BLUE-GREEN ALGAE IN OWASCO LAKE, THE 2019 UPDATE.
THE 2019 ANNUAL REPORT TO THE FRED L. EMERSON FOUNDATION

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INTRODUCTION

The recent onset of blue-green algae (BGA) blooms and their associated toxins (HABs) has heightened awareness about water quality issues in Owasco and neighboring Finger Lakes. In 2016, BGA toxins were detected in the Auburn and Owasco municipal drinking water supplies that draw water from Owasco Lake. Since then, toxins were detected in the City of Syracuse's municipal water intake that draws water from Skaneateles Lake in 2017 and in Rushville's municipal drinking water that draws water from Canandaigua Lake in 2018. The largest measured BGA concentrations throughout these lakes were typically at shoreline locations, where lakeshore residents want to use the lake. A three-year research award from the Fred L. Emerson Foundation to Halfman and others at the Finger Lakes Institute (FLI) at Hobart and William Smith Colleges (HWS) was designed to investigate the limnological factors controlling the growth and persistence of BGA, especially along nearshore and shoreline areas. The award also supported the operation of FLI's water quality monitoring buoy at a mid-lake site to provide a daily record of the open water limnology and allow for a comparison of the open water limnology to the nearshore data.

This report details our findings from the third and final year of this three year award, and proposes recommendations for additional research efforts into the future. This year continued the reconnaissance effort that focused on six nearshore sites to test and refine the hypotheses outlined in 2017. Based on the first year results and remediation recommendations, the Owasco Lake Watershed Association funded an assessment of potential HABs mitigation technologies at eleven shoreline/dock sites. The second year results stimulated funding from Seneca Lake Pure Waters Association and the Finger Lakes – Lake Ontario Watershed Protection Alliance to deploy meteorological and limnological instrumentation at a number of docks along the shoreline of Seneca and Owasco Lakes. The collected data from all these efforts increased our understanding of shoreline BGA blooms in the lake. All of these projects complement and dovetail nicely with the lake/watershed monitoring effort supported by Cayuga County through the Owasco Lake Watershed Municipal Council. Each report is available online at Halfman's web site (http://people.hws.edu/halfman/)[1,2]. A summary of the project's findings and proposed future research directions are next.

The Owasco Lake and watershed monitoring program supported by Cayuga County focused on two offshore lake sites, water grab samples from streams in the watershed, and a daily analysis of nutrient and sediment loads from Dutch Hollow Brook to the lake. The primary conclusions based on this work include:

- Owasco Lake has been borderline oligotrophic/mesotrophic since 2005, and water quality declines during "wet" years and improves during "dry" years.
- Phosphorus to nitrogen ratios significantly exceed 1:7 indicating that algal growth is limited by phosphorus in Owasco Lake.
- Annual mean, open-water, total phosphorus concentrations were never sufficient to support the amount of phosphorus required for the BGA nearshore blooms measured to date.
- Since 2011, estimated annual phosphorus budgets for the lake revealed larger inputs than outputs through 2015, and more recently, smaller inputs than outputs. The change is in the correct direction but additional remediation efforts over more time must be completed as water quality has not yet significantly improved in the lake.
- Nonpoint sources of nutrients from, e.g., runoff from agricultural areas, roadside ditches, drain tiles, and construction sites, provided over 80% of the phosphorus load to the lake. The exact percentage of non-point to point sources varied from year to year depending on the amount and intensity of the rainfall, especially in the spring.
- Over 90% of the total loads were delivered to the lake during precipitation events.
- Various best management practices and the recently developed Owasco Watershed Rules and Regulations have been and should continue to be implemented and expanded to reduce nonpoint and point sources of nutrients to the lake.

The first two years of the Emerson award focused on the limnology and sediment character at six nearshore sites. The results include:

- BGA blooms favored calm waters, and were detected in the late summer and early fall, after the peak warmth in water temperature. The largest blooms were detected along the shoreline, highlighting the need to better understand the nearshore environment.
- The nearshore area lacked sufficient nutrients to support the populations of BGA in these blooms. In fact, very few differences exist between the nutrient and algal composition of the nearshore and offshore water columns.
- The quantity and quality of nitrogen and phosphorus within the shoreline sediment organic matter is sufficient to support the observed bloom activity.

[1]Halfman, et al., 2019. The 2019 Water Quality Monitoring Report for Owasco Lake, NY. Submitted to Cayuga County & Owasco Lake Watershed Municipal Council. Finger Lakes Institute, Hobart & William Smith Colleges. 48 pgs.
[2]Halfman, et al., 2019. Nearshore HABs in Seneca Lake; A Report to the Seneca Lake Pure Waters Association. Finger Lakes Institute, Hobart & William Smith Colleges. xx pgs.

2019 SUMMARY AND FUTURE RESEARCH:

2019 Summary:

- Our nearshore sample sites in 2 to 3 m of water never had sufficient nutrient concentrations in the water column to support the observed blooms in Owasco Lake. BGA blooms were rare at the sample sites. It again suggests that the sediments along the shoreline, and not the water column, most likely provides the nutrients and BGA resting stage "seed" cells for shoreline blooms.
- Surface water temperature again decreased by a few degrees centigrade just before most BGA blooms. The 2019 declines were more subdued than previous years. The declines indicate that wind and/or storm events and the associated waves, that likely caused the temperature decrease, could have disturbed the sediments, released the nutrients and BGA resting stage cells to nearshore areas and thus stimulated nearshore BGA blooms. The blooms were typically detected on the next sunny and calm day.
- The hypothesis spawned by this project and the 2018 HABs Mitigation Technology Assessment dockside research brokered additional funds from Seneca Lake Pure Waters Association (sponsored by the Tripp Foundation) and from Cayuga County (sponsored by the Finger Lakes – Lake Ontario Watershed Protection Alliance) to deploy weather stations, automated cameras and prototype FLI Sensor Nodes at a number of docks along Seneca and Owasco Lake to investigate the linkages between meteorological and limnological variables and BGA blooms.
- The automated cameras detected BGA blooms. Along Seneca Lake, the cameras detected blooms missed by local HABs volunteers; and conversely, the volunteers detected blooms missed by the cameras. The Owasco Lake DEC-HABs locations were not available to determine similar linkages in Owasco. The SLPWA volunteer, one-day a week, weekly surveys probably missed blooms on other days of the week, and their survey of entire shoreline zones detected blooms outside of the camera's 3x4 meter field of view. See the companion SLPWA report for more information[3].
- The prototype FLI Sensor Nodes had challenges in the field. When they worked, the data revealed significant, 2 to 4°C, daily oscillations in temperature at 1 m depth. These oscillations were detected across the nearshore. Temperatures measured by the buoy and CTD did not detect similar oscillations offshore due to less frequent sampling. The 2018 USGS water quality buoy data revealed slightly smaller daily oscillations in temperature, 1 to 2°C at 3-ft depth. The offshore temperatures were most likely more subdued because it is easier to warm up and cool down shallow water than deep water sites.
- Shoreline dissolved oxygen concentrations detected by the Sensor Nodes also increased during the day and decreased during the night indicating a huge influence by nearshore biota, i.e., macrophytes, zebra/quagga mussels, algae and bacteria. Similar temperature and dissolved oxygen oscillations were detected in Seneca Lake. It suggests that photosynthesis by algae and macrophytes during the daylight and respiration by organisms, especially at night, was important in the nearshore environment, and perhaps bacterial decay of organic matter released enough nutrients into the sediments to support the BGA bloom populations once mixed into the water column by onshore waves.
- Wind speeds decreased and wind directions were significantly different between the two neighboring nearshore areas, and between the nearshore areas and the open lake. The

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[3]Halfman, et al., 2019. Nearshore HABs in Seneca Lake; A Report to the Seneca Lake Pure Waters Association. Finger Lakes Institute, Hobart & William Smith Colleges. xx pgs

shoreline orientation must have impacted the regional winds. Variability along the shoreline suggests that one shoreline can experience calm conditions and a bloom, whereas neighboring shorelines with different orientations may experience sufficient winds to retard bloom development. The scenario provides a likely reason why blooms are localized in time and space. Nutrient availability probably impacts bloom development as well.

- The BGA blooms were observed migrating parallel to the shoreline, supposedly transported by nearshore currents. A bloom initiated at one location can thus impact neighboring down-current locations.
- Preliminary macrophyte and mussel surveys tentatively indicate that their populations were potentially sufficient to fertilize the nearshore blooms. The macrophytes also supported a large population of attached zebra and quagga mussels. However, more detailed macrophyte and mussel surveys are required to pinpoint their lake-wide contributions to BGA blooms.
- Preliminary nutrient flux tests from nearshore sediments revealed a significant store of nutrients in the sediment column.

Future Research

The Emerson and related projects highlighted a number of important relationships to test in the future.

- Confirm the relationship among wind and/or storm events, shoreline geometry, nearshore currents, biological impact on dissolved oxygen concentrations, and the occurrence of nearshore BGA blooms. This requires additional weather stations, automated cameras and commercial loggers to measure meteorological and limnological conditions at a number of sites around Owasco and neighboring lakes and assess their correlation to BGA blooms. Deployment of an occasional current meter to detect nearshore currents is suggested as well.
- Determine the relationship between the extent and type of macrophytes, as well as the extent of zebra & quagga mussels at nearshore regions to the occurrence of BGA blooms. The macrophyte and mussel enumerations requires detailed quadrat surveys of the lake-floor by SCUBA divers on multiple dates at the nearshore sites.
- Determine the bioavailability and quantity of nutrients in the nearshore sediments and its flux to the water column, especially after sediment disturbance. This requires collection of short sediment cores at selected nearshore sites, and nutrient flux experiments in the lab.
- Perform lab experiments to determine which nutrient limits BGA growth. It has been assumed that phosphorus is the limiting nutrient due to its scarcity relative to nitrogen in the water column, but the scientific literature suggests that nitrogen may be important as well, even in P-starved systems.
- Finally, continue the deployment of the FLI meteorological and water quality monitoring buoy at its mid-lake site to consistently monitor water quality improvements (or declines) over time.

METHODS

This project focused on the limnology of six nearshore sites in Owasco Lake. These results will be compared to: (a) offshore data provided by the water quality and meteorological monitoring buoy, and (b) identical limnological data collected at two mid-lake, offshore sites. Another part of the study focused on preliminary macrophyte enumeration and sediment nutrient flux studies from a few nearshore locations. Finally, to follow up on promising results in 2018, the feasibility of weather stations, automated cameras and FLI Sensor Nodes to detect blooms and precursor meteorological and limnological events before each BGA bloom was assessed.

Site Locations: The 2019 fieldwork focused on six nearshore sites, Sites A, C through G (Table 1, Fig. 1). Site B, sampled in 2017, was discontinued since, in favor of Site G, located just offshore of the Owasco Yacht Club. All six sites were sampled from May through the end of September. The survey dates increased in frequency from bi-weekly intervals at the start at the field season, to weekly surveys through July, August and September. The sample design enabled a comparison when BGA blooms were least likely and most likely to be present, and maximized sampling during the late summer and early fall when blue-green algae blooms were most likely to be present. The specific 2019 survey dates were: 5/29, 6/10, 6/25, 7/9, 7/16, 7/23, 7/30, 8/6, 8/13, 8/20, 8/27, 9/3, 9/10, 9/17, and 9/24.

The nearshore sites were selected based on the lake-floor morphology and the presence and/or absence of BGA blooms in the past. The largest morphological variant along the nearshore in Owasco Lake was the extent of a shallow water shelf and its associated macrophyte and mussel beds extending from the shoreline and gently descending to depths of 3 to 5 m before steeply descending to greater depths (Fig. 2).

Table 1. Owasco Lake Site Locations and Water Depths.

Site Name	Latitude	Longitude	Water Depth	Adjacent Dockside Instrumentation?
Nearshore Sites:				
A – Fire Lane 20	42° 48.69' N	76° 30.92' W	2 - 3 m	No
B – Wyckoff Rd	42° 50.61' N	76° 31.58' W	2 - 3 m	No
C – Stone School Rd	42° 52.01' N	76° 31.98' W	2 - 3 m	No
D – Burtis Pt	42° 51.89' N	76° 30.96' W	2 - 3 m	Yes
E – Martin Pt	42° 53.64' N	76° 31.59' W	4 - 5 m	Yes
F – Buck Pt	42° 53.35' N	76° 32.65' W	2 - 3 m	No
G – Yacht Club	42° 53.23' N	76° 31.23' W	5 m	No
Offshore Sites:				
Site 1	42° 52.40' N	76° 31.35' W	34 m	
Site 2	42° 49.15' N	76° 30.45' W	52 m	
Buoy Site	42° 50.35' N	76° 30.85' W	49 m	

Fieldwork: The fieldwork was consistent with the earlier research. A CTD water quality profile, a bbe FluoroProbe profile, Secchi disk depth, vertical plankton tow (80-μm mesh), and surface water samples were collected at each site. A bottom water sample was also collected from each offshore site. 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 fluorescence (a measure of chlorophyll-a, μg/L) using a SeaBird SBE-25 CTD. The CTD was lowered from the surface to the lake floor, collecting data every 0.5 second (~0.1 meters) along the downcast.

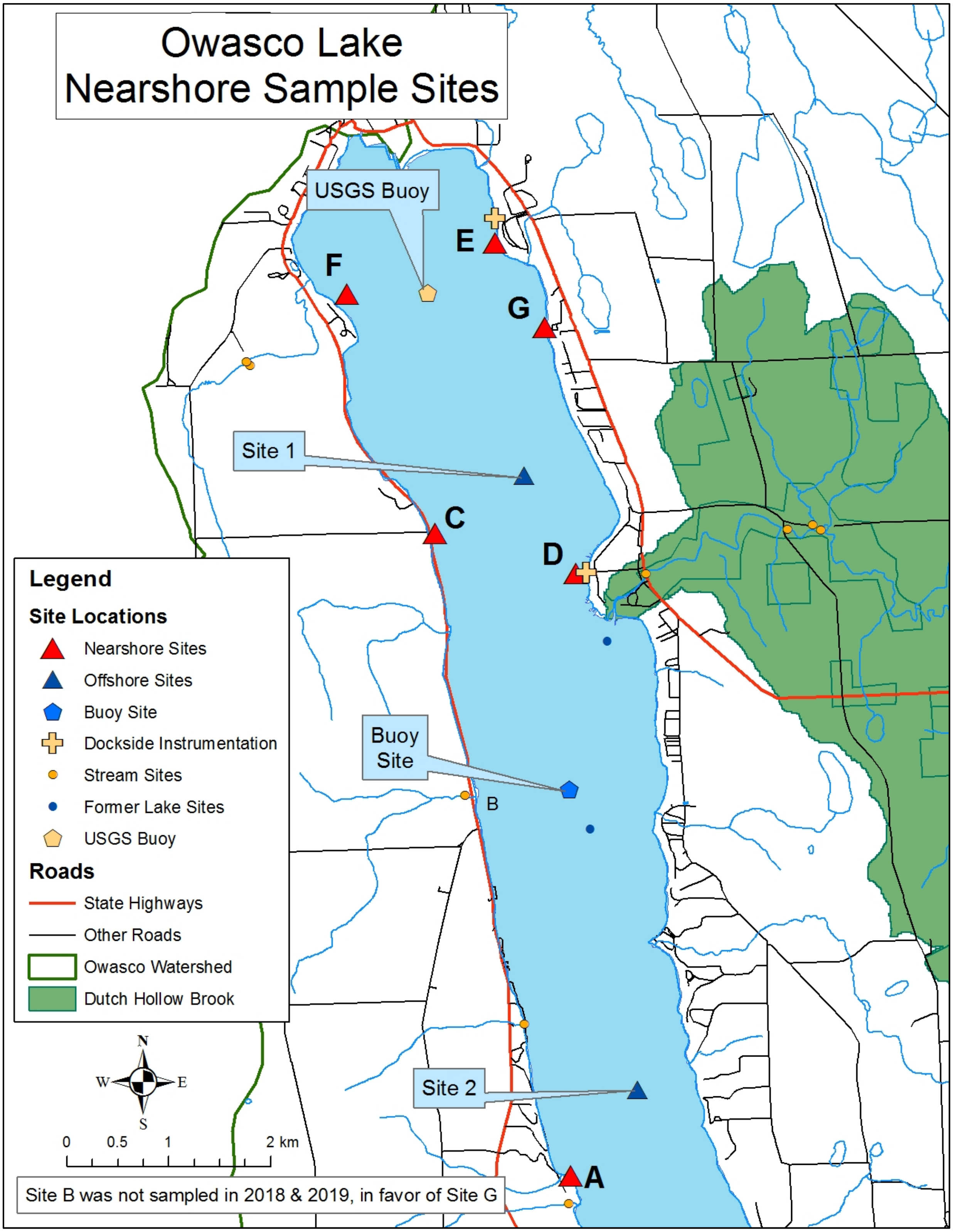

Fig. 1. The 2019 Owasco Lake nearshore, dockside, buoy and offshore survey sites.

The bbe FluoroProbe electronically measures four different algal groups based on their accessory pigments. It distinguishes among: 'green' algae (Chlorophyta and Euglenophyta), 'brown' algae (diatoms: Baccillariophyta, Chyrsophyta, and Dinophyta), 'blue-green' algae (Cyanophyta), and 'red' algae (Cryptophyta). The bbe FluoroProbe was attached to the CTD and deployed on every CTD cast. Water grab samples were also collected in amber bottles for additional bbe FluoroProbe algal enumerations in the lab. Phytoplankton was collected using an 80 μm mesh net integrating the algae through a depth of 20 m (or the lake floor if shallower). The net contents were preserved in a 6-3-1 water-alcohol-formalin solution and enumerated, typically to species 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 analyzed back in the laboratory for total phosphorus (μg/L, P), soluble reactive phosphate (SRP, μg/L, P), nitrate (mg/L, N), chlorophyll-a, soluble reactive silica (μg/L, Si), and total suspended solid (mg/L) concentrations.

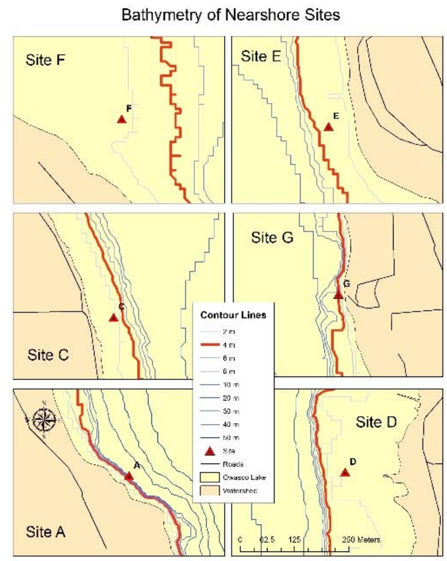

Fig. 2. The nearshore bathymetry. The contour interval shown is 2 m, in shallow water (< 10m), and 10 m in deeper water. Each map was drawn at the same scale. The two meter bathymetric contour is highlighted in red for comparison between sites.

One *ONSET* HOBO U20L-04 temperature and water level data logger was attached to a dock leg near each nearshore site from 6/18 through 9/16 (dock out at a few sites). The loggers at Burtis Point and Martin Point were continued through 10/9 as part of the dockside meteorological and limnological instrumentation investigation. The six loggers were programmed to record water temperature every hour at a depth of about 1 m below the lake's surface to determine if any site experienced unique temperature swings from the rest of the lake.

Macrophyte Surveys: As in previous years, two rake tosses were completed at each nearshore site on each survey date to qualitatively determine the aquatic macrophyte (rooted / attached plant) assemblages, relative abundance, and approximate volumes for potential changes through the summer season. More detailed macrophyte and zebra/quagga mussel sampling occurred at three sites (Fig. 1) on three dates. On 7/10, samples were taken from sites C and G. On 7/24 and 9/9, samples were taken at sites C, D, and G. Sites were selected based on substrate type and water depth (2 - 3m). Site G had a hard substrate where predominantly cobbles/boulders were present, whereas Sites C and D had a macrophyte covered substrate. At each site, three replicate 0.5x0.5m quadrats were randomly tossed into the water. Scuba divers then removed all of the plants and mussels in the quadrat and placed them in a mesh bag. The plants were then separated, sized, identified to species and weighed wet. Mussels were also counted, weighed wet, and separated by species (Zebra vs. Quagga). Subsamples (20%) were used for any sample weighing over 300g. The mussels were also sorted into small (0-8mm), medium (8-15mm), and large (>15mm) size classes. The mussels were removed from any rocks in the field to limit crushing during transport to the lab.

Drone Flights: Drones were flown at an altitude of 50 m at the six nearshore sites to investigate the extent of nearshore macrophytes and BGA blooms (Fig. 3). A DJI Phantom 3 Advanced drone with a Sony EXMOR gimbaled camera. Each 12 megapixel digital image spanned an area of ~100 by 150 meters at this flight altitude. Multiple (~15), overlapping nearshore images were collected at each site. Flights dates duplicated the lake survey dates.

Fig. 3. The drone used in this study, a Phantom 3 Advanced by DJI.

Owasco Buoy: The FLI meteorological and water quality monitoring buoy manufactured by YSI/Xylem was redeployed at its mid-lake site in 49 m of water from 4/15 through 10/30 (Table 1 & Fig. 1). The buoy was programmed to collect water column profiles every 12 hours (noon and midnight) of temperature (°C), conductivity (μS/cm, reported as specific conductance), dissolved oxygen (mg/L & % saturation, by optical sensor), turbidity (NTUs by backscattering), and fluorescence measuring both total chlorophyll and blue-green algae phycocyanin (RFUs, by specific pigment excitation at different wavelengths of light) using a YSI/Xylem EXO2 water quality sonde. The sonde data were collected every 1.5 meters down the water column starting at 1 m below the lake's surface. Every thirty minutes, the buoy also recorded five-minute, mean, air temperature, barometric pressure, relative humidity, light intensity, wind speed and wind direction data. All of the raw data were transferred to HWS by cellular technologies ~1 hour after collection and made available on the internet soon afterwards[4]. Minimal solar power due to unrelenting cloudy/rainy weather prevented collection of water quality data from 4/15 – 4/20, 4/22 – 4/24, 4/28, 4/30, 5/13, 5/22, and 10/20; and meteorological data from 4/17 through 4/23. The buoy's EXO2 sonde was calibrated before and after the deployment and minimal instrument drift was noted. The raw buoy data were then calibrated against *in situ* CTD and laboratory data collected over the entire field season from the offshore sites. Calibrated buoy data are presented in this report.

Nearshore/Dockside Water Quality Monitoring: Last year's results from the dockside HABs mitigation project suggested that blooms developed on the next calm and sunny day after a dip in water temperature, probably induced by a wind/rain event. Seed funding in 2019 from FL-LOWPA tested the suitability of weather stations, water temperature loggers, automated cameras and FLI Sensor Nodes with dissolved oxygen sensors to detect and elucidate occurrences of nearshore BGA blooms as well asprecursor weather and water quality information for each bloom. This instrumentation was deployed at Sites D and E, located at Martin and Burtis Points in the northeast side of the lake (Fig. 1). At each site, a weather station (Ambient 1002-WS) recorded air temperature, rainfall, barometric pressure, humidity, light intensity, wind speed and direction at 30 minute intervals (Fig. 4). An *ONSET* HOBO U20L-04 data logger was placed inside 2" PVC pipe and strapped to a dock post at each site in ~1 m of water to record water temperature and lake level at 30 minute intervals. A Brinno TLC-200 automated camera was deployed on the weather station mast 3 to 4 m above the lake's surface to collect images of the

[4] http://fli-data.hws.edu/buoy/owasco/

lake's surface every 10 minutes from dawn to dusk. At this deployment height, the camera's 60° field of view collected 2 x 3 to 3.5 x 5 meter images of the lake's surface. The purpose was to image nearshore water quality, i.e., clear, turbid water, and hopefully nearshore BGA blooms. Finally, prototype FLI Sensor Nodes were deployed at each site to independently record water temperature and dissolved oxygen. Each site was visited bi-monthly to measure water temperature (by handheld meter), dissolved oxygen concentrations (by titration), atmospheric data (Kestral 5000), and swap SD memory cards in the camera for image analysis in the laboratory. Funds from Seneca Lake Pure Waters Association underwritten by the Tripp Foundation, supported a similar dockside effort at eight sites around Seneca Lake as well.

Fig. 4. A weather station (upper white instrument), automatic camera (green box) attached to a dock (left), and the FLI Sensor Node (grey box) with solar panel deployed in the field (right). The Node's sensors were tied to the dock leg.

Laboratory Analyses: Plankton enumerations identified over 100 individual algae (colonies counted as an individual) to genus (and typically species) level under a microscope using appropriate taxonomic keys and reported as date averaged relative percentages. Laboratory analyses for nutrient, chlorophyll-a, and total suspended sediment concentrations followed standard limnological techniques[5]. An aliquot of each water sample was analyzed for total phosphorus using a colorimetric analysis by spectrophotometer after digestion of any organic-rich particles in hot (100ºC) persulfate for 1 hour. Additional sample water was filtered immediately on our return from the field through both a Gelman HA 0.45 μm membrane filter and a pre-weighed, Millipore, 0.45 μm glass-fiber filter. The membrane filter was kept frozen until chlorophyll-a analysis by spectrophotometer after pigment extraction in 90% acetone and its filtrate was stored at 4°C until soluble reactive phosphate (SRP), nitrate and soluble reactive silica colorimetric analyses by spectrophotometer. The glass-fiber filter and residue were dried at 80°C for at least 24 hours. The weight gain and filtered water volume determined the total suspended sediment concentration. Multiple reagent blanks and standards were run with each

[5] Wetzel and Likens, 2000. Limnological Analyses, 3rd Edition. Springer-Verlag, New York.

analysis for a continuous check on data quality. The nitrate triplicate blanks and standards occasionally yielded concerns. Laboratory precision was determined by periodic replicate analyses resulting in the following mean standard deviations: TSS ±0.2 mg/L, TP & SRP ±0.1 μg/L, Si ±5 μg/L, and NO_3 ±0.1 mg/L.

Pilot Sediment Nutrient Flux Experiments:

Field Methods: Preliminary flux experiments at sites C and D were conducted to better understand the cycling of nutrients to and from sediments. These experiments are based on recently completed work on Honeoye Lake where FLI has been working in collaboration with researchers from Wright State University in OH to examine phosphorus and nitrogen species released from sediment cores to overlying water. For the Owasco Lake experiments, water samples and four intact sediment cores with associated overlying water were collected from site C and D in October. Water samples for nutrient (SRP, NO_2-NO_3, NH_4) analysis were filtered in the field through sample-rinsed, 0.22-μm nylon syringe filters. Samples were then placed on ice in the field, and were frozen upon return to the laboratory. Cores (~5-8 cm of depth) with overlying water were collected by hand using core tubes (6.75 cm diameter) in the nearshore region of C and D in a water depth of ~ 1 m using the methods of Gardner and McCarthy, 2009[6]. Approximately 20-L of water for the incubations was also collected in pre-rinsed, ~20-L cubitainers® from each core site.

Laboratory Sediment Incubations and Lab Analysis: In the laboratory, continuous-flow incubations of intact sediment cores were started within ~ 2 hrs of field collection. For each site, two cores were incubated with just sediment and two other cores were incubated with aquatic macrophytes (~15 g wet weight) that were present at each site. 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. Each core received aerated site water from the cubitainer through polyetheretherketone (PEEK) tubing connected to the inflow and outflow ports of a peristaltic pump at a flow rate of ~1.15 mL of site water per minute[7] (McCarthy et al. 2016). Inflow and outflow water was sampled at 24 hour intervals for three days. The daily water samples were immediately filtered for nutrient analysis as described above. 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.

BLUE-GREEN ALGAE AND HARMFUL ALGAL BLOOMS BACKGROUND

Owasco Lake has experienced significant surface-water, nearshore, blue-green algae (BGA) blooms in the past few years (Fig. 5). BGA are unique in that these phytoplankton contain gas vacuoles that enable them to regulate their water depth to take advantage of optimum levels of light and nutrients. The depth regulation is simple. Photosynthesis of dense carbohydrates force BGA to sink, typically by mid-day or late afternoon. Respiration of their carbohydrates, creates

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[6] 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.

[7] 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.

carbon dioxide gas which fills the vacuoles, and allows the BGA to buoyantly rise, typically by mid-morning.

Many species of BGA exist, each trying to gain an ecological advantage over the others. For example, some species of *Dolichospermum* (*Anabaena)* can "fix" atmosphere nitrogen (N_2) for their photosynthetic source of nitrogen. Whereas most other forms of BGA 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 BGA have an ecological edge in nitrogen-limited lakes like Honeoye. Nitrogen limitation should not be a concern in Owasco and the other phosphorus-limited Finger Lakes, especially in the open water. However, a better understanding of the phosphorous and nitrogen dynamics, especially the different types of nitrogen available in the water column and released from nearshore sediments require additional study. Both *Dolichospermum* (*Anabaena)* and *Microcystis* were detected in Owasco Lake. Typically *Dolichospermum* (*Anabaena)* preceded *Microcystis* in a given field season.

BGA 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 BGA taxa synthesize toxins. BGA taxa that can make toxins do not synthesize toxins all the time. The environmental triggers to produce toxins are poorly understood. To complicate the situation, different toxins are synthesized by different BGA taxa, and each toxin, in sufficient concentrations, can impact different parts of the body, most notably, the skin, liver, nervous and/or gastrointestinal 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* (*Anabaena)*, and total microcystin is commonly used in New York State to assess BGA toxin status. Another common toxin group, anatoxins, impact the nervous system and can be synthesized by *Dolichospermum* (*Anabaena)* and other BGA genera but not *Microcystis* species.

The impact of these toxins at low concentrations on human health is still 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[8]. 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[9]. The half-life, time interval for decomposition, of anatoxin is very short, less than 24 hours, which makes detection in the water column difficult. The NYSDEC defines a BGA bloom when the blue-green chlorophyll (phycocyanin) concentration exceeds 25 μg/L, and a bloom is reclassified as a harmful algal bloom or a bloom with high toxins when microcystin concentrations exceed 20 μg/L in nearshore areas and 10 μg/L in offshore areas.

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

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

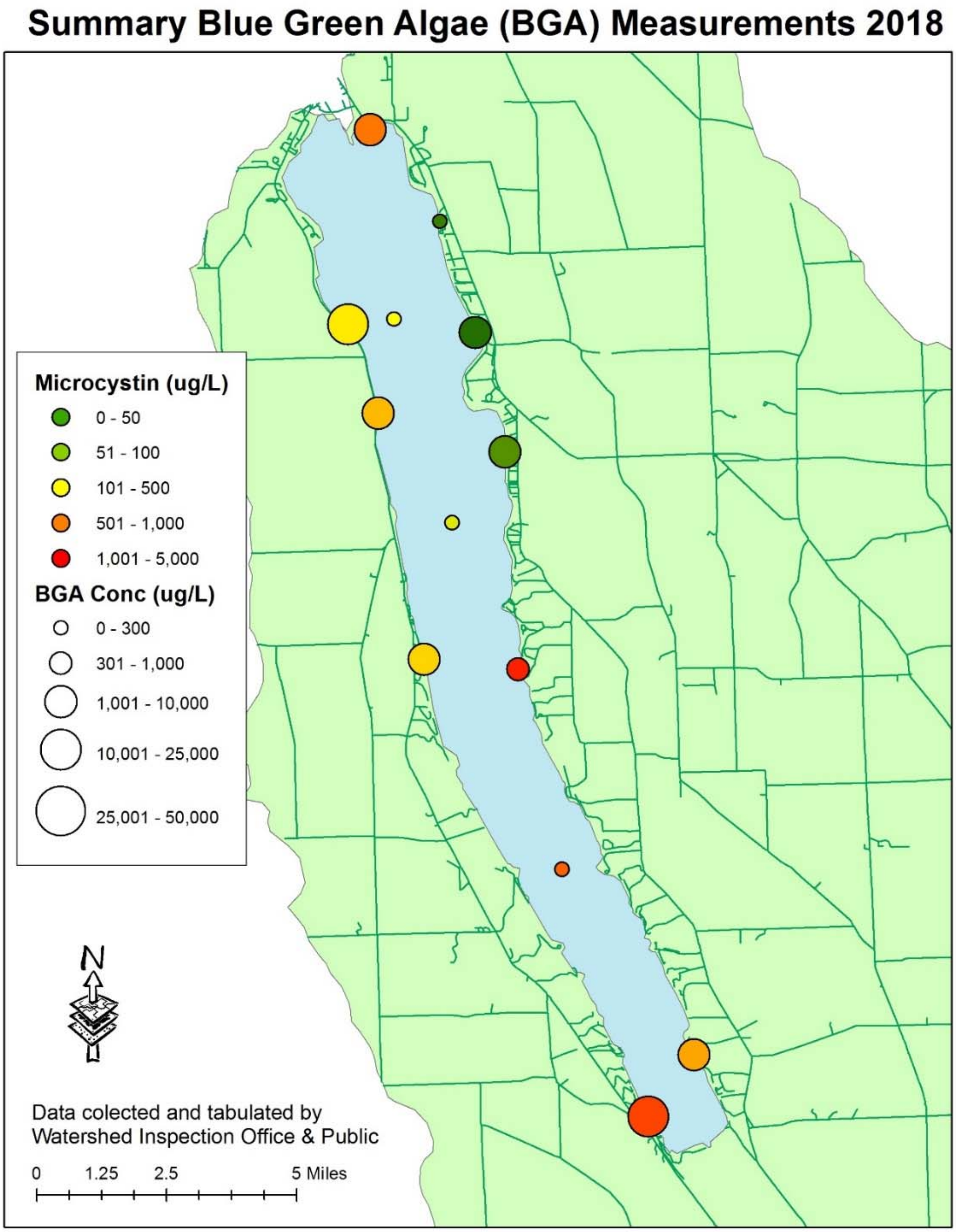

Fig. 5. Map of the 2018 BGA bloom and microcystin concentrations detected by the HABs Shoreline Surveillance volunteers (permission by the DEC). A greater percentage of blooms were detected along the western shoreline in 2018 than earlier years.

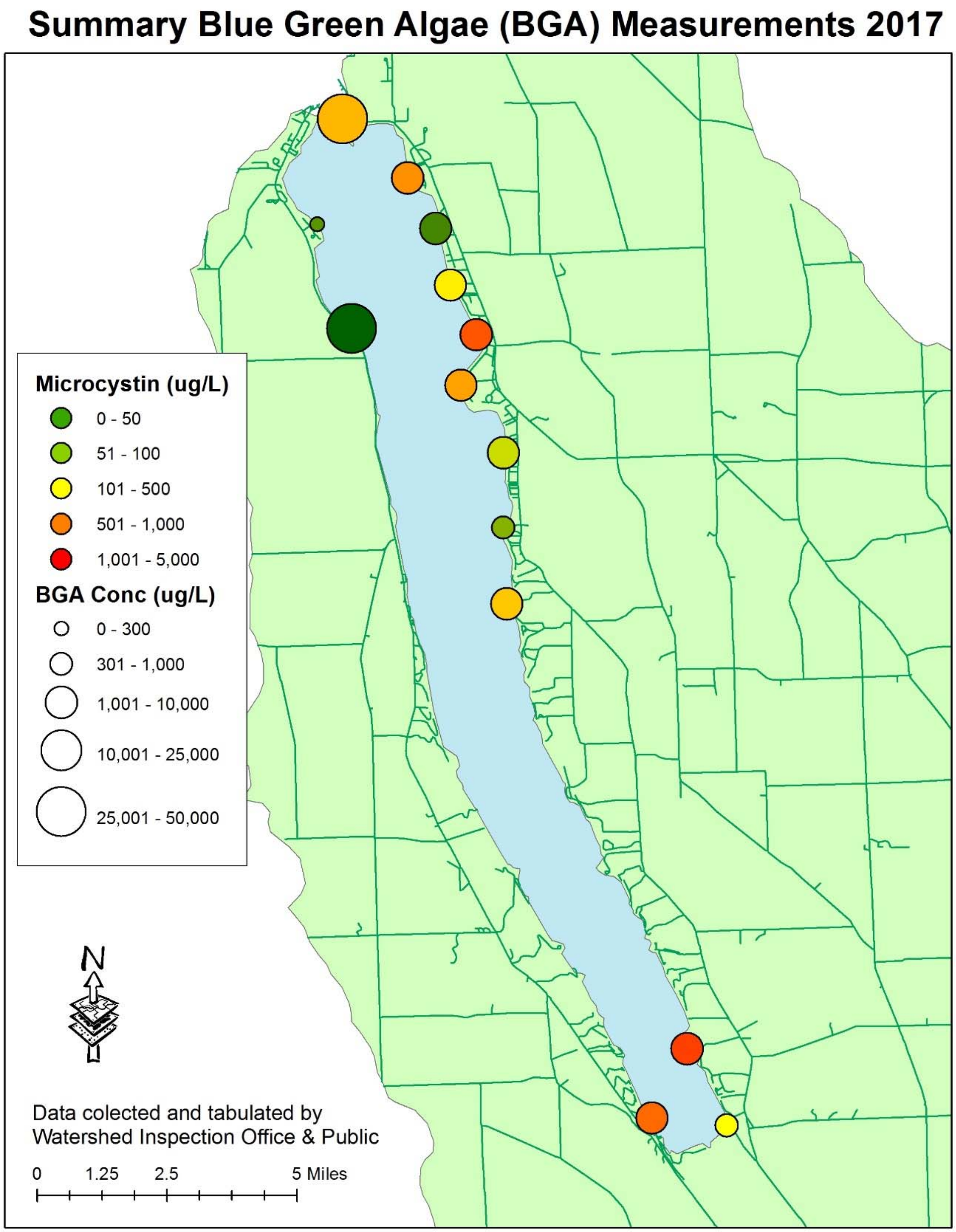

Fig. 5 (cont). Map of the 2017 BGA bloom and microcystin concentrations detected by the HABs Shoreline Surveillance volunteers (permission by DEC).

Harmful algal blooms are not unique to Owasco Lake. In 2017, 2018 and 2019, major BGA blooms were confirmed in almost, if not all of the Finger Lakes (Fig. 6). Over 160 lakes in New York State had confirmed BGA blooms in 2018 out of the 7,849 lakes in the state (all identified lakes and ponds with or without monitoring programs, Rebecca Gorney, DEC, pers. comm.). The 2019 NYS HABs concentration and toxin data has yet to be released by the DEC.

In Owasco Lake, the number of DEC confirmed blooms increased as follows: one in 2012 (9/6 – 9/27), two in 2013 (8/25 – 10/3), seven in 2014 (8/22 – 10/12), nineteen in 2015 (7/10 – 10/16), twenty-eight in 2016 (7/29 – 10/14), then declined to twenty-three in 2017 (7/21 – 10/20) and eleven in 2018 (8/6 – 9/10, Fig. 6). The time interval (in brackets) is the length of time DEC listed the lake on its notification web site. The nearshore blooms were commonly detected along the northern and northeastern margins of the lake. The distribution spread to the western shoreline in 2018 (Fig. 5). Caution is warranted because the BGA data location and concentration data may be biased by sampling protocols, and the intensity, diligence and number of people looking for blooms.

Notwithstanding, the past six years have seen increasingly larger concentrations of BGAs and their toxins. Reported BGA concentrations in Owasco Lake ranged from 0 to 1,100 µg/L and averaged 165 µg/L in 2014, from 2 to 4,500 µg/L and averaged 820 µg/L in 2015, from 60 to 16,800 µg/L and averaged 3,150 µg/L in 2016, from 297 to 45,463 µg/L and averaged 4,910 µg/L in 2017 and from 300 to 14,063 and averaged 4,958 µg/L in 2018 (Fig. 6).

Reported toxin concentrations ranged from 0 to 75 µg/L in 2014, 1 to 860 µg/L in 2015, 0 to 1,800 µg/L in 2016, from 55 to 1,704 µg/L in 2017 and from 0 to 1,300 µg/L in 2018. On a number of dates in 2019 when blooms were noted in the lake, toxins were measured on raw and finished water provided by municipalities by the Cayuga County Department of Health. Only one toxin result at 0.81 µg/L was above the EPA's drinking water threshold in the Auburn raw water on 9/26, and one at 0.186 µg/L in the Town of Owasco finished drinking water in 2019[10]. None of the tested finished drinking water samples in 2019 were above the drinking water threshold of 0.3 µg/L for the most vulnerable populations. Both facilities draw water from Owasco Lake and collectively distribute water to ~45,000 residents. Despite numerous HAB events in the lake, the recently installed upgrades and protocols to remove BGA toxins from municipal water supplies appear to be working.

Lakeshore residents with private water systems should use bottled water during BGA outbreaks along their shoreline[11], because their private systems are challenged to remove BGAs from the water without busting the cell walls. Cell wall integrity is critical because once they are compromised, the toxins can be released to the water, and more easily impact human health. The watershed should seriously consider extending public water around the lake to decrease the potential health risks from drinking lake water.

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[10] https://www.cayugacounty.us/1519/2019-Drinking-Water-Sampling-Data

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

Fig. 6. Annual mean (±1σ) BGA (left top) and toxin (right top) concentrations and the number of conformed blooms (bottom left) reported in Owasco Lake (HABs Shoreline Surveillance volunteers and the Owasco Lake Watershed Inspector's office). The number of Finger Lakes with BGA blooms since 2012 (bottom right, by permission DEC). The NYS-DEC has yet to release the 2019 HABs data.

NEARSHORE WATER QUALITY RESULTS & DISCUSSION

CTD: The nearshore sites revealed similar water temperatures on any given date as the surface water (upper 5m) mean temperature at the offshore sites (Fig. 7). The lake floor at the nearshore sites was always within the epilimnion (warm surface water) of the lake. The spatial similarity in surface temperatures across the lake on any given date was confirmed by the nearshore HOBO data loggers (see Nearshore Temperature section).

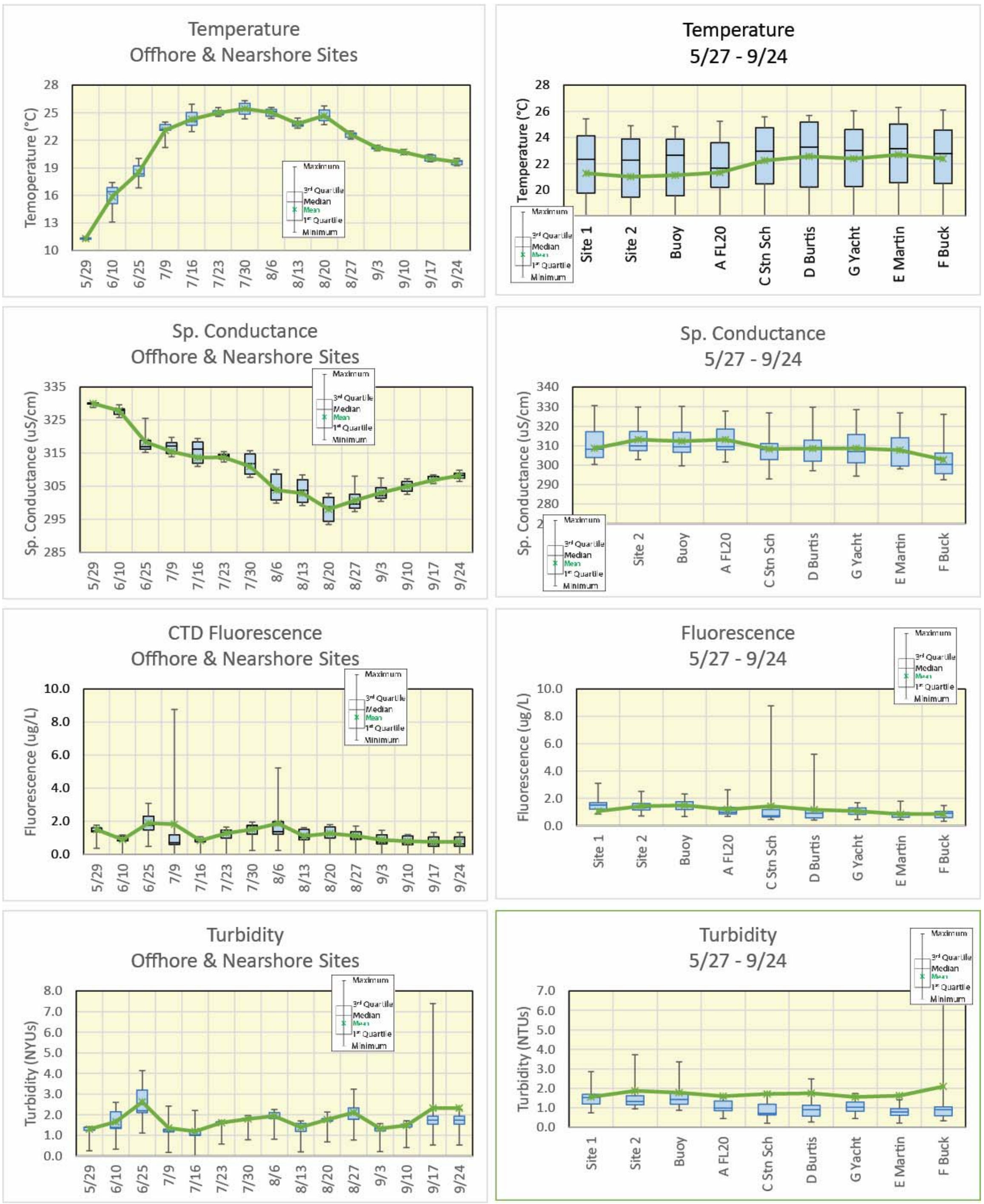


Fig. 7. Nearshore to offshore temporal (left) and spatial (right) comparison of 2019 CTD data.

The nearshore sites revealed similar specific conductance data on any given date as the surface water (upper 5m) mean specific conductance at the offshore sites (Fig. 7). Photosynthetically available radiation (PAR) was also similar across the lake (not shown). At the lake floor, light levels were sufficient (significantly above 1% surface light intensities) to support algal or attached (macrophyte) plant growth at every nearshore site.

The nearshore sites revealed similar algae concentrations (CTD fluorescence) as the surface water (< 10m) mean fluorescence at the offshore sites (Fig. 7). The smaller nearshore algal concentrations may reflect nearshore grazing pressures by zebra and quagga mussels in shallow water areas, and/or an artifact of using a 10 m, surface-water average of the offshore data. The 10 m interval occasionally included larger values at depth in the water column as the offshore algal concentrations peak between 5 and 15 m below the lake's surface. Two nearshore sites, C & D, occasionally experienced much larger algal concentrations than elsewhere in the lake as indicated by larger positive whiskers on the box and whisker (B&W) plots. These excursions were related to shoreline blooms.

Unlike 2017, the 2019 turbidity CTD data revealed uniform or nearly uniform turbidities across all sites (Fig. 7). Survey dates in 2019 did not coincide with strong onshore winds and waves and/or rain events that would have stirred up the lake floor sediments and/or introduced runoff turbidity to the nearshore locations as it did in 2017. Like 2018, 2019 turbidity data were smaller than those detected in 2017 as well. Turbidity was the only CTD parameter to reveal a significant limnological change in 2017.

bbe FluoroProbe Profiles: The bbe FluoroProbe surface water, grab sample data revealed the dominance of green algae, diatoms with lesser amounts of cryptophytes and blue-green algae throughout the lake (Fig. 8). Mean epilimnetic total fluorescence concentrations exceeded 10 μg/L (mesotrophic/eutrophic threshold) at one or more sites on four of the thirteen surveys of the lake. BGA concentrations were larger on 7/30 and again later in the summer 8/20, 8/27 and 9/3, with no one site or groups of sites consistently revealing more BGA. BGA concentrations ranged from 0 to 7.6 μg/L at the nearshore sites, and were generally low, only exceeding 2 μg/L in five nearshore samples. On 7/30, BGA were also detected by the automated cameras at the dock sites but this commonality was not detected on the other dates. This discrepancy highlights the shoreline hugging and localized distribution of the majority of the BGA blooms, and the critical need to better understand the limnology of the shoreline areas.

Secchi disk depths, total phosphorus, nitrate, and chlorophyll-a data at each nearshore site, and mean data from the offshore sites data were typically uniform across the lake (Fig. 9a). Some temporal variability in the limnological parameters was noted through the 2019 field season but consistent temporal trends over the field season were not observed (Fig. 9b). Total phosphorus peaked in mid-July and early September. The soluble reactive phosphorus peaked in early August.

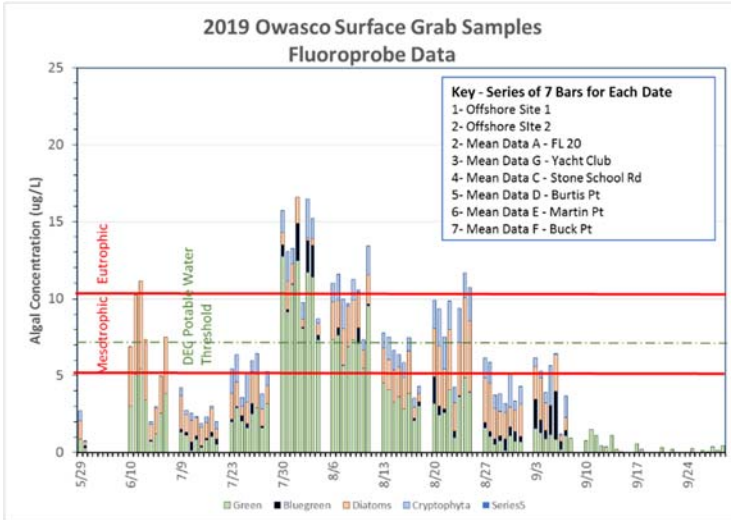


Fig. 8. bbe FluoroProbe grab sample data from each site (mean surface concentrations from Sites 1&2, and nearshore sites A, C-G) on each survey date. The dock surveys started on 6/10.

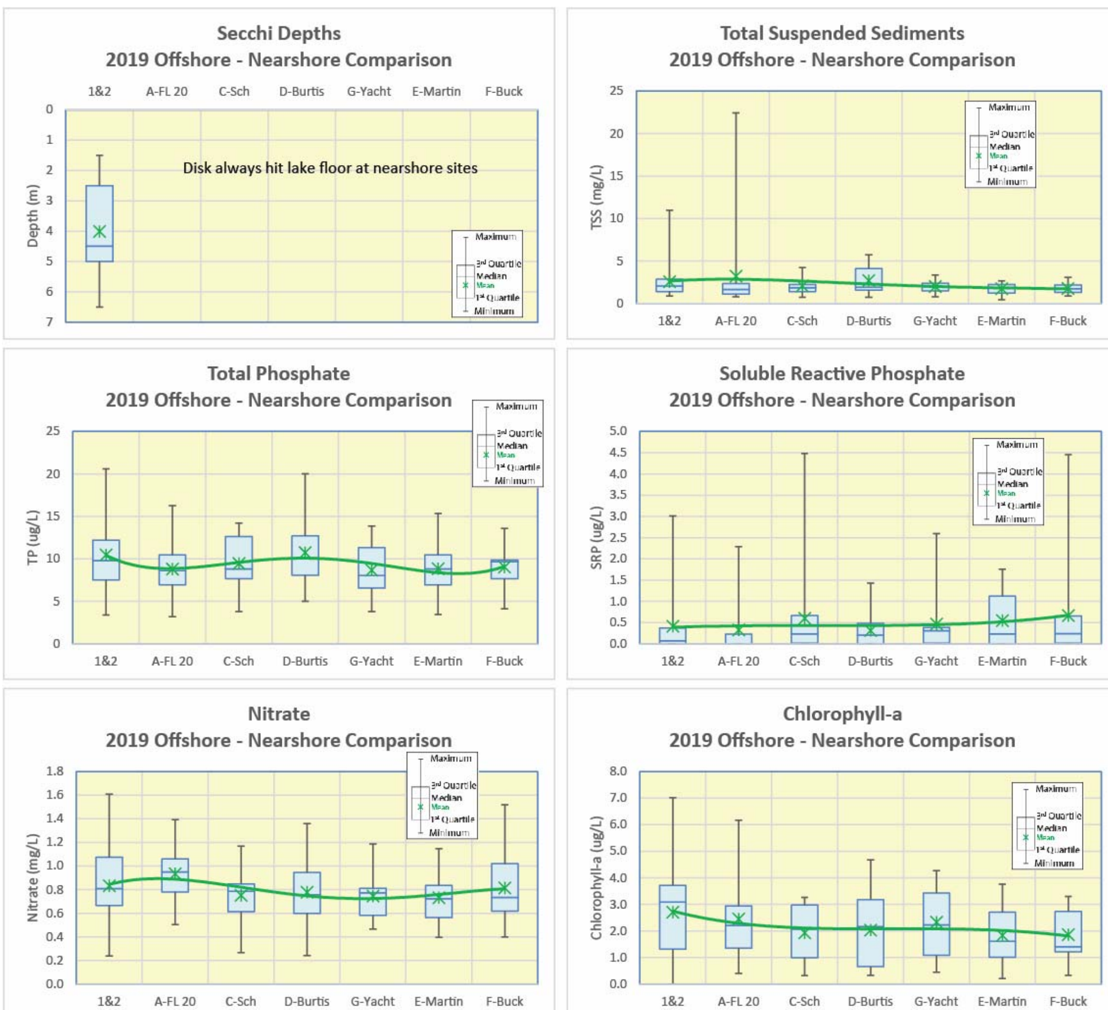


Fig. 9a. Nearshore to offshore spatial comparison of the limnological data.

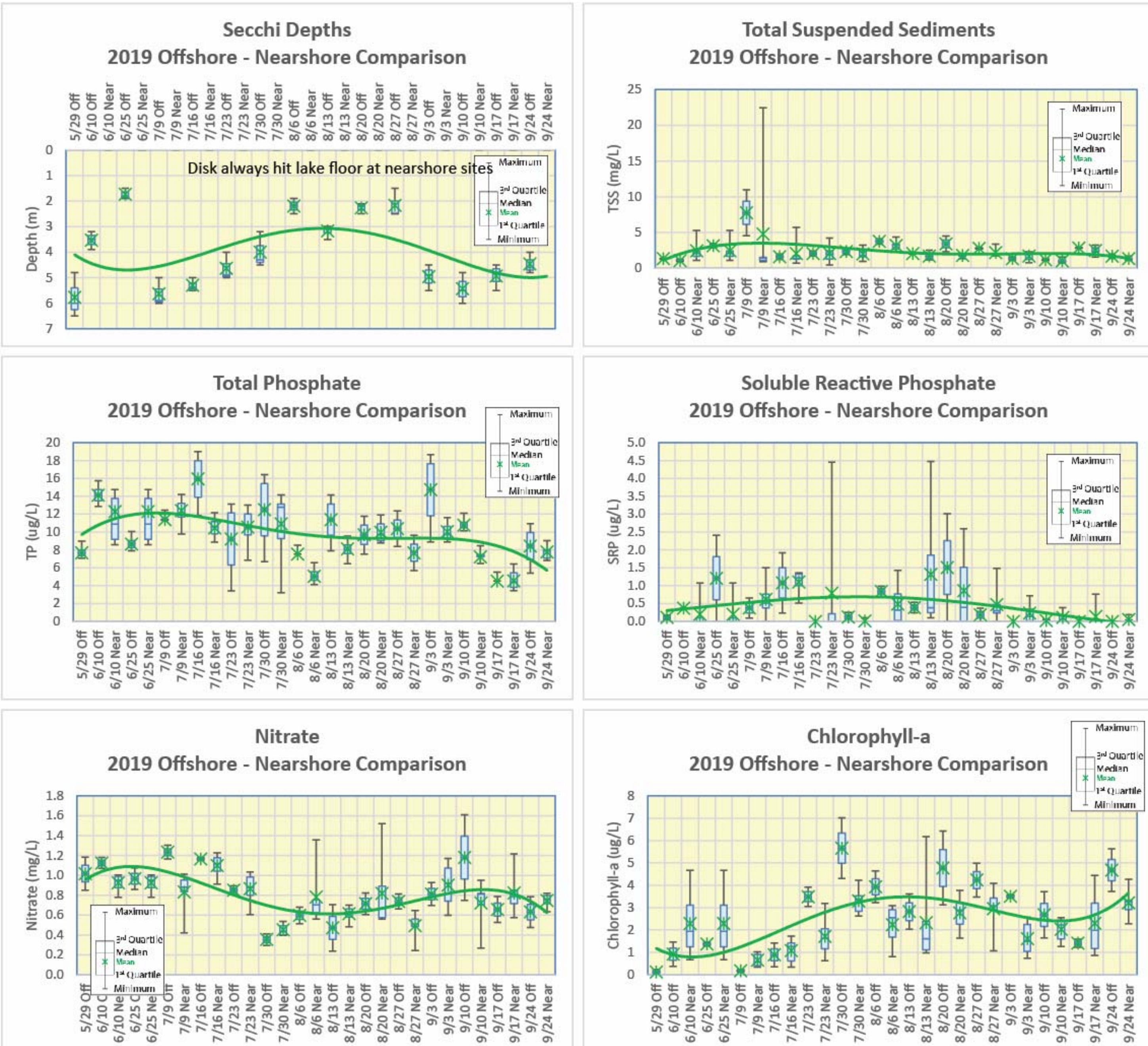


Fig. 9b. Nearshore to offshore site temporal comparison of the limnological data.

Plankton Data: The phytoplankton (algal) species in Owasco Lake during 2019 were dominated by diatoms, primarily *Fragilaria* and *Asterionella*, with smaller numbers of *Diatoma,* and other species (Fig. 10). Unlike 2018, the distribution was similar to earlier years. The reason for the mid-summer *Synedra* dominance in 2018 is unclear at this time and it has never dominated the algal population in the past. *Dolichospermum* and *Microcystis* dominated the plankton assemblages in early September and were consistently detected throughout the field season. Besides blue-greens, other phytoplankton species included a few *Dinobryon* and *Coalcium*. Zooplankton species were dominated by rotifers, namely *Keratella,* with some copepods and cladocerans also present. Zebra and quagga mussel larvae were also detected in the plankton tows. The September nearshore plankton tows have yet to be counted.

Zebra & Quagga Mussels: Site C had the lowest number of both zebra and quagga mussels, with an average of 445 zebras/quadrat and 157 quaggas/quadrat (Fig. 11). Site D had the highest number of zebra mussels, with 3,247/quadrat, while Site G had the highest number of quagga mussels with 1807/quadrat. When macrophytes are excluded from Site G, the difference between the number of zebra mussels and quagga mussels increases from 975 to 1000. Zebra mussels had significantly higher numbers per gram of plant for every species of plant (Fig. 12). The lowest rate of zebra attachment on any species, 1.4 mussels per gram of *Chara*, exceeded the highest rate of quaggas on any species, 1.3 mussels per gram of slender pondweed. Eelgrass had the similar rates of zebra and quagga attachment, at 0.4 and 0.1 mussels per gram respectively, and the lowest mussel attachment rates.

The number of mussels/quadrat was negatively related to mussel size, with the exception of quagga mussels at Site G (Fig. 11). Excluding Site G, small mussels were most common, making up 55-65% of samples, medium mussels followed with 32-45%, and large mussels made up 0-2%. Site G had 19% small, 53% medium, and 28% large quagga mussels. Among most macrophytes species, the majority of the mussels were small (Fig. 12). Small mussels made up 55-92% of samples, while medium mussels were 8-45%, and large mussels were 0-2%. The six exceptions included *Chara* with 49% small, 49% medium, and 2% large quaggas; eelgrass with 48% small, 46% medium, and 4% large quaggas; milfoil with 7% small, 93% medium, and 0% large quaggas; southern naiad with 5% small, 95% medium, and 0% large zebras and 18% small, 74% medium, and 8% large quaggas; and starry stonewort with 47% small, 53% medium, and 0% large zebras.

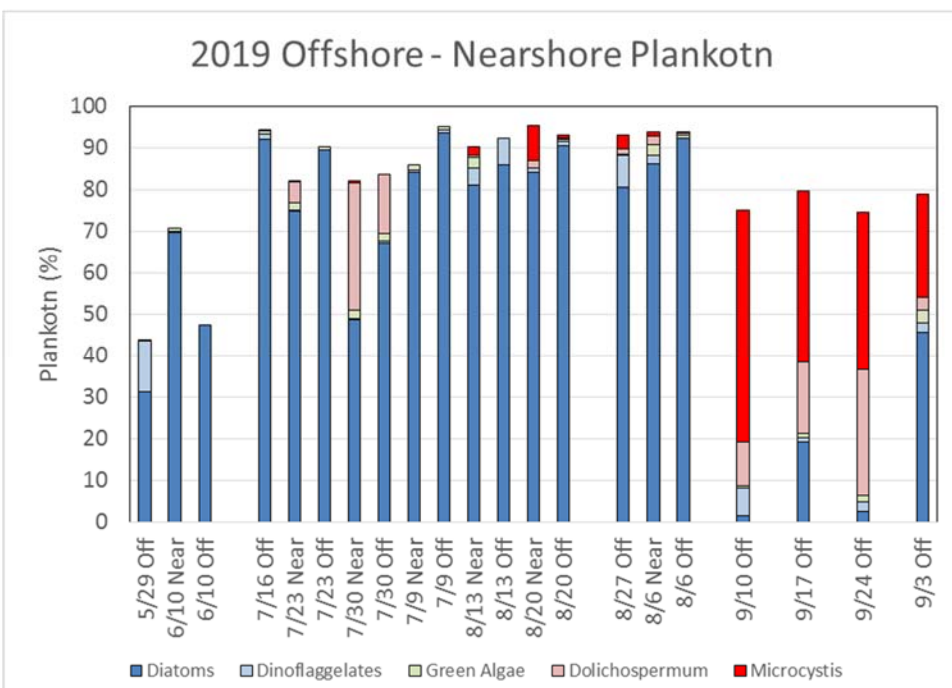


Fig. 10. Offshore to nearshore comparison of the plankton relative percentage by dominant groups.

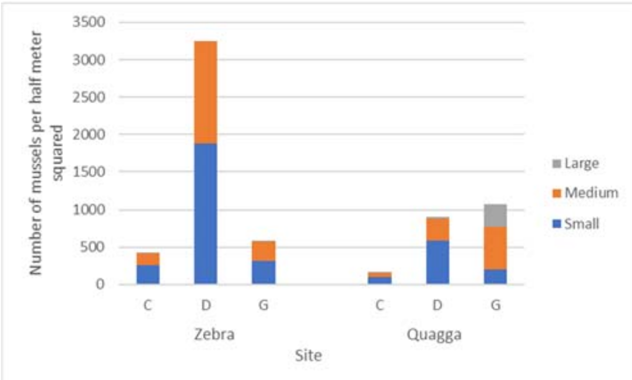


Fig. 11. Average number of mussels per quadrat ($0.5m^2$) by site, mussel species and mussel size.

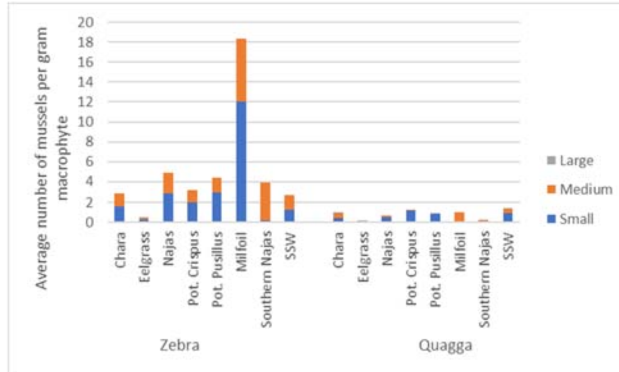


Fig. 12. Average number of mussels per gram of macrophyte by plant and mussel species and mussel size.

Macrophyte Data: The volume of macrophytes recovered by each rake toss date peaked at 7,500 mL at Site G in August. Site G also had the highest average macrophyte volume at 2,735 mL. Sites D, E, F, C, and A followed at 1,957 mL, 1,754mL, 1636mL, 1,279mL, and 864mL, respectively. The largest volumes were detected in late August and early September with Sites D, E, F and G revealing the largest volumes and largest variability by date. *Chara* was the most frequent macrophyte, occurring no less than seven times at any given site (Fig. 13). The exception was Site A, which never had it. Starry stonewort (*Nitellopsis obtusa*) was the second most common macrophyte, occurring between five to seven times at any site excluding A, where it was only found twice. The macrophyte substrates had more zebras than quaggas, whereas the rocky substrates had more quaggas than zebras. Perhaps the zebra mussel byssal threads are better suited to attaching to macrophytes than quagga byssal threads. Alternatively, the smaller zebra mussel might be better suited to attaching to the thin stems of the macrophytes. Plant species and surface area also influenced mussel density. Milfoil had a large amount of mussels per gram while eelgrass only a very few. The reason for the difference is not clearly understood. A few words of caution are required. Sites A and G had steep bathymetric drop offs that influenced the results. A rake toss to deeper water recovered significantly less material than shallower water. The limited sample size for the quadrat surveys, i.e., only three quadrats per site at only three sites on three dates, also dictates tentative relationships at this time and limits estimation of mussel biomass per site and thus extrapolation of these findings to the entire lake. It suggests that more sites should be surveyed in the future to confirm the relationships detected by this survey.

Zebra & quagga mussel concentrations and BGA concentrations did not correlate. Although Site D had both the highest average mussel and BGA concentrations, which would suggest selective predation, Site G revealed the next highest mussel concentration, but the lowest BGA concentration of the three sites. It suggests that selective filtration by dreissenids (mussels) does not exclusively control BGA populations in Owasco Lake. Other factors like nutrient concentrations, sunlight availability, and water temperature probably also play a role, a complexity that requires further examination.

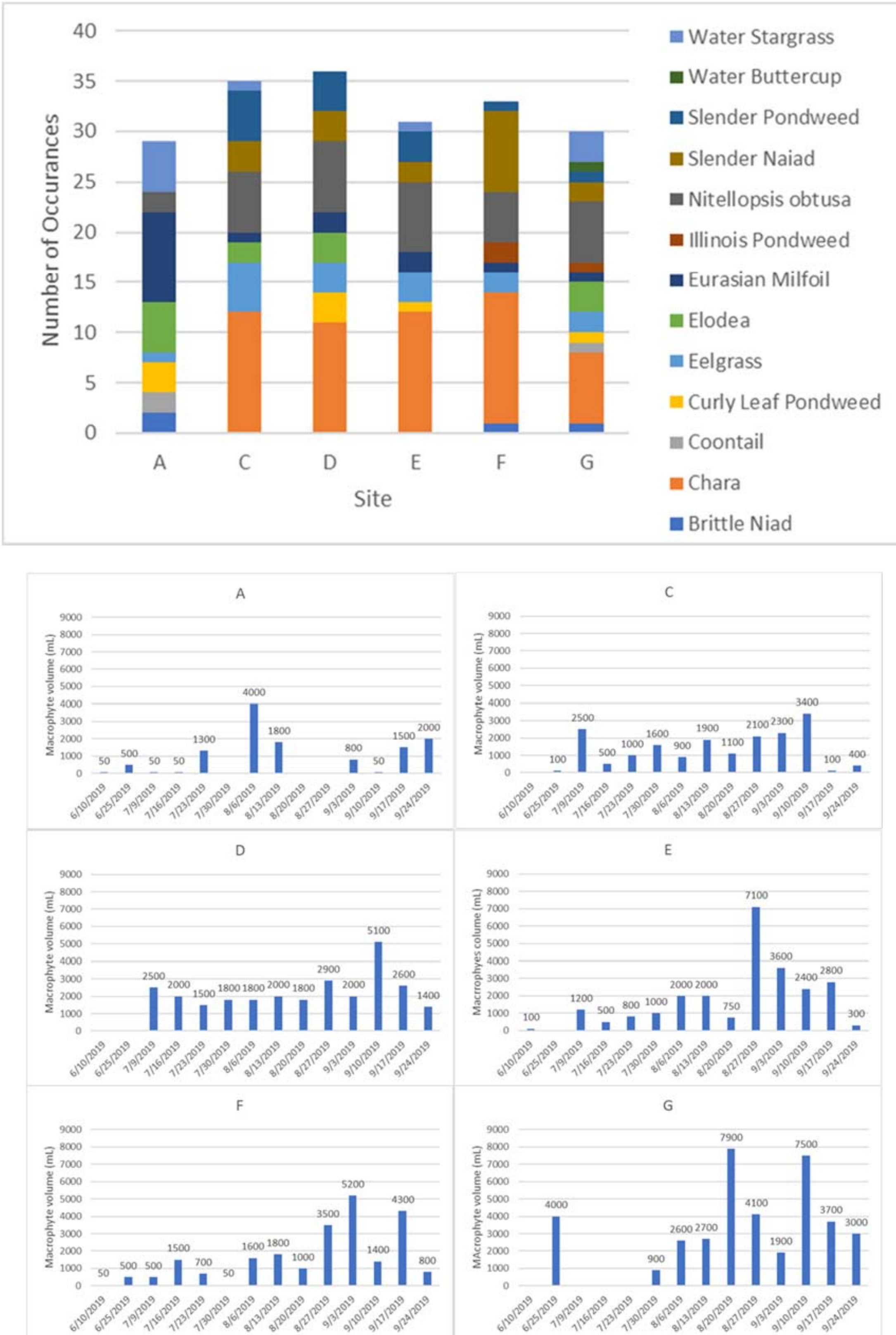


Fig. 13. Macrophyte volumes detected by rake tosses by survey site (above), and by time (below).

DRONE FLIGHTS

Unfortunately BGA blooms were not detected in the drone images during the specific site visits during 2019 (Fig. 14). Complete spectra (from 340 to 823 nm at ~0.5 nm intervals) of the upwelling and down-welling light were again collected at a number of offshore sites to find a better indicator in the drone images of open-water algal concentrations. The intent was to determine if the difference between upwelling and down-welling spectra could resolve algal concentrations. The 2019 results confirmed the earlier findings and revealed potential algal signatures in the near infrared portions of the light spectrum where plants emit the most light (wavelength of 750 nm). More work must be done next summer to improve these techniques, and we propose to continue our periodic drones flights and recovery of spectral signatures on more surveys to assess water quality in Owasco and neighboring lakes. Further, we plan to map the distribution and concentration of nearshore macrophytes, attached algae and blue-green algae blooms in the years ahead. More details can be found in the 2019 Cayuga County report referenced at the beginning of this report.

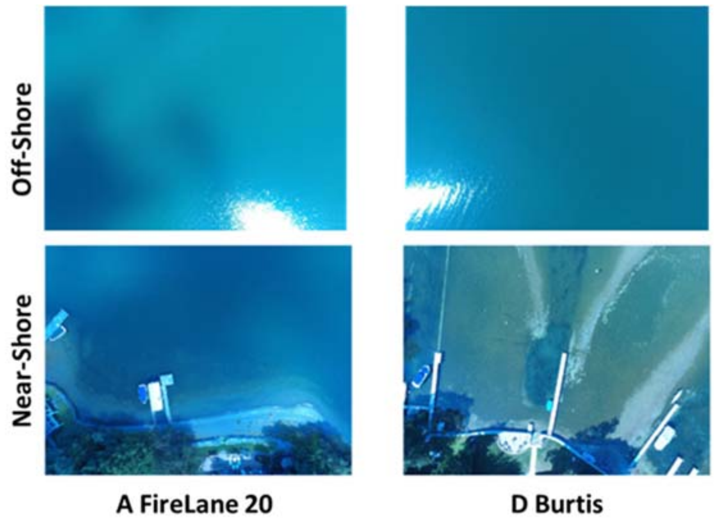
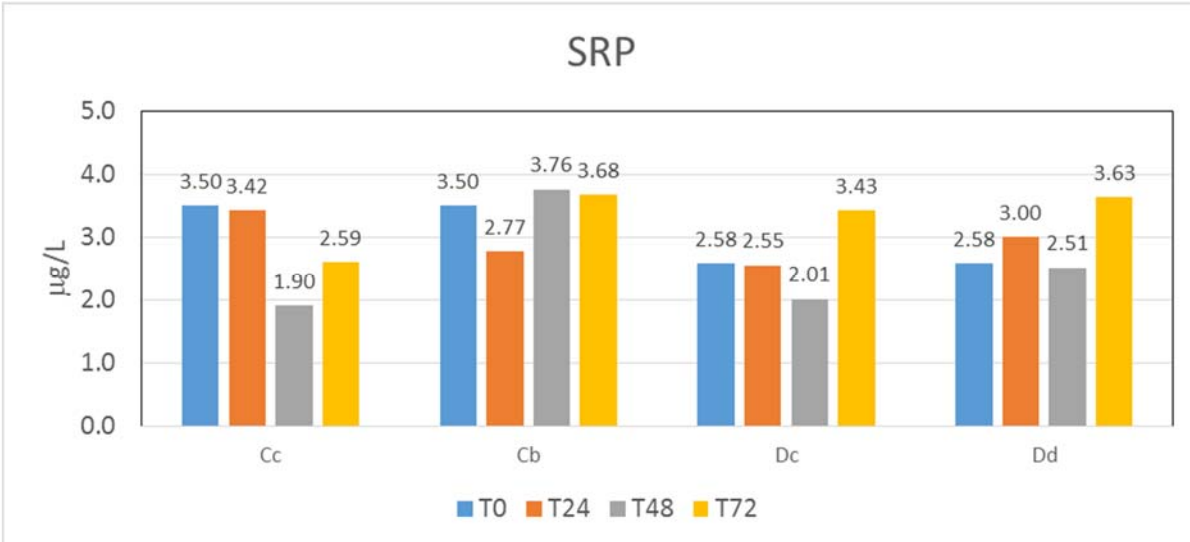
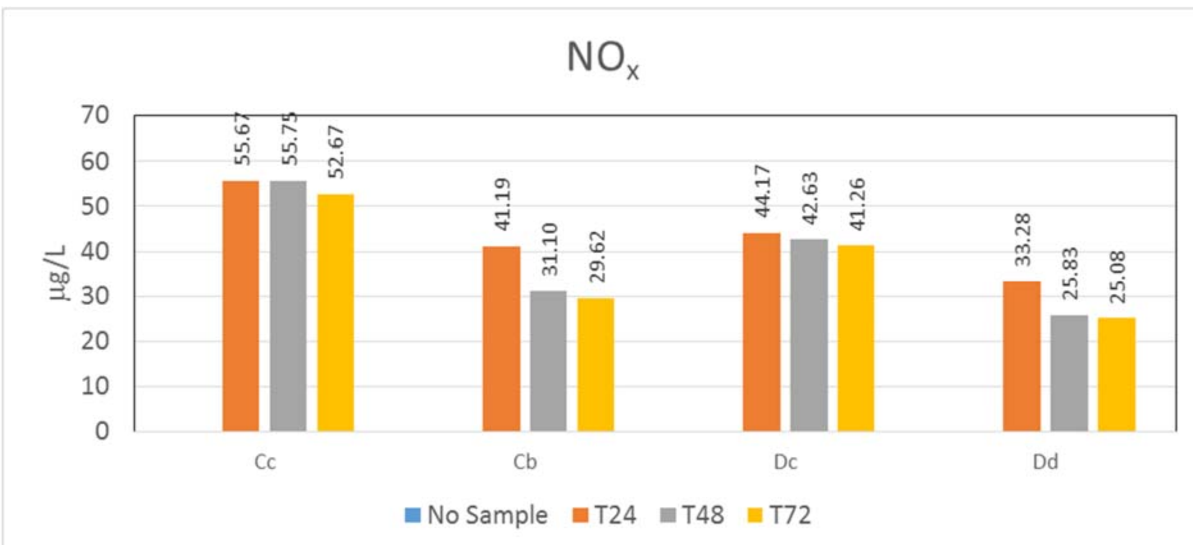


Fig. 14. Example nearshore and offshore drone images from Firelane 20 and Burtis Point.

SEDIMENT INCUBATION RESULTS:

Results from the 2019 sediment incubation studies showed that this approach can yield useful information for a better understanding of changes to nutrient concentrations in water overlying sediments (Fig. 15). In general, very little change was seen in the soluble reactive phosphorus concentrations over the incubation period of 72 hours and between sites and treatments. The presence of macrophytes may have kept the nutrients concentrations more constant relative to controls, but overall changes in concentrations were less than 1 µg/L from the control at the start of the experiment (T_0). Similarly, nitrite-nitrate (NO_x) concentrations did not increase during the incubations. Unfortunately the T_0 results are not available so it is difficult to assess differences from the beginning of the incubation. However, the samples with just sediment showed virtually no change in concentration over time from both sites. For the samples with sediments and macrophytes, the NO_x concentrations decreased. In contrast, ammonium (NH_4) concentrations increased during the incubations for the cores with just sediments. Sediment only cores from site C (Cc) showed increases each day of the incubation with a sevenfold increase in ammonium concentrations while site D (Dc) showed a threefold increase. The addition of macrophytes stimulated even higher ammonium concentrations for both sites. It has been shown that high concentrations of NH_4 (and/or urea) correspond to non-nitrogen fixing HABs, such as Microcystis. Further, cyanobacteria growth is higher with the addition of both phosphorus and nitrogen compared to either nutrient alone[12,13,14]. Our next step will be to quantify nitrogen transformation rates using isotopes to better understand the fate of nitrogen in aquatic systems, which in turn benefits management and modeling efforts focused on predicting the effects of reducing internal and external nutrient inputs.





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[12] Elser JJ, Bracken MES, Cleland EE, Gruner DS, Harpole WS, Hillebrand H, et al. 2007. Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial systems. *Ecology Letters* 10:1135-1142.

[13] Scott JT and MJ McCarthy. 2010. Nitrogen fixation may not balance the nitrogen pool in lakes over timescales relevant to eutrophication management. *Limnology and Oceanography* 55:1265-1270.

[14] Scott JT and MJ McCarthy. 2011. Nitrogen fixation has not offset declines in Lake 227 nitrogen loading and shows that nitrogen control deserves consideration in aquatic systems. *Limnology and Oceanography* 56:1548-1550.

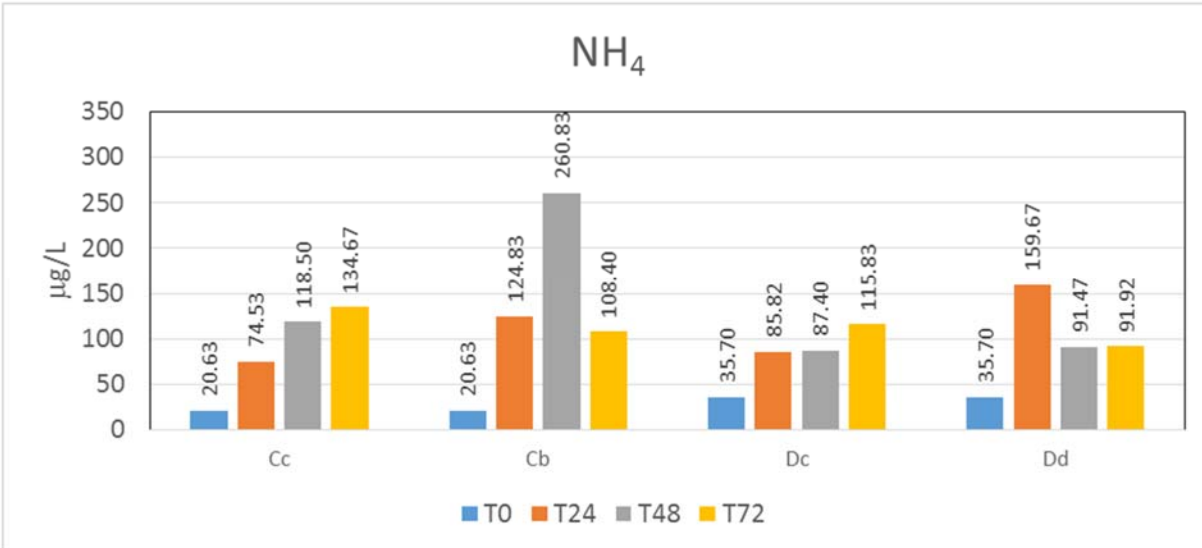


Fig. 15. Change in nutrient (SRP, NOx, NH_4) concentrations between water incubated with sediments collected sites C and D over 72 hours. Site C is on left. Cc is the average of nutrient concentrations measured in overlying water of two cores with just sediment, and Cb is the average of two cores with sediments and macrophytes. Site D is on the right. Dc is the average of nutrient concentrations in overlying water of two cores with just sediment, and Db is the average of two sediment cores with sediments and biota.

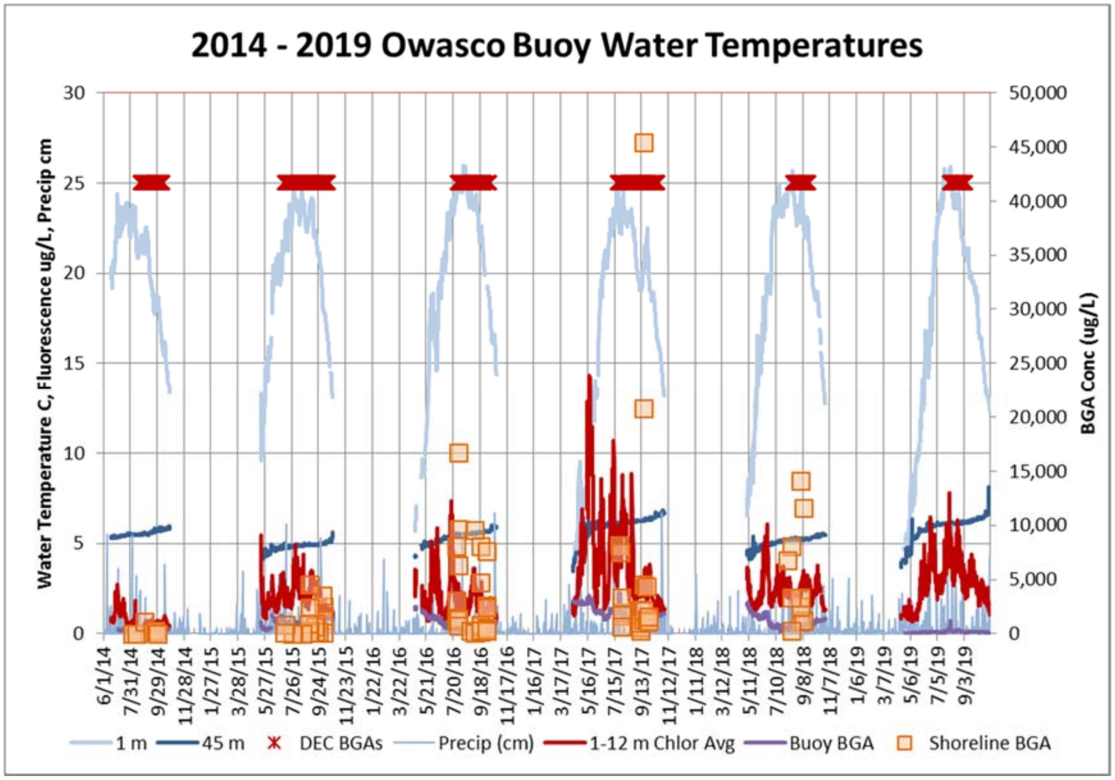
BUOY DATA

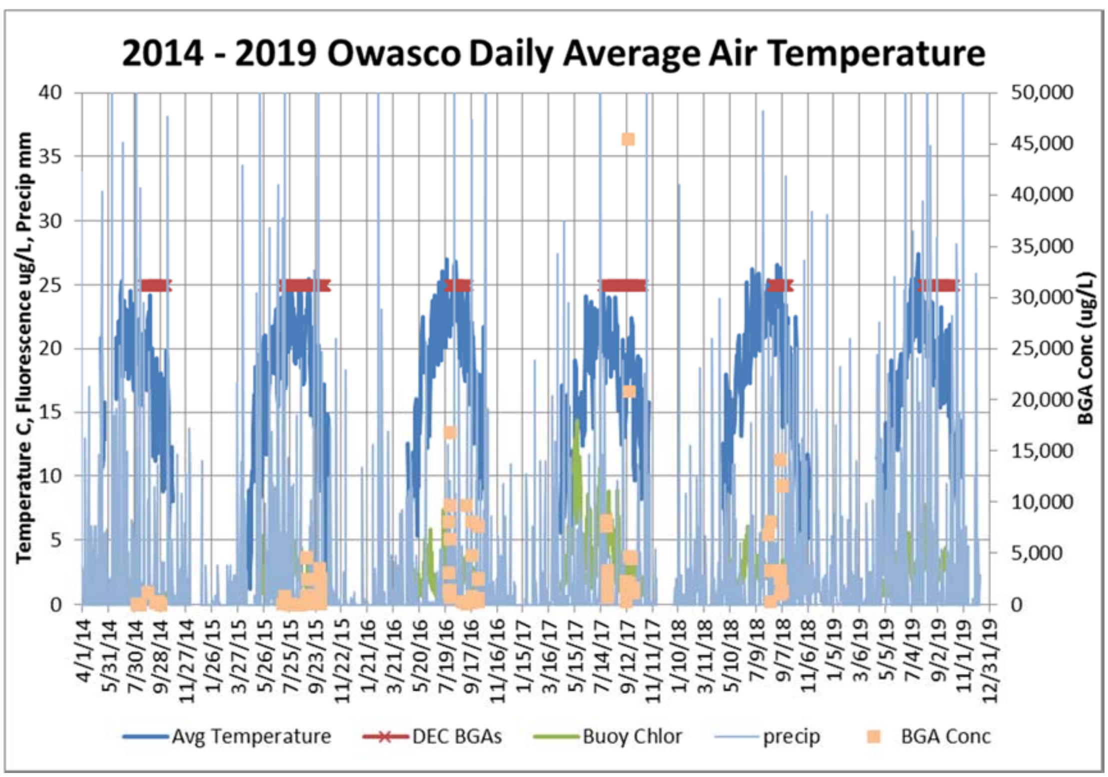
As outlined in the 2017 report, BGA blooms prefer the following conditions:

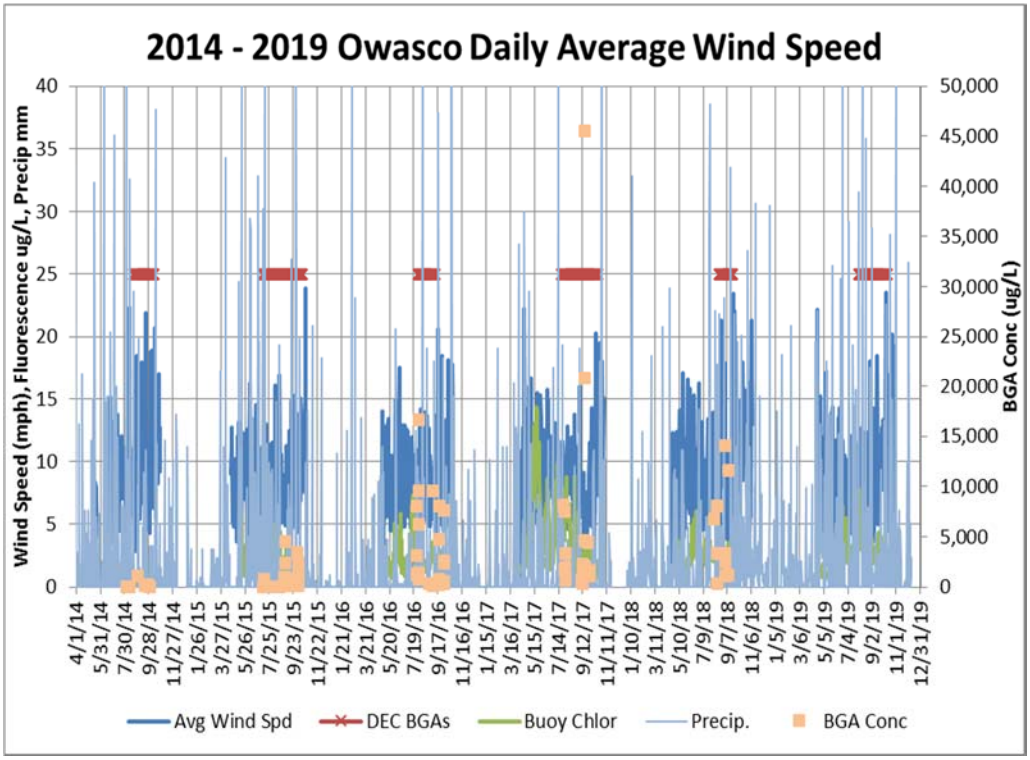
- warm water, temperatures between 15 to 30°C (60 and 80° F);
- elevated (eutrophic) concentrations of nutrients, especially waters rich in phosphorus, the limiting nutrient for many BGAs;
- light levels that are sufficient for photosynthesis and growth;
- lake stratification, as BGA buoyancy regulation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

However, predicting their occurrence remains a challenge due to the large number of BGA species and the diversity of their habitats. BGA blooms in the Finger Lakes are a larger challenge because most of these lakes are oligotrophic or mesotrophic systems, and not the nutrient-rich, eutrophic lakes where BGA blooms were more commonly detected a decade ago. The last six years of buoy data have shed some new light on the occurrence and development of BGA blooms in Owasco Lake (Fig. 16).

Buoy Total Algae and BGA Fluorescence: Minimal correlations were observed between the buoy fluorescence and nearshore BGA data (Fig. 16). The lack of a correlation is not disturbing because the buoy measures open water parameters, and the bulk of the BGA blooms were at shoreline locations, especially those with large concentrations. The buoy detected progressively larger algal concentrations and more frequent offshore algal blooms from 2014 through 2017. Smaller concentrations of algae were detected in 2018. The 2018 decline probably reflected the reduced nutrient loads from the watershed to the lake based on measured nutrient loads at Dutch Hollow Brook. The NYS-DEC has released the dates for the 2019 suspicious and confirmed blooms in Owasco Lake but not the concentration and location data.







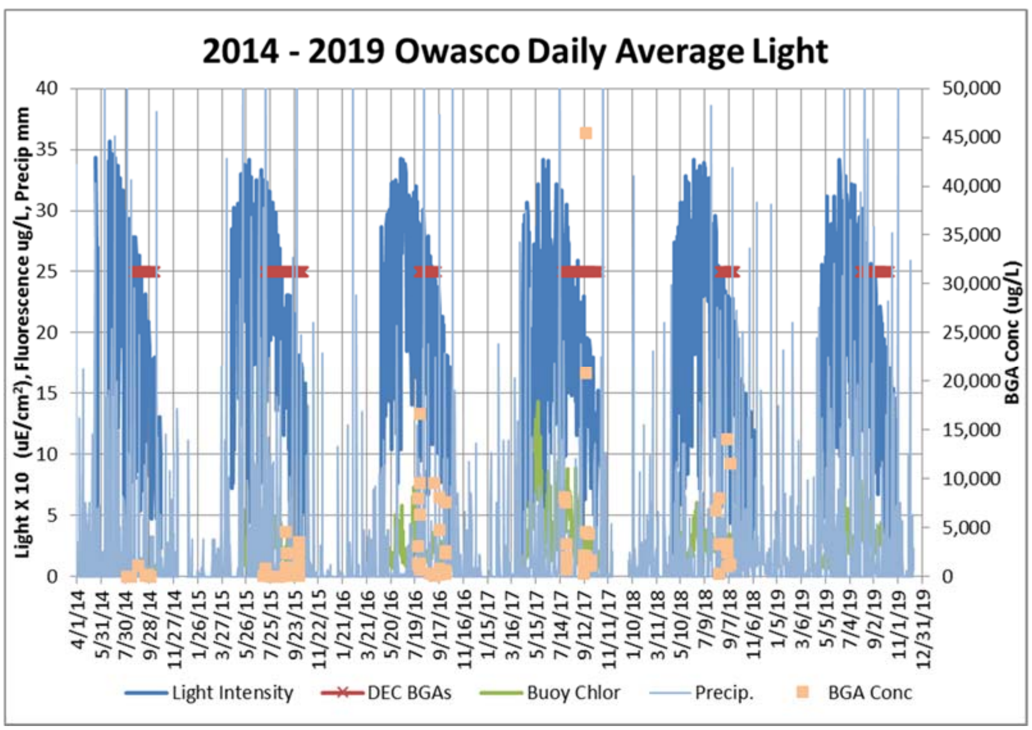


Fig. 16. Six years of water temperature, total and phycocyanin (BGA) fluorescence, and daily mean air temperature, wind speed and light intensity data. The weeks Owasco Lake was on DEC's notification web site, the measured concentration of shoreline BGA blooms and daily precipitation totals are also shown (1 FNU ≈ 1 ug/L). NYS-DEC has yet to release the 2019 HABs data, bloom sightings at Burtis and Martin Pts were used instead.

Buoy Lake Temperature: In all six years, shoreline BGA blooms occurred in warm water, 22 or 23°C (70 – 75°F, Fig. 16). However, in every year but 2015, blooms did not appear until a week or two after the warmest water temperature was observed, indicating that warm water by itself does not trigger bloom activity. The warm water promotes faster bacterial decomposition of the nearshore sediment organic matter. The persistent time lag between the warmest lake temperatures and the first blooms may reflect the time required for sufficient bacterial decomposition and nutrient release in the sediments. More rain fell in 2015 than the other years, and the correspondingly larger delivery of nutrients may have jumpstarted BGA blooms in 2015. BGA blooms were not detected after the surface water cooled below 15°C (60°F).

Buoy Air Temperature: Like water temperatures, the shoreline BGA blooms commonly occurred a few weeks after peak (23 to 24°C, 70-75°F) air temperatures (Fig. 16). Colder air temperatures in the fall, i.e., 10°C (50°F), coincided with no additional BGA 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 are linked to and ultimately forced by changes in solar insolation.

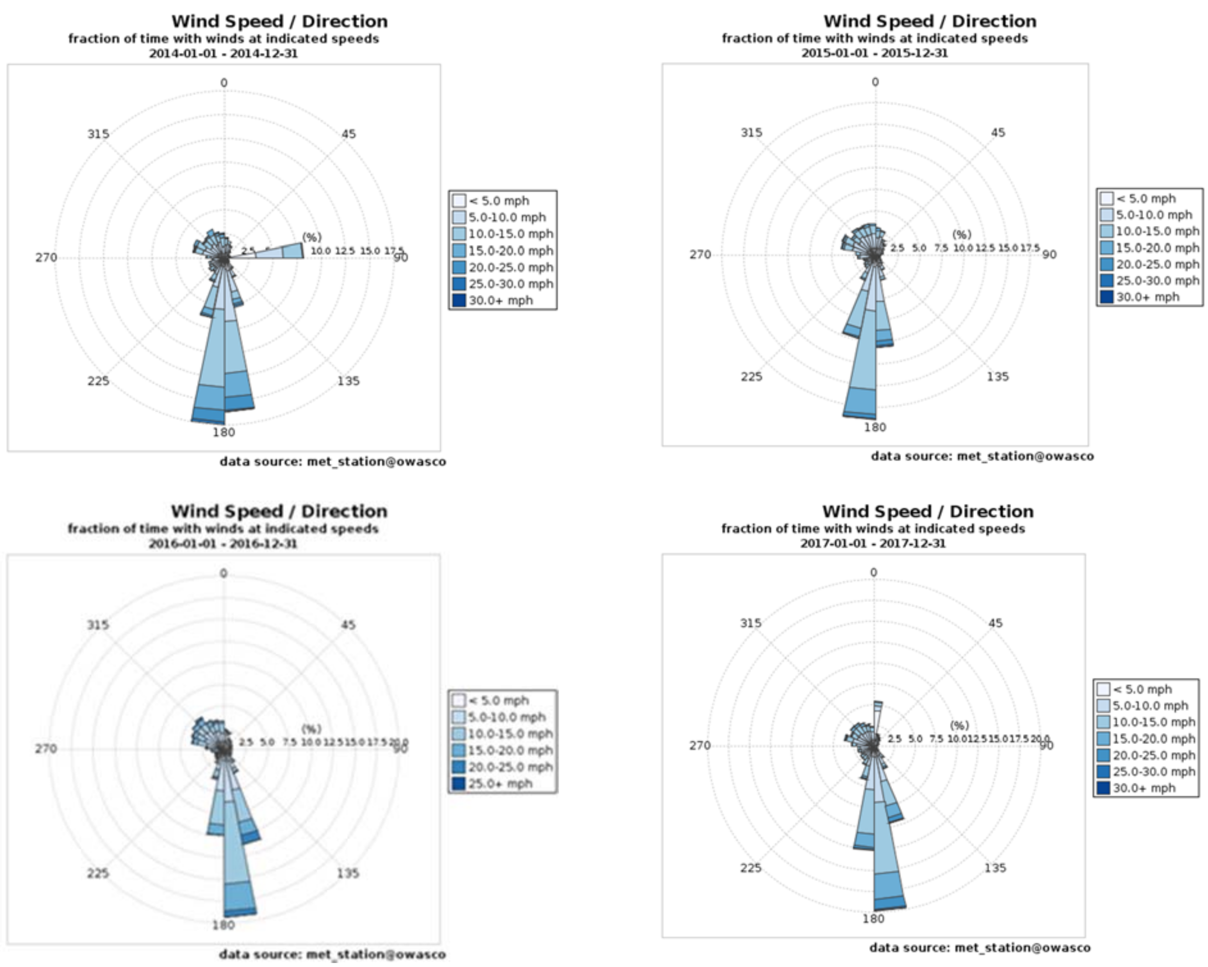
Buoy Sunlight Intensity: The first BGA blooms for the season happened after summer solstice, and BGA blooms were no longer detected when mean daily insolation (sunlight) decreased from just above 340 $\mu E/cm^2$ in mid-June to below 150 $\mu E/cm^2$ by late September/early October (Fig. 16). Warmest water and air temperatures also peaked after summer solstice and all three peaked before the BGA blooms. Lower light levels experienced in the early fall might favor BGA blooms because BGA can position themselves at depths with optimum light levels. Thus, warmer air and water temperatures after summer solstice favor blooms. However, blooms were NOT detected on every warm and sunny day. Thus, solar intensity, air and water temperatures were associated with, but were not the sole trigger for a bloom.

Rainfall: In all six years, shoreline BGA blooms typically appeared after a rain storm but not every rainstorm (Fig. 16). This is more obvious in the dockside monitoring data (see below). It suggests that storms and their associated runoff brought nutrients to nearshore areas and stimulated a bloom. The storm may have also disturbed the lake sediments and facilitated nutrient release and transfer from the anoxic sediment layer to the water column. Interestingly, BGA appeared to "wait" for the subsequent calm, sunny day after the rain event to bloom. Bloom activity in 2016 and 2018 was absent until mid-August, and only detected after the first major rain events of the summer season. In contrast, the abnormally large spring rains of 2014, 2015 and again in 2017 with their associated nutrient/sediment loads may have provided enough nutrients and organics to the lake to trigger the initiation of larger and more numerous BGA blooms along the shoreline in Owasco and many other Finger Lakes during the past six years.

Buoy Wind Speed & Direction: The summers of 2015, 2016, 2017 and 2019 were not as windy as 2014 and 2018, especially on days when BGA blooms were detected (Fig. 16). The mean daily wind speeds in 2015, 2016, 2017 and 2019 were at or below 8.8 mph (3.9 m/s, small waves) with only a few days with wind speeds above 15 mph (large waves with white caps). In 2014 and 2018 had fewer calm to light-breeze days and more days with wind speeds above 15 mph. The increased wind speeds in 2014 and 2018 compared to other years parallels fewer detected blooms by the Watershed Inspectors Office and Owasco Lake HABs Surveillance volunteers. This suggests that BGA bloom development is more likely during calm or light-breeze days. However, BGA blooms are not detected on every calm or nearly calm day, so calm days by themselves are not the sole trigger for BGA blooms. Winds above 20 mph (8.9 m/s, very large waves with white caps) also coincided with the end of the bloom activity in 2015, 2016, 2017, 2018, and perhaps 2019, but not 2014. These very large wind speeds probably mixed any BGA throughout the epilimnion and towards open water.

Over the past six years, The dominant wind direction measured at the buoy during the annual deployments was typically from the south, with the next most common wind directions from the west and northwest (Fig. 17). These directions are consistent with the majority of the BGA detections along the northern and northeastern margins of Owasco Lake (Fig. 5). A slight eastward shift from due south in wind direction was detected in 2016, 2017 and 2018, and a slight westward shift from due south in 2014, 2015 and 2019.

Previously, it was suggested that the dominant winds might push surface BGA blooms towards the downwind shore. Direct observations noted the disruption of BGA blooms that formed on calm days after the development of light winds. Apparently the wind and vertical mixing by waves (gravity not capillary waves) are sufficient to overcome the buoyancy provided by the BGA gas vacuoles. Wind directions might still might play a role in bloom genesis as wind can concentrate decaying macrophyte and other organic matter towards the downwind shoreline. The nutrients released by bacterial decomposition of the accumulated organics can then stimulate the next BGA bloom at these nearshore locations.



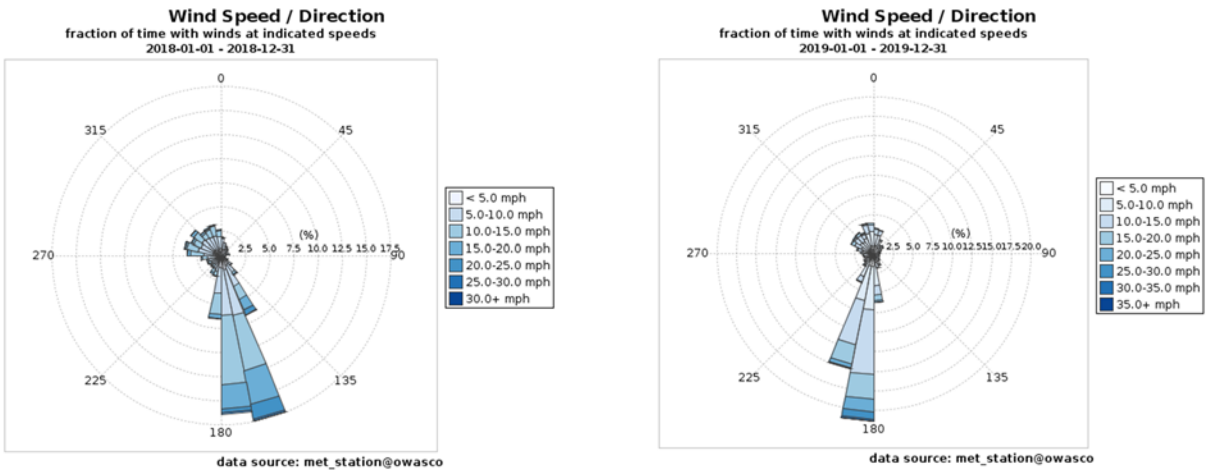


Fig. 17. Wind rose diagrams showing frequency of wind direction and speed for 2014 (upper left), 2015 (upper right), 2016 (mid left), 2017 (mid right), 2018 (bottom left) and 2019 (bottom right) from the Owasco Lake buoy.

NEARSHORE TEMPERATURES & BGA BLOOM HYPOTHESIS

Mean, daily, surface water temperatures revealed nearly consistent changes in temperature in all of the nearshore data loggers (deployed at 1 m depth) and surface water (1m deep) temperatures detected offshore by the buoy and CTD (Fig. 18). Some variability was observed. Site A (FL-20) experienced the smallest change in daily temperatures and was typically cooler than the buoy. The lake floor at Site A descends quickly into very deep water and lacks an extended nearshore shelf observed at the other nearshore sites (Fig. 2). Perhaps internal seiche activity or runoff brought colder hypolimnetic (bottom) water to this site. The other nearshore sites typically revealed larger and slightly warmer temperature swings than Site A and the buoy. The differences are expected, as extensive shallow water masses are easier to warm (and cool) than deeper water masses during sunny (or cloudy) days.

As observed in 2017 and 2018, the 2019 August and early September shoreline BGA blooms were typically preceded by lake-wide, multi-day, decrease (~1°C) in water temperature. The 2019 decrease was more subdued than previous years. Unfortunately, the NYS-DEC has yet to release its 2019 HABs concentration and location data. They did email the OLWMC members, dates for suspicious and confirmed blooms. Thus, unlike previous years, suspicious and confirmed blooms were plotted in Fig. 18. Once concentrations are known and only confirmed blooms plotted, it might improve the correlations. Lake-wide temperature declines in the surface water may reflect cooler air and cloudier conditions, and/or wind/storm events that generate surface waves and internal seiche activity ultimately mixing some colder hypolimnetic water into the epilimnion. This suggests that waves and internal seiche activity can be the first step in propagating BGA blooms. These same events could also introduce nutrient-rich hypolimnetic waters to the nearshore areas and resuspend nearshore sediments and decaying macrophytes, which in turn release more nutrients to nearshore areas. Runoff from rain events can also introduce nutrients to the shoreline areas from the watershed. These additional nutrients might provide sufficient nutrients to fertilize BGA blooms.

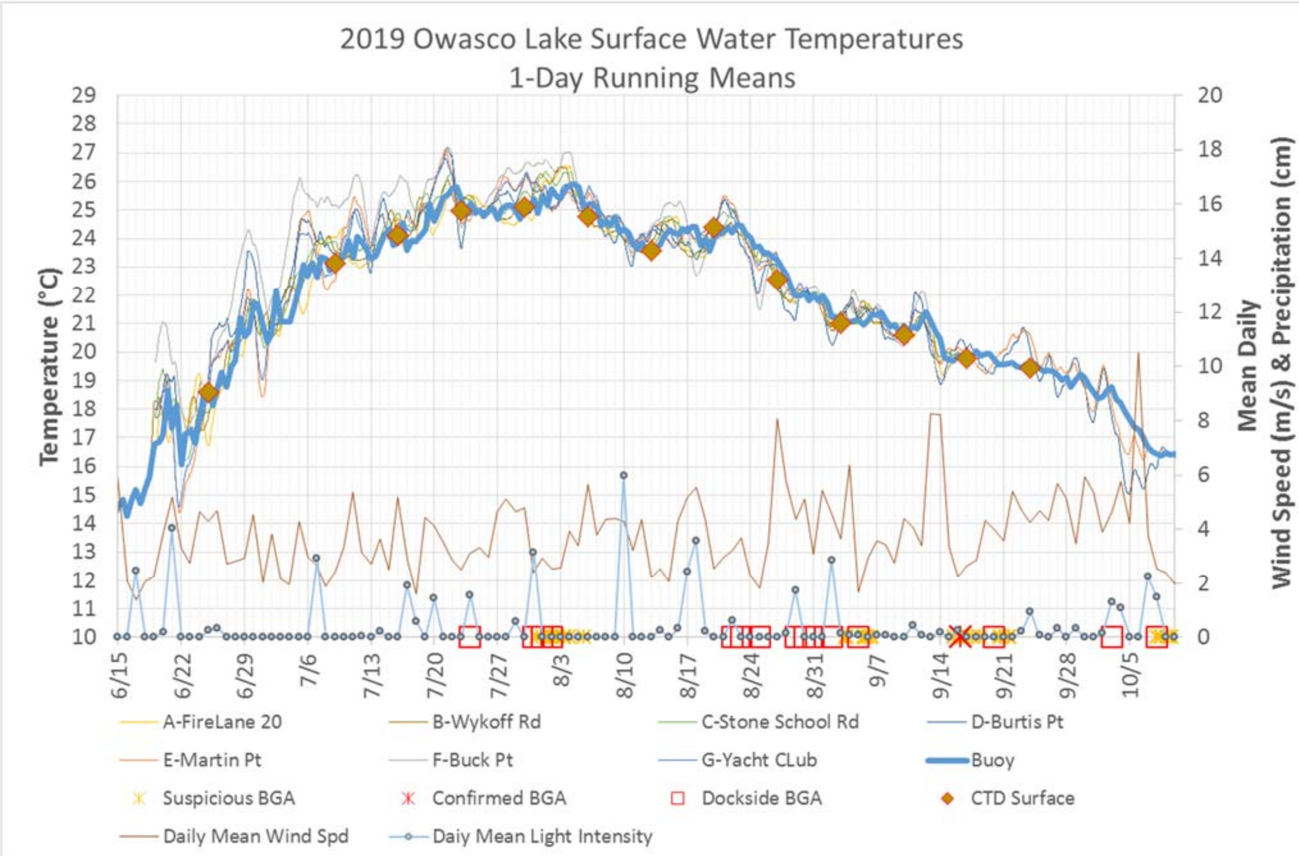


Fig. 18. Plot of nearshore and buoy 1m water temperatures, nearshore BGA suspicious, confirmed and dockside blooms, rainfall and mean daily wind speeds.

Like previous years, not every dip in water temperature during 2019 resulted in BGA blooms during the next calm weather episode, especially those dips earlier in the summer. It suggests that nutrients released by bacterial decay, no matter the source, need the summer's warmth and time to sufficiently increase the nutrient concentrations in the hypolimnion and nearshore sediments to promote the BGA blooms, as bacterial decomposition of organic matter is faster in warmer conditions. The macrophytes also need time to grow and mature through the summer. Once they die and are decomposed, the released nutrients can also contribute to the nutrients in nearshore areas. Not every bloom was preceded by a temperature dip as well but this issue may be resolved once the HABs concentration and location data are released by the DEC.

The mixing scenario is consistent with data recorded by an YSI/Xylem EXO2 water quality sonde deployed on a dock at 1m water depth in Seneca Lake in 2017 and 2018 (Fig. 19). When the wind blew onshore during 2018 (e.g., 9/4, 9/6, 9/10, 9/17, 9/21, and 9/25-9/26), waves resuspended the lake floor sediments and made the water column turbid. Other wind events (e.g., 9/7, 9/8, 9/14, and 9/20) were blowing offshore, and minimizing the impact by waves and resuspension of sediments at this site. More importantly, algal concentrations, both total and BGA concentrations, increased during and just after the shoreline, wave-induced turbulence. The turbulence probably stirred up any algae attached to the lake floor and any BGA resting stage cells within the sediments. These events were typically followed by a HAB event detected by the Seneca Shoreline HABs Surveillance volunteers at this site. The EXO2 sonde did not detect the bloom because the blooms float near the surface and hug the shoreline, whereas the sensor was ~1 m below the surface, and ~10 m beyond the shoreline. This may suggest that BGA resting stage cells wait in the sediments for the right conditions (i.e., nutrient augmented, warm, and calm waters) to bloom and subsequently accumulate at the lake's surface.

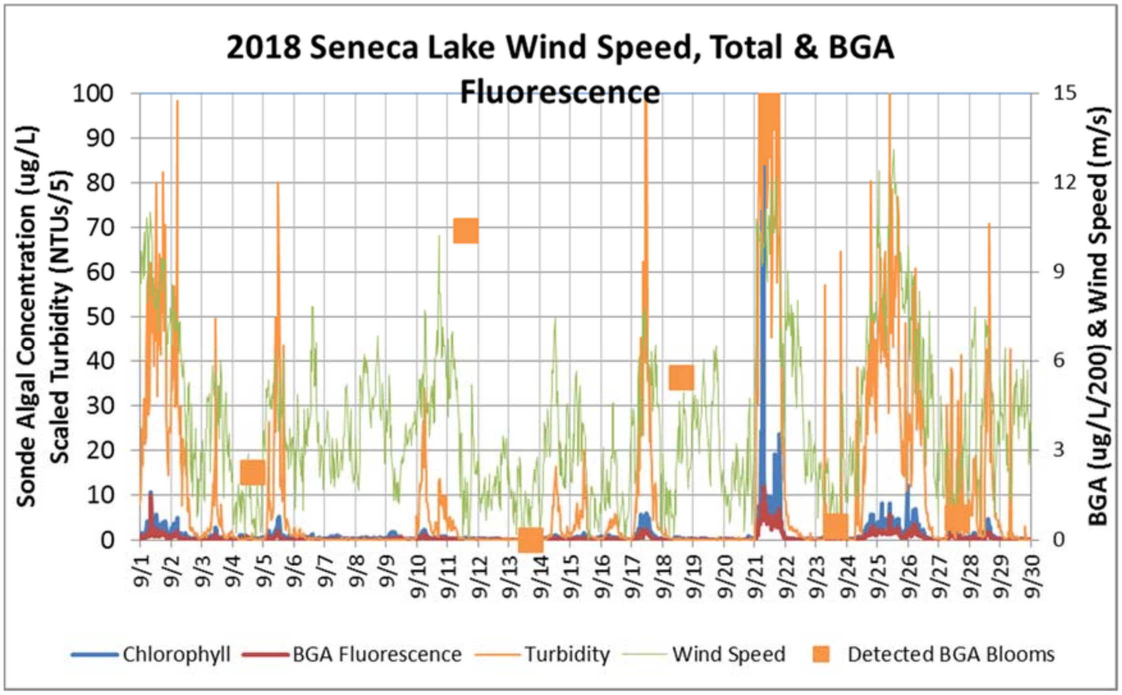


Fig. 19. Water turbidity, total and BGA fluorescence measured at a dock in Emerson Cove, Seneca Lake by an YSI EXO2 sonde. BGA concentrations at this site were from the Seneca HABs Surveillance team (with permission). Wind speed was measured by the Seneca Lake monitoring buoy, just offshore of this shoreline location.

DOCKSIDE MONITORING BY WEATHER STATIONS AND AUTOMATED CAMERAS

FLI Sensor Nodes: The FLI Sensor Node is a student designed and built, low cost, data logger designed to record a host of environmental variables. Each self-contained unit integrates an Arduino processor, SD memory card, solar panel, associated electronic components and can log up to four commercial sensors at an estimated cost of $400 (without sensors). The FLI Sensor Node reads each sensor and record the data on an SD card at preset time intervals. Thus, it provides a data logger at a fraction of the cost of comparable commercial counterparts. In 2019, two prototype sensors were deployed in Owasco Lake, one at Burtis Point (Site D) and another at Martin Point (Site E) to test the sensor's suitability in the field. Unfortunately, the deployed units had sporadic power, memory and other issues.

The recoverable temperature data from both sites (~two weeks) was informative (Fig. 20). The calibrated temperatures data from duplicate thermistors at each site were very similar to the HOBO results at the same site (r^2 of 0.90 and 0.94). These data revealed significant daily oscillations in temperature with amplitudes of 2 to 4°C. The water warmed during the day and cooled during the night, following the availability of sunlight. Similar daily temperature variability was detected at the other nearshore sites in the lake (Fig. 20). Interestingly, daily oscillations were not detected at the Buoy site, however the 12-hour sample rate precluded detection of daily and shorter term oscillations. A subdued daily oscillation in surface (3-ft) temperature was detected by the USGS buoy through September but not in October of 2018. The 2019 USGS data were too ambiguous to use.

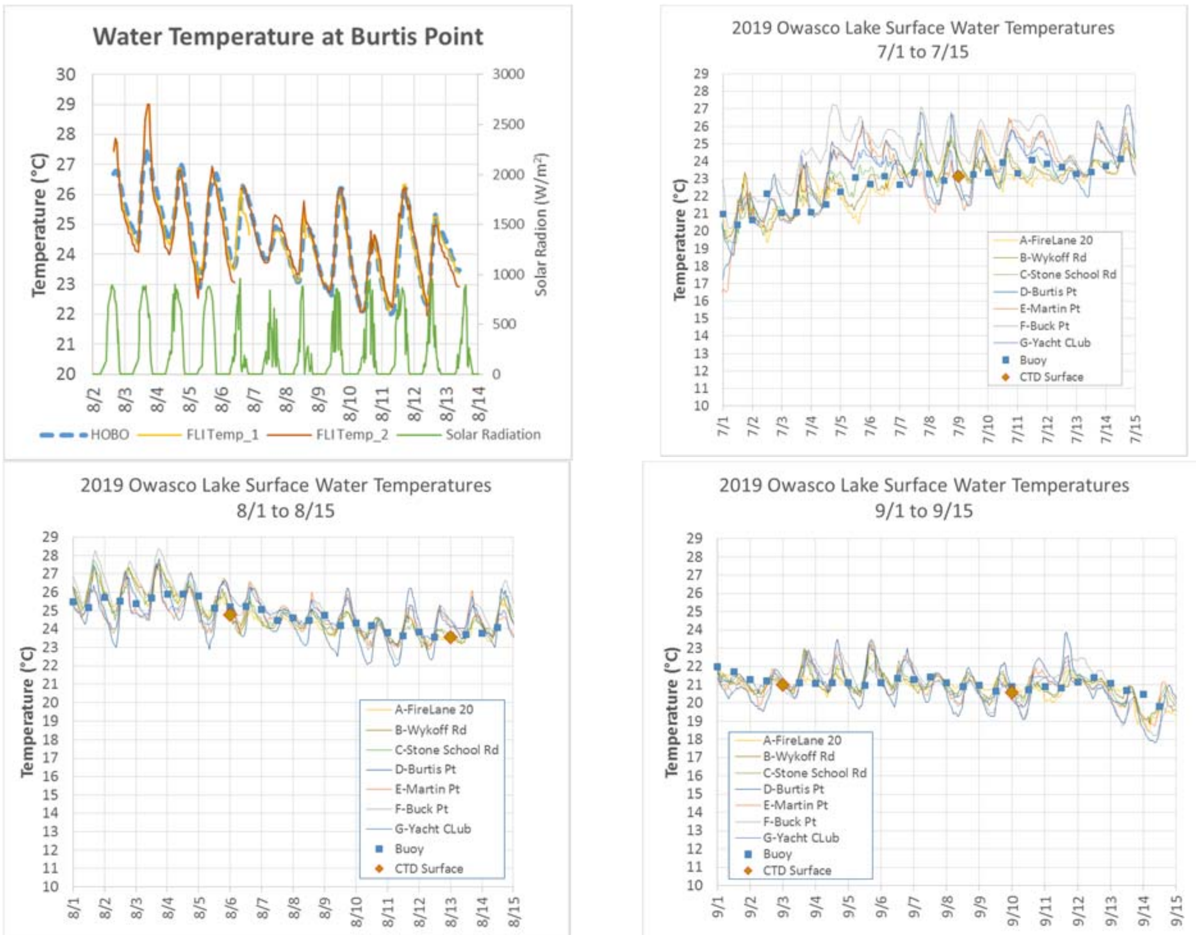


Fig. 20. Dockside FLI Sensor Node and HOBO surface water temperatures at Burtis Point (above left). The FLI temperatures were calibrated using a linear transformation to the HOBO data. Additional 2-week water temperature data from all the HOBO sensors around the lake, 7/1 to 7/15 (top-right), 8/1 to 8/15 (bottom left) and 9/1 to 9/15 (bottom left) depicting similar daily fluctuations in nearshore settings. Similar FLI Sensor Node results were observed at Martin Pt. but not in the FLI Buoy or the CTD data

The duplicate but uncalibrated dissolved oxygen (DO) FLI Sensor Node probes also revealed daily oscillations in DO concentration that co-varied with water temperature at both sites (Fig. 21). Sufficient independent DO data were not available to calibrate the Sensor Node results. Regardless, the available data are informative. Water temperature inversely controls saturated dissolved oxygen concentrations. However the diffusion of oxygen between the atmosphere and water column to achieve saturation is a relatively slow process compared to biological activity, i.e., photosynthesis and respiration and their impact on DO concentrations. If biological activity is intense enough, it will add oxygen to the water column during the day (photosynthesis by macrophytes and algae when light is available) and remove oxygen from the water column during the night (respiration by all organisms). The covariance between the temperature and DO fluctuations indicates that biology had a major impact on nearshore dissolved oxygen concentrations. It suggests that bacterial respiration of organic debris and the release of nutrients is important in nearshore areas, and potentially the growth of blue-green algae. Similar co-variance of water temperature and dissolved oxygen was detected by an EXO2 sonde deployed at a dock in Seneca Lake (Fig. 22). It dictates future deployment of commercial sondes with temperature, dissolved oxygen, turbidity and fluorescence sensors at a number of docks around the lake to investigate if these daily cycles are common everywhere in the lake and influence changes in algal biomass and BGA bloom intensity and frequency.

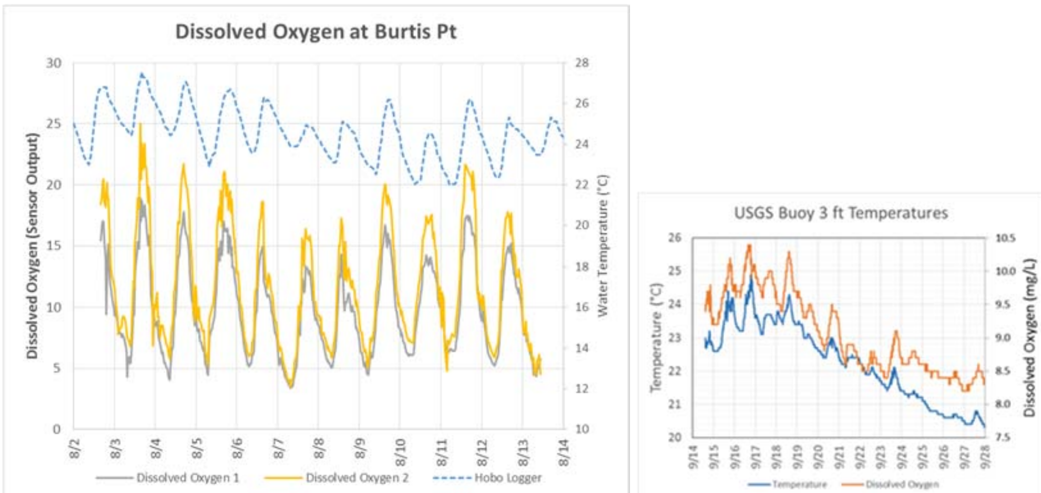


Fig. 21. Dockside FLI Sensor Node duplicate dissolved oxygen concentrations co-varied with the HOBO water temperature at Burtis Pt (left). The FLI Sensor Node dissolved oxygen output was not calibrated. Similar results were observed at Martin Pt. and at the USGS Buoy in September, 2018 (3-ft surface water sensor, right).

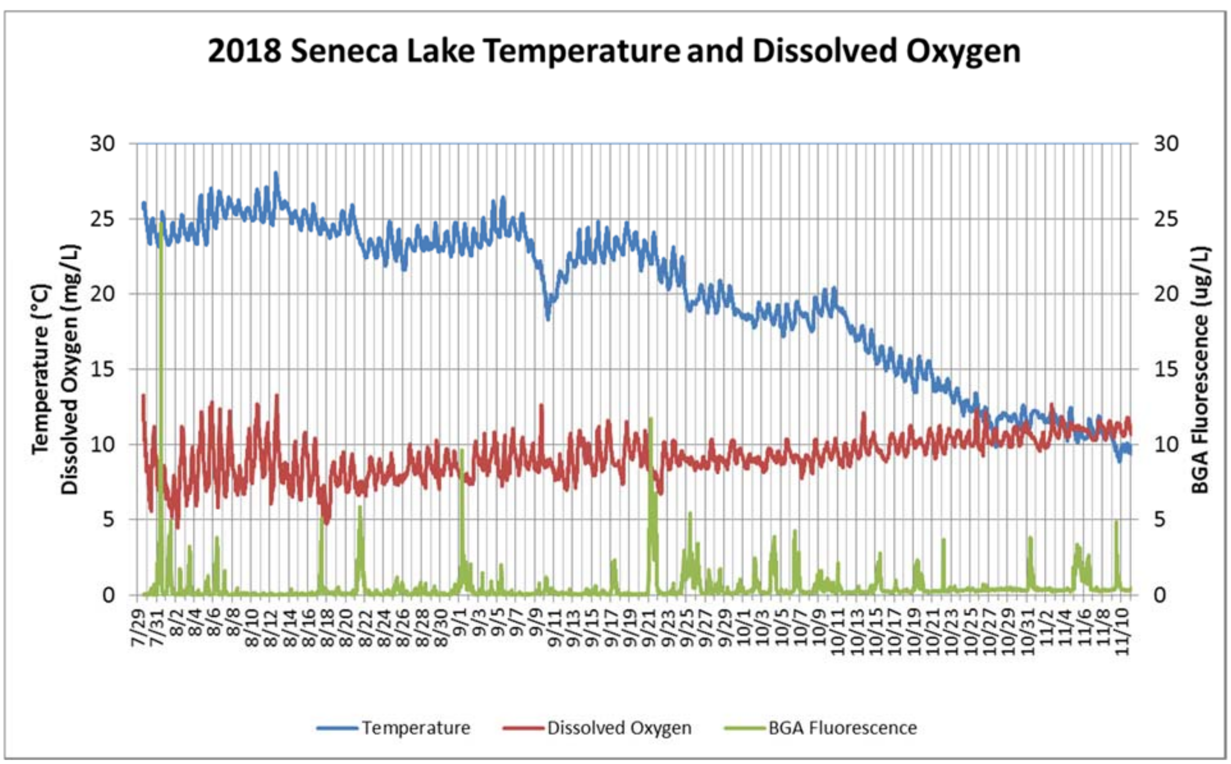


Fig. 22. Seasonal deployment of an YSI EXO2 Sonde in Seneca Lake that also revealed daily oscillations and co-variance of water temperature and dissolved oxygen concentrations.

Automated Cameras: The Brinno cameras faithfully recorded ~3 x 4 meter images of the lake every 10-minutes from 7 am to 6 pm from 6/26/2019 through 10/9/2019. They detected 10 to 14 BGA appearances (Table 2, Fig. 23). BGA concentrations were not concurrently measured to calibrate the image results; thus BGA detections in the images cannot be officially called blooms but instead appearances.

Table 2. Brinno Automated Camera Results

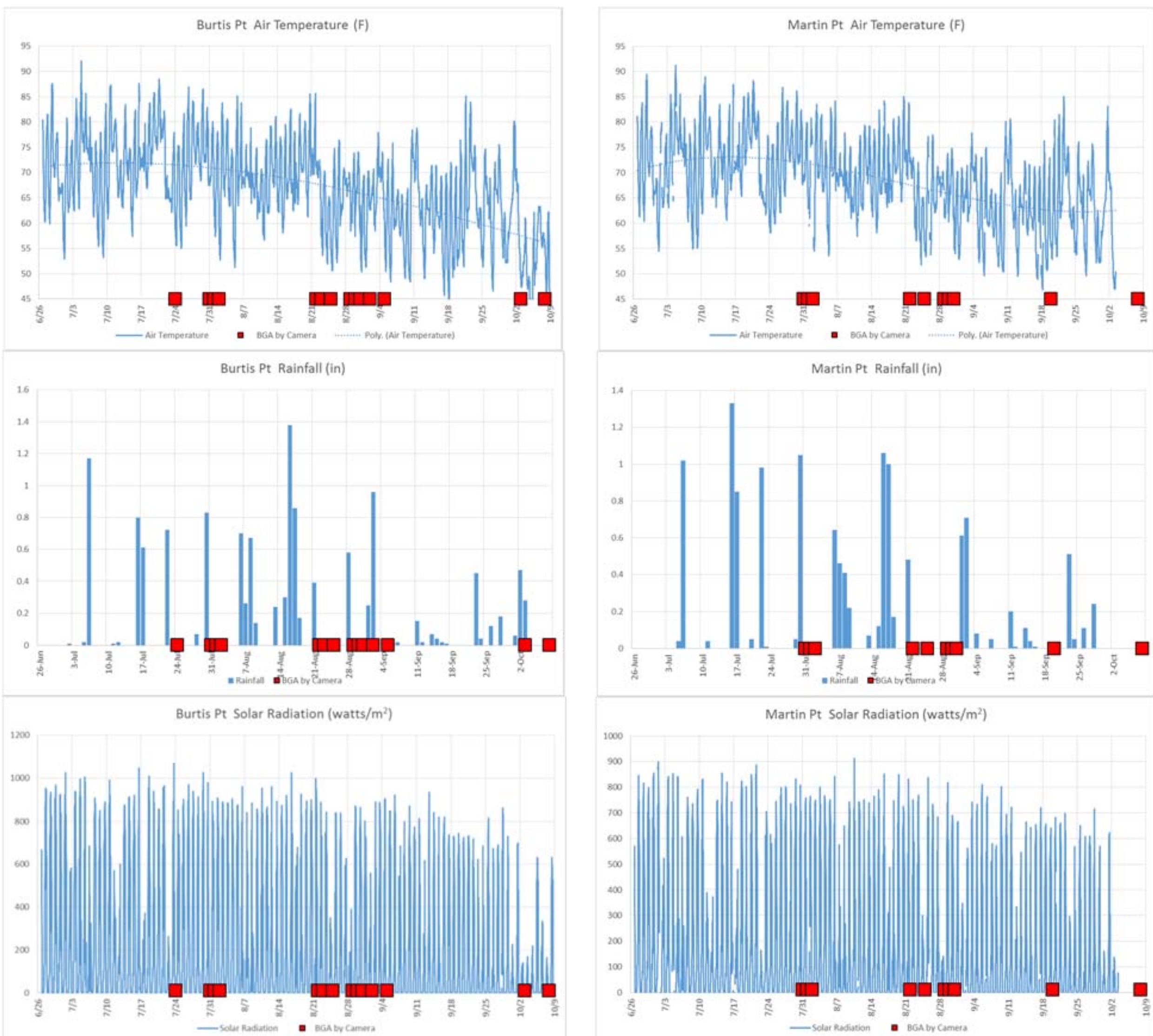
Camera Results (in days)	Martin Pt	Burtis Pt
Blooms Detected (unknown conc.)	10	14
Clear Water (bottom was visible)	94	80
Turbid Water (bottom not visible)	7	17
Glare Impacted Image	10	2
Camera Malfunctions	0	0

The images also differentiated between turbid (lake floor not visible) and clear water (lake floor visible). Glare from the sun did impact a portion of the afternoon images, especially at Martin Point as its camera pointed west, and suggests that cameras should point to the north in future deployments. Unfortunately, the available 2019 HABs volunteer data from the NYS-DEC lack locations to determine which method was better at detecting blooms. However, Seneca Lake Pure Waters Association HABs volunteers detected a similar number of blooms as identical cameras deployed at eight sites around Seneca Lake this past summer, but blooms were typically detected on different dates by the different methods. The SLPWA HABs volunteer weekly surveys probably missed blooms at other times of the day and/or other days of the week, and their survey of entire shoreline zones detected blooms outside of the camera's 3x4 meter field of view. On one day with a BGA appearance, a twig influenced the shoreline parallel northward migration of the bloom at Martin Point (Fig. 23). Bloom migrations parallel to the shoreline were also noted by HABs volunteers. Although expensive, perhaps nearshore currents should be measured at selected sites in the future.

Fig. 23. Example dockside BGA appearances imaged by the Brinno camera (left: Burtis Pt, right: Martin Pt.) Note how glare impacts the image quality and a twig influenced BGA movement at Martin Pt.

Weather Station Data: Air temperature, rainfall, solar radiation, wind speed and direction data are consistent with BGA bloom hypothesis (Fig. 24). BGA typically appeared during the next sunny and calm day after a rainfall event and declining air temperatures and wind speeds at these two sites. For example, over the course of the deployment, the mean wind speed for all the blooms was 1.8 and 2.7 mph, at Martin and Burtis Pts, respectively, compared to a mean wind speed of 2.1 and 3.8 mph at Martin and Burtis Pts. Perhaps all of the appearances did not fit the hypothesis because not all of the appearances were concentrated enough to be blooms. It suggests that similar instrumentation should be deployed again and water grab samples analyzed for FluoroProbe and nutrient concentrations in the future for a more complete statistical analysis of these potential correlations.

Interestingly, the mean wind velocities significantly declined at the two nearshore sites compared to the FLI buoy site (Fig 25). The dominate wind direction significantly differed at all three sites as well (Fig. 25). The shoreline orientation at each dock site can decrease wind speeds from non-onshore winds and thus dictate which shoreline locations will experience subdued regional winds which do not. It suggests an interesting speculation. If one shoreline is experiencing calm and sunny conditions, and a bloom appears, other shorelines may not, and instead experience sufficient winds and waves to retard bloom development. Thus, BGA blooms can appear at different segments of shoreline on different days, which is what is commonly observed. Additional sites should be monitored in the future to confirm this speculation.



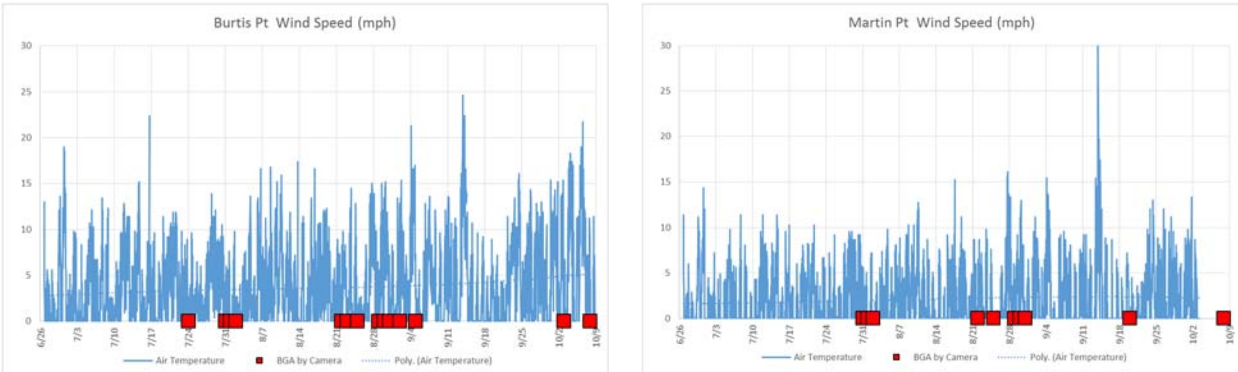


Fig. 24. Dockside air temperature, daily rainfall, solar intensity and wind speed data from Burtis Pt (Left) and Martin Pt (right). The red boxes are dates when BGA were observed in the camera images at the site.

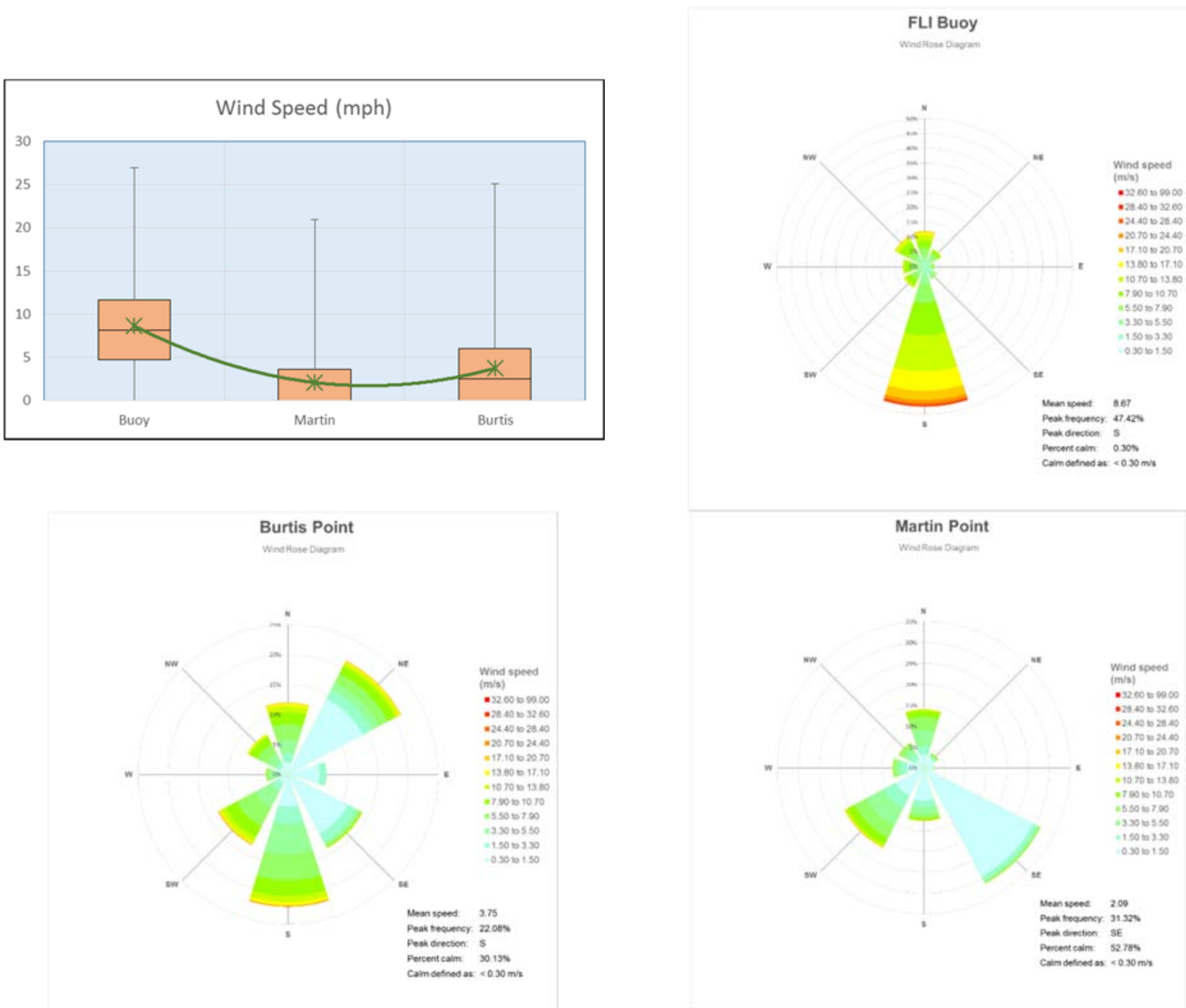


Fig. 25. Box and Whisker plots of wind speed (upper left) and wind roses from the FLI Buoy (upper right), Burtis Pt (lower left) and Martin Pt (lower right) over the deployment.

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