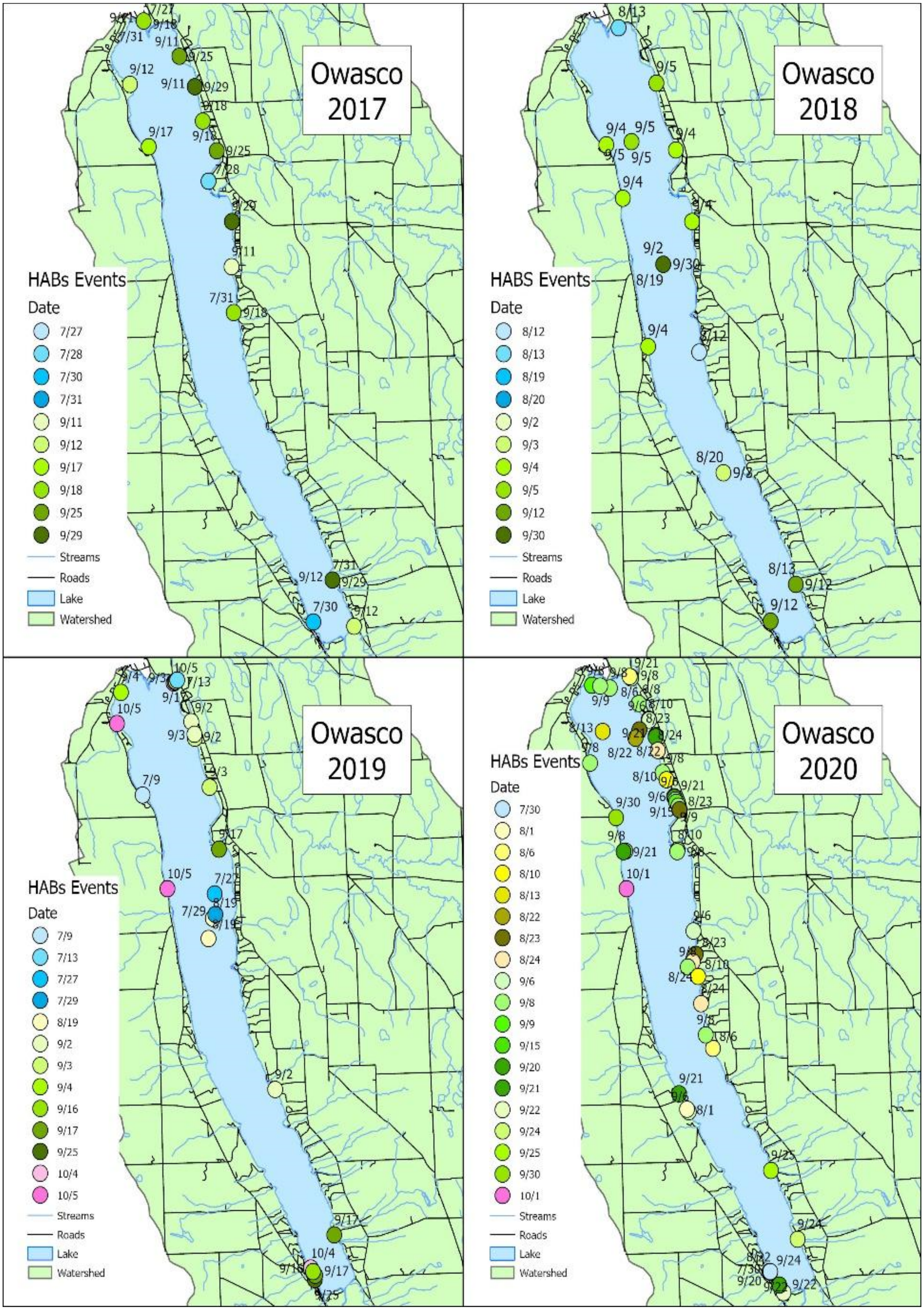
Appendix 1. Confirmed cyanobacteria blooms in Seneca and Owasco Lakes form 2017 – 2021.




Owasco 2017
HABs Events
Date
7/27
7/28
7/30
7/31
9/11
9/12
9/17
9/18
9/25
9/29
Streams
Roads
Lake
Watershed
Owasco 2018
HABS Events
Date
8/12
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8/19
8/20
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9/3
9/4
9/5
9/12
9/30
Streams
Roads
Lake
Watershed
Owasco 2019
HABs Events
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Streams
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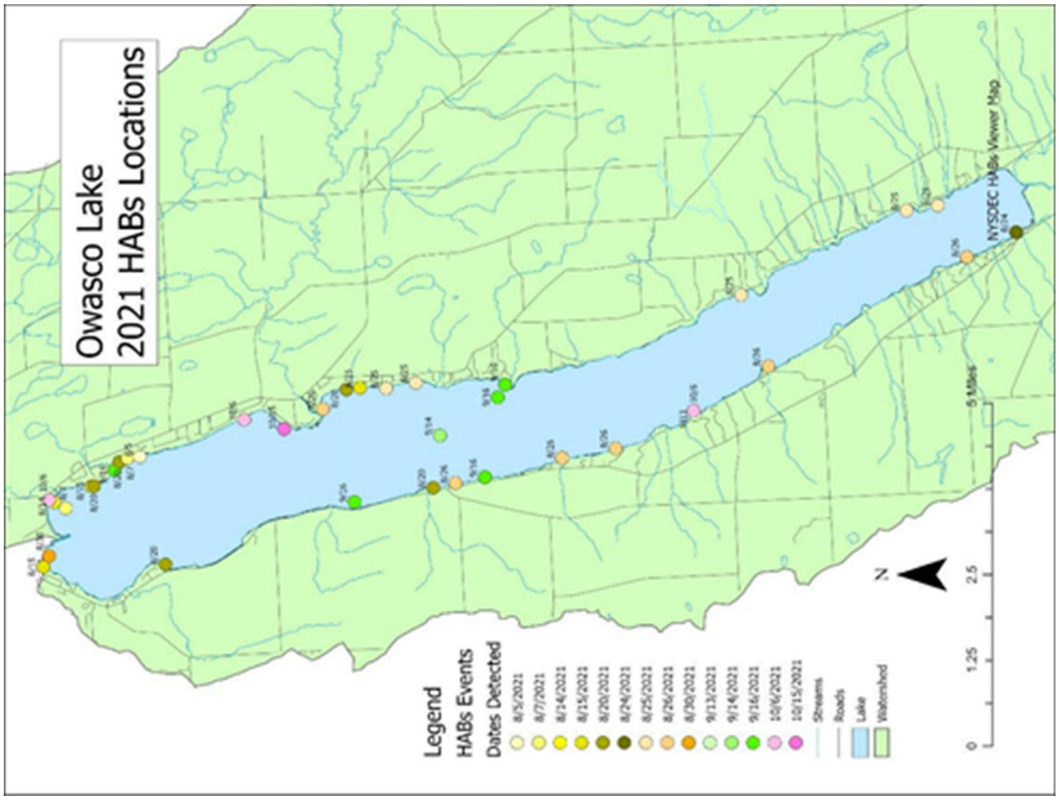
Owasco Lake
2021 HABs Locations
Legend
HABs Events
Dates Detected
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8/7/2021
8/14/2021
8/15/2021
8/20/2021
8/24/2021
8/25/2021
8/26/2021
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9/13/2021
9/14/2021
9/16/2021
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10/15/2021
Streams
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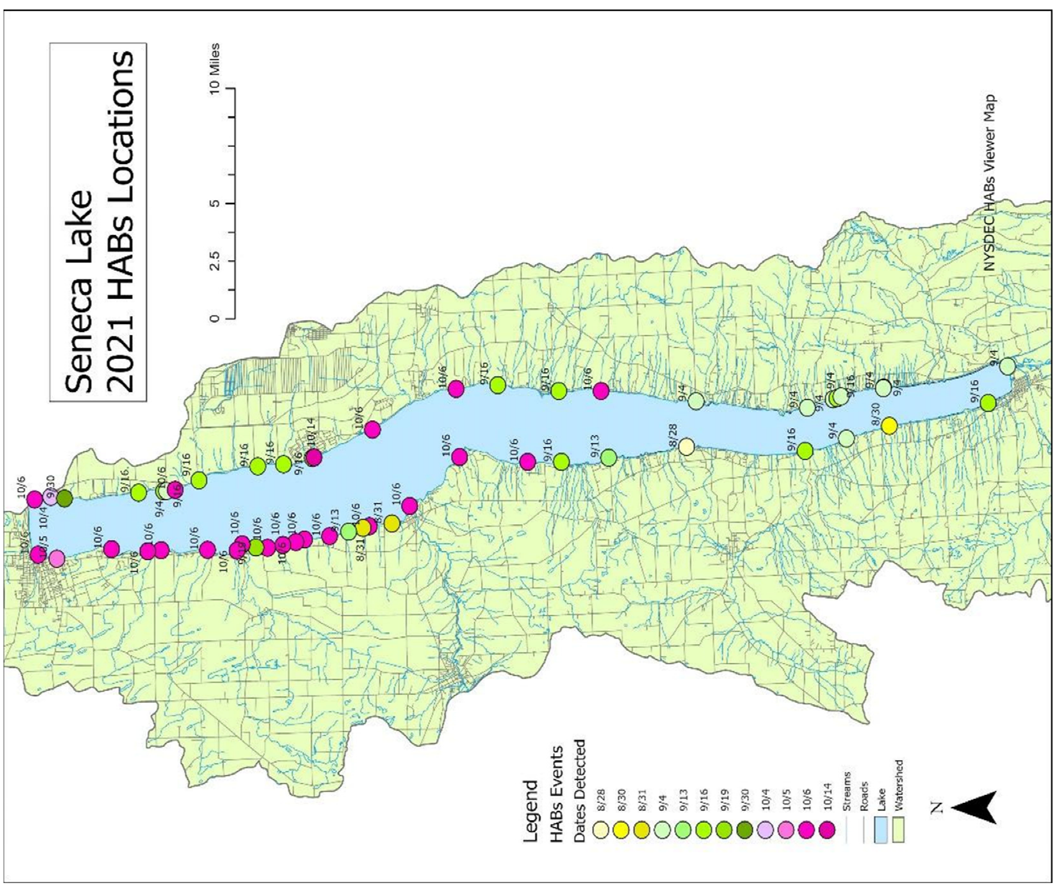
NYSDEC HABs Viewer Map


Seneca Lake
2021 HABs Locations
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Legend
HABs Events
Dates Detected
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10/4
10/5
10/6
10/14
Streams
Roads
Lake
Watershed
N
NYSDEC HABs Viewer Map