DOCKSIDE MONITORING OF BLUE-GREEN ALGAE IN SENECA LAKE.

THE 2019 FLI REPORT TO THE SENECA LAKE PURE WATERS ASSOCIATION

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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 Seneca 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 also detected in the City of Syracuse's municipal water intake that draws water from Skaneateles Lake in 2017, and in Rushville's municipal drinking water that draws water from Canandaigua Lake in 2018. The largest measured BGA concentrations in the Finger Lakes are typically at shoreline locations, where lakeshore residents want to use the lake. By 2017, all of the Finger Lakes reported HABs events, even Skaneateles, Canandaigua and Keuka Lakes. Seneca Lake is no exception. Since 2015, Seneca Lake has been listed on the New York State Department of Environmental Conservation's (DEC) HABs website with documented BGA blooms, some with high toxin concentrations. The majority of these events were localized to the shoreline. These events stimulated concerned citizens in each watershed to form HABs volunteer monitoring groups under the guidance and training of NYS-DEC staff.

Seneca Lake Pure Waters Association (SLPWA) has taken the lead on volunteer HABs monitoring in the Finger Lakes region. They have also advanced methods to report HABs events to the local community. SLPWA's program has grown quickly, and now HABs volunteers enter HABs detection reports and photos electronically using cell phones or tablets, and bring samples to the Finger Lakes Institute to determine BGA concentrations. If the bloom is a confirmed bloom (>25 μg/L blue-green chlorophyll), then the sample is delivered to laboratories in Syracuse (SUNY ESF, UFI) for toxin analysis. The program has been adopted by numerous groups around New York State. SLPWA members have also spearheaded the development of an interactive web site that maps HABs event locations with links to a photo or two of the bloom, and BGA and toxin concentrations. A similar web-based map is the basis of DEC's statewide map. A critical result of this and neighboring monitoring programs is that HABs are concentrated along the shoreline, and HABs events are sporadic in both space and time. Last year was no exception, with localized HABs events of multiple concentrations detected around the shoreline of Seneca Lake on different dates during the July – October HABs season.

This report details our findings from the Seneca Lake dockside monitoring program, and proposes recommendations for future research. It follows up on promising research by Halfman and his collaborators on Owasco Lake[1], which documented the sporadic nature of BGA blooms in both space and time, and that the nutrients were lacking in the nearshore water column to support the observed bloom concentrations. Finally, this research hypothesizes that HABs form along the shoreline after an onshore wind event during the subsequent calm and sunny day. It also suggests that shoreline features influences nearshore wind speeds and directions enough to dictate where shoreline blooms develop.

This project was designed to investigate four questions:

- What are potential meteorological and limnological triggers for a bloom event?
- What is the source of nutrients for the shoreline blooms?
- Why are bloom events variable in both time and space?
- Most importantly, are the hypothesized BGA triggers also important in Seneca Lake?

We thank the hard work and dedication of SLPWA volunteers that put this proposal together, requested and received funding to underwrite this project from the Tripp Foundation, and worked closely with Halfman and his collaborators on all aspects of this project.

METHODS

This project addressed these questions by monitoring the meteorological and limnological conditions at eight shoreline sites equally distributed around Seneca Lake. The sites utilized homeowners who already were SLPWA HABs volunteers and were willing to host the dockside instrumentation (Fig. 1). At each site, a weather station, a water temperature logger, and an automated camera were deployed to detect and elucidate occurrences of nearshore BGA blooms, and precursor weather and water quality information for each bloom (Fig. 2). The weather station (Ambient 1002-WS) recorded air temperature, rainfall, barometric pressure, humidity, light intensity, wind speed and direction every 30 minutes on an SD card. A Brinno TLC-200 automated camera was deployed on the weather station pole approximately 3 m above the lake's surface. Each camera saved daily images of the lake's surface every 10 minutes from dawn to dusk (7 am to 6 pm) on an SD card in a movie format (*.avi), each day saved in a separate file. The camera's 60° field of view imaged a 2x3 meter area of the lake's surface at this deployment height. A *HOBO* TidBit MX data logger was placed inside a 2" PVC pipe and the assembly was strapped to a dock post at each site in ~1 m of water to record water temperature every 30 minutes. The instrumentation was deployed on 6/26 and recovered on 10/9, a timeframe anticipated to span the HABs season.

In addition, each site was visited every two weeks to measure water temperature (by handheld meter), dissolved oxygen concentrations (by titration), atmospheric data (Kestral 5000), replace the camera batteries, and swap SD memory cards for image analysis in the laboratory. The weather station and camera remained at the NW Site (Roege) through the fall. Two additional instrument packages were deployed at the NW Site (Roege). A vertical thermistor string of twelve TidBits was deployed from a float ever three inches down the water column to investigate the vertical temperature structure and water stratification of the nearshore area. A prototype FLI Sensor Node was deployed to independently record water temperature and dissolved oxygen concentrations.

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[1] **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.

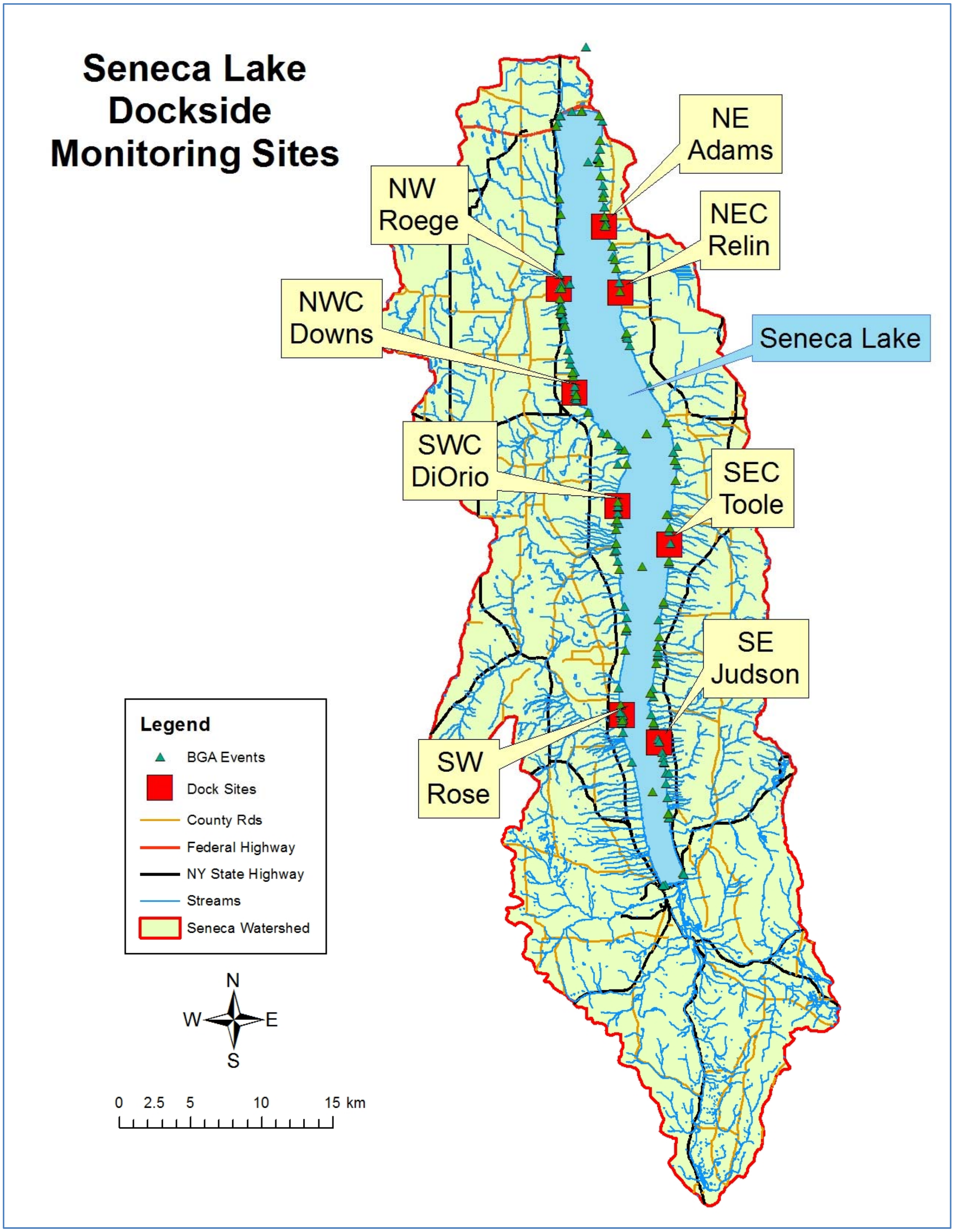

Fig. 1. The 2019 site locations. BGA "events" mark where blooms were detected from 2017 through 2019.

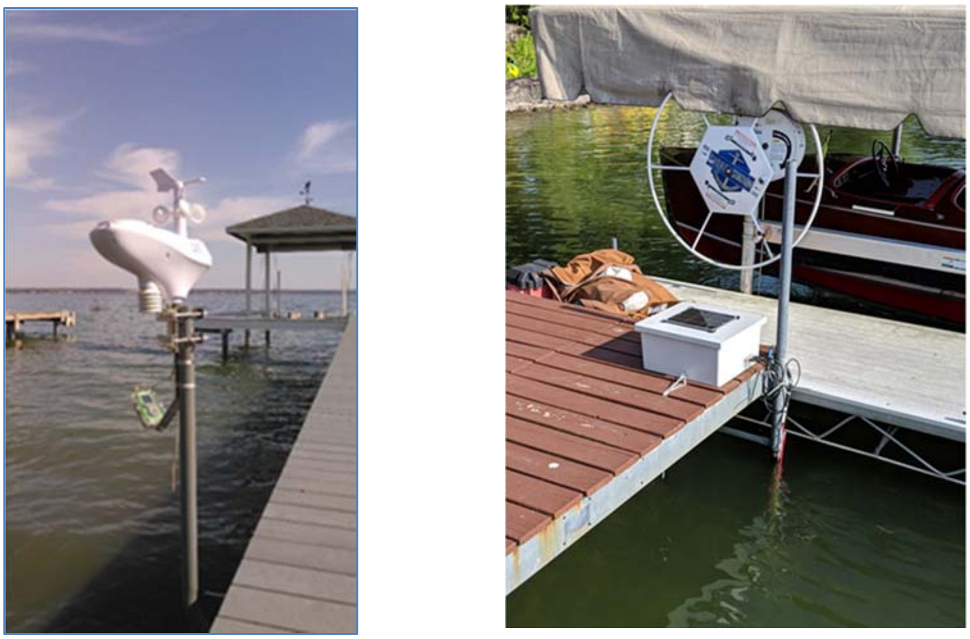

Fig. 2. A weather station (upper white instrument) and automatic camera (green box) attached to the weather station pole at a dock (left). The FLI Sensor Node (grey box) with solar panel deployed in the field (right). The sensors were strapped to a dock leg.

At four sites, NW (Roege), SWC (DiOrio), SEC (Toole) and NE (Adams), the homeowners collected weekly water samples by submersible pump from a depth of 50 cm for algal group and nutrient analyses at the Finger Lakes Institute. Samples were collected in 250 mL amber bottles and stored at 4°C until analysis for the concentration of four major algal groups by bbe FluoroProbe in the lab. The nutrient analyses included total phosphorus (TP), total nitrogen (TN), soluble reactive phosphate (SRP), nitrate/nitrite (NOx), ammonium (NH_4) and total suspended solid (TSS) concentrations. The TP, TSS and TN analyses were performed on raw lake water which was stored in plastic bottles and transported to the lab cold. The SRP, NOx, NH_4 samples were filtered in the field through a 0.2 μm filter, stored in sealed test tubes and transported to the lab cold. Water samples were kept frozen until analysis. Sample were collected weekly from 7/8 through 10/14, a time frame anticipated to span the HABs season.

Laboratory Analyses: Total phosphorus and soluble reactive phosphate were analyzed following EPA method 365.1 rev 2. Both methods utilize a molybdate color reagent paired with an ascorbic acid reduction. Total phosphorus pretreatment included a persulfate digestion in an autoclave for 30 minutes. Nitrate, the oxidized form of dissolved oxygen, followed EPA method 353.2. Sample pretreatment passed each sample through a cadmium column to reduce nitrite (NO_2) to nitrate (NO_3); thus sample results are presented as NO_X as they also include NO_2, which is likely negligible in lake water. Analysis for ammonia (NH_4), the reduced form of dissolved nitrogen, followed EPA Method 350.1. Ammonia samples are heated and mixed with salicylate and hypochlorite in an alkaline phosphate buffer. All of the spectrophotometric analyses were performed on a Lachat QuikChem 8500 flow injection analyzer. QA/QC included establishing method detection limits, analyzing replicate standards, conducting matrix spikes, and analyzing third party certified reference materials traceable to NIST as dictated by the EPA. If any QA step failed, the samples were re-run.

Offshore Data: Seneca Lake Weekly Monitoring Program and the Seneca Buoy: The nearshore data will be compared to data from the Seneca Lake weekly monitoring program and the FLI monitoring Buoy to place it in perspective. Weekly cruises aboard the *William Scandling* collected and analyzed a CTD water quality profile, a bbe FluoroProbe profile, Secchi disk depth, vertical plankton tow (80-μm mesh), and surface and bottom water samples from a mid-lake site offshore of Kashong Point in ~ 110 m of water (Site 3). 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. The bbe FluoroProbe electronically measures four different algal groups: green algae, diatoms, blue-green, and red algae, and 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 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 analyzed back in the laboratory for total phosphorus (μg/L, P), soluble reactive phosphate (SRP, μg/L, P), total nitrogen (mg/L), nitrate/nitrite (mg/L, N), ammonium (mg/L, N) chlorophyll-a, and total suspended solid (mg/L) concentrations.

The FLI meteorological and water quality monitoring buoy manufactured by YSI/Xylem was deployed at its northern, mid-lake site in 60 m of water from April through October. 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. Data were collected every 1.5 meters down the water column starting at 1 m depth. The buoy also recorded five-minute, average, air temperature, barometric pressure, relative humidity, light intensity, wind speed and wind direction data every 30 minutes. All of the raw data were transferred to HWS by cellular technologies ~1 hour after collection and made available on the internet soon afterwards[2]. Minimal power due to unrelenting cloudy/rainy weather prevented collection of water quality data on 9/30, 10/5 to 10/12 and 10/19 (buoy recovery). The buoy's EXO2 sonde was calibrated before and after the deployment and minimal instrument drift was noted. The raw buoy data were then calibrated against *in situ* CTD and laboratory data collected over the entire field season from the offshore sites, and the calibrated data are presented in this report. The BGA concentrations were normalized to a constant temperature due to the sensor's temperature sensitivity.

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[2] http://fli-data.hws.edu/buoy/seneca/

BLUE-GREEN ALGAE AND HARMFUL ALGAL BLOOMS BACKGROUND

Seneca Lake has experienced significant surface-water, nearshore, blue-green algae (BGA) blooms, some with toxic levels of microcystin and other toxins since 2015 (Fig. 3).

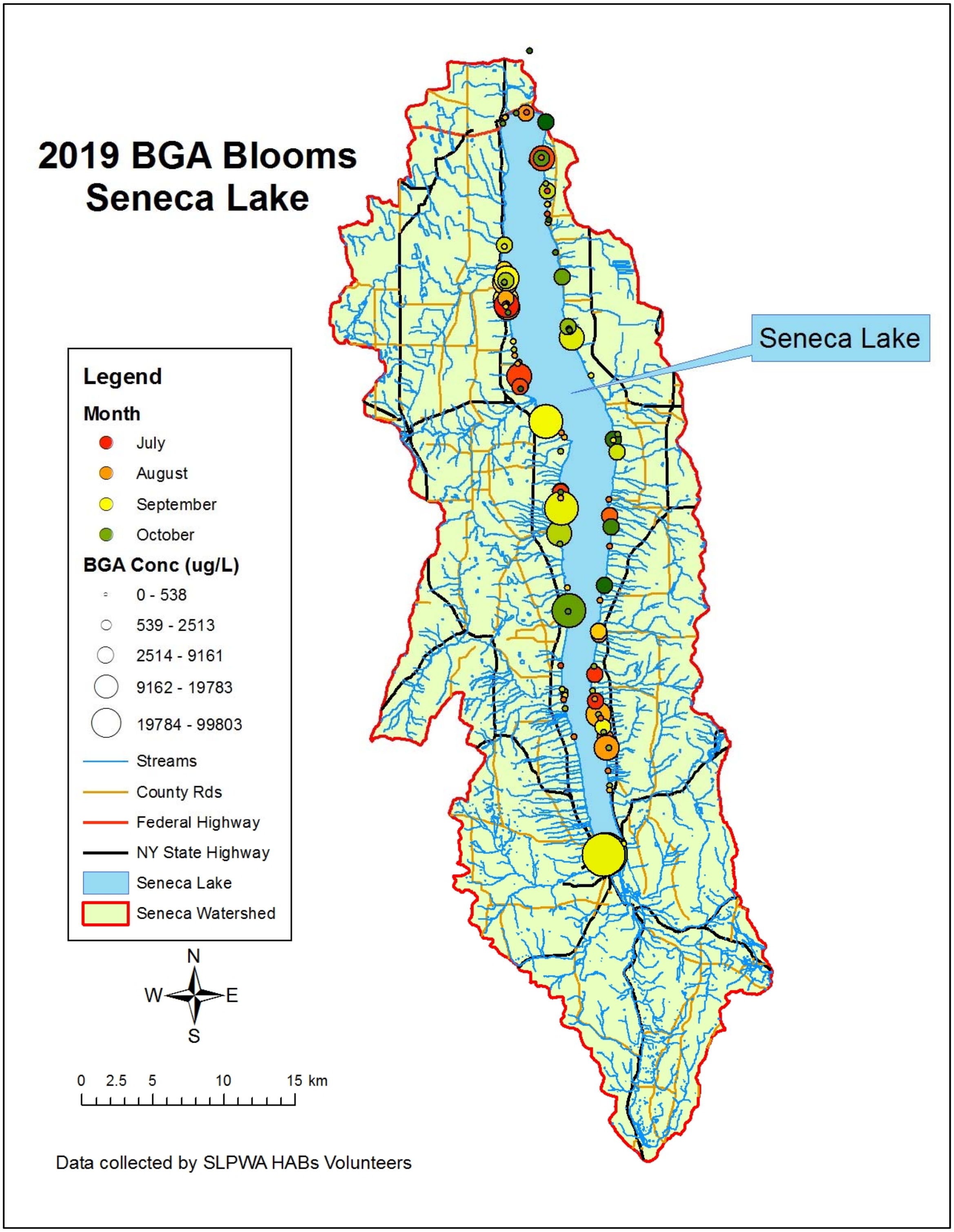

Fig. 3. The 2019 Seneca Lake BGA concentrations. The symbol size is proportional to the BGA chlorophyll concentration, and the symbol color is the month the bloom was detected.

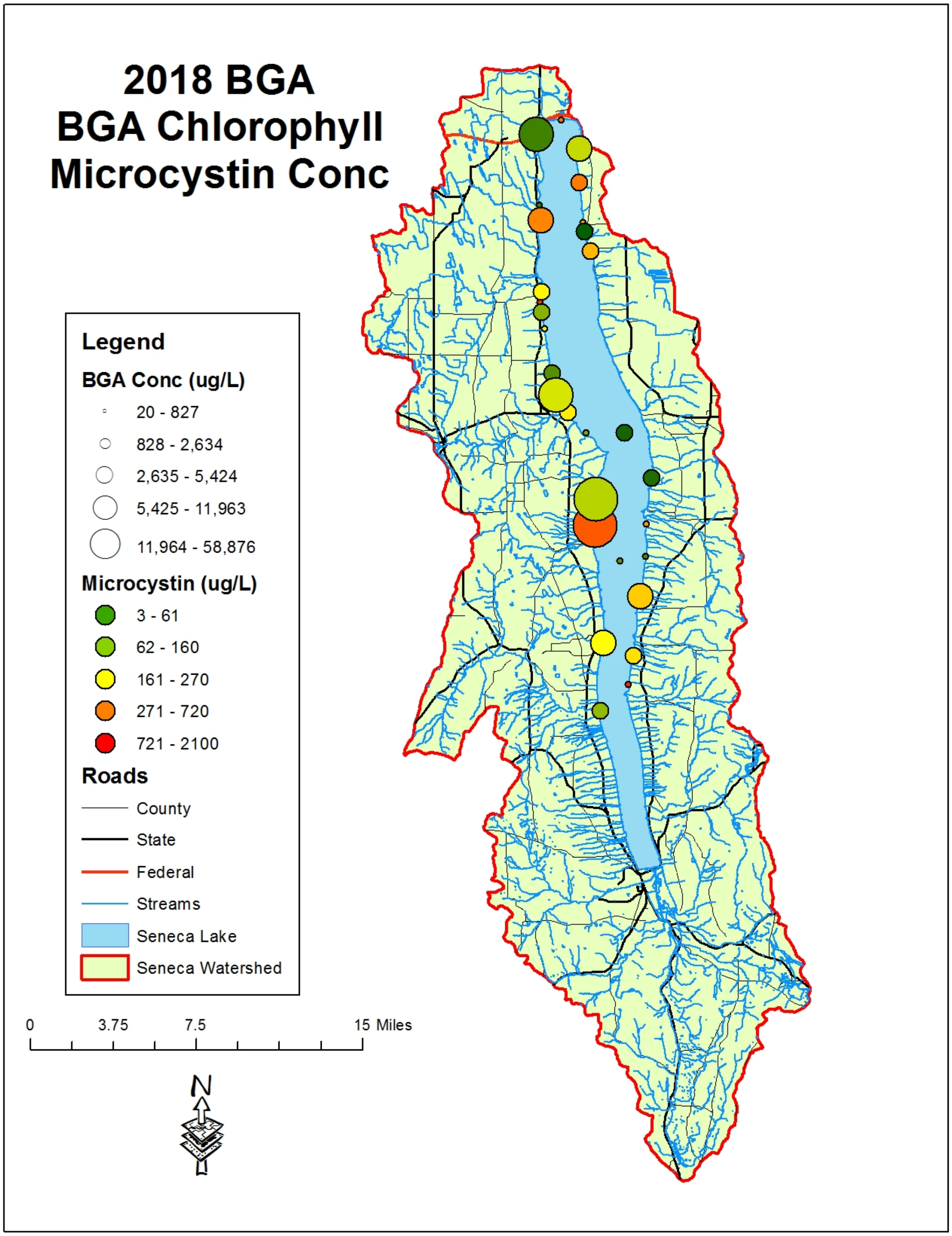

Fig. 3 cont. The 2018 BGA bloom and microcystin concentrations (permission by the DEC). The bubble size is proportional to the BGA concentration and the color provides the microcystin concentration.

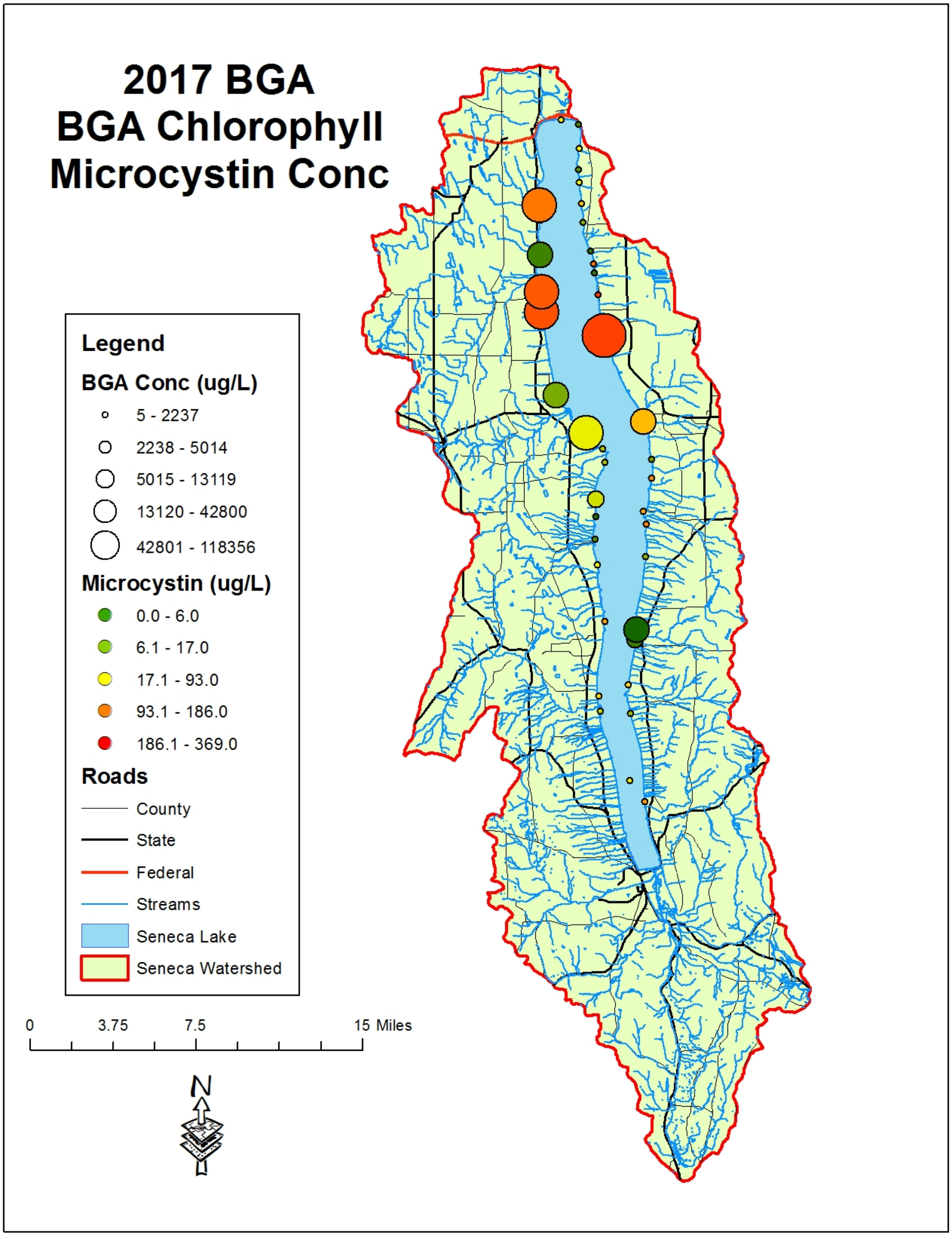

Fig. 3 cont. The 2017 BGA bloom and microcystin concentrations (permission by the DEC). The bubble size is proportional to the BGA concentration and the color provides the microcystin concentration.

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 source of nitrogen to synthesize organic matter. 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 Seneca 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, is not very well understood. Both *Dolichospermum* and *Microcystis* were most often detected in Seneca Lake. Typically *Dolichospermum* 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 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 BGA taxa, and each toxin, in sufficient concentrations, can impact different parts of the body, most notably, the skin, liver, gastrointestinal and/or nervous systems. Liver cyanotoxins like microcystins are most commonly found in HAB blooms, and can cause organ damage, heart failure and death at high doses in lab animals. Microcystins are a class of related toxin compounds (heptapeptides) that can be synthesized by various species of *Microcystis* and *Dolichospermum*, and total microcystin is commonly measured in New York State to assess BGA toxin status. Another common toxin group, anatoxins, impact the nervous system and can be synthesized by *Dolichospermum* and other BGA genera but not *Microcystis* species.

The impact of these toxins on humans at low concentrations still remains unclear. The World Health Organization (WHO) has issued a provisional finished drinking water guideline of 1 μg/L for chronic exposure to microcystin, and recreational exposure limit of 20 μg/L[3]. 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[4]. The anatoxin half-life, the time interval for decomposition, is very short, less than 24 hours, which makes detection in the water column difficult. The DEC defines a 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.

Harmful algal blooms are not unique to Seneca Lake. Since 2017, major BGA blooms were confirmed in almost, if not all of the Finger Lakes (Fig. 4). 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.

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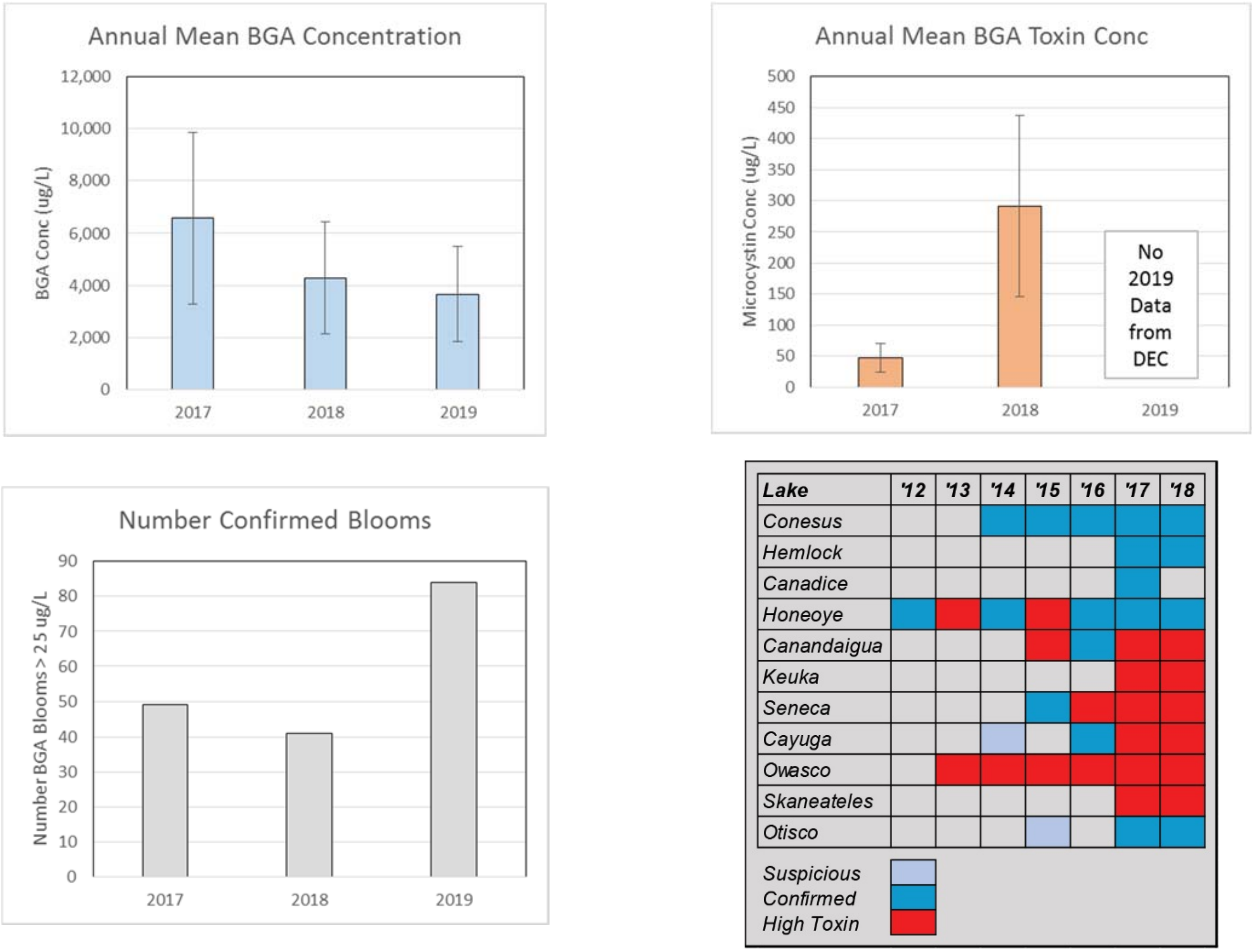
[3] WHO, 2011. Guidelines for Drinking Water Quality. 4th Edition. World Health Organization. Switzerland.

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

The number of weeks and when the DEC listed Seneca Lake on the BGA Notifications Page are: six in 2015 (8/21 – 10/16), two in 2016 (9/2 – 9/23), five in 2017 (9/22 – 10/20) and six in 2018 (8/24 – 10/5). The nearshore blooms were commonly detected along the western and northwestern margins of the lake before 2019, and spread to the eastern shoreline in 2019 (Fig. 3). Caution is warranted because the data may be biased by sampling protocols, and the intensity, diligence and number of people looking for blooms.

Notwithstanding, the past three years have seen significant concentrations of BGAs, some with harmful concentrations of toxins, from 2017 through 2019. Confirmed BGA chlorophyll concentrations in Seneca Lake ranged from 5 to 118,400 μg/L in 2017, from 20 to 58,900 μg/L in 2018, and from 31 to 99,000 μg/L in 2019 (Fig. 4). Reported toxin concentrations ranged from 0 to 369 μg/L in 2017, and from 3.4 to 2,100 μg/L in 2018.



Lake	*'12*	*'13*	*'14*	*'15*	*'16*	*'17*	*'18*
Conesus			🟦	🟦	🟦	🟦	🟦
Hemlock						🟦	🟦
Canadice						🟦	
Honeoye	🟦	🟥	🟦	🟥	🟦	🟦	🟦
Canandaigua				🟥	🟦	🟥	🟥
Keuka						🟥	🟥
Seneca				🟦	🟥	🟥	🟥
Cayuga			▨		🟦	🟥	🟥
Owasco		🟥	🟥	🟥	🟥	🟥	🟥
Skaneateles						🟥	🟥
Otisco				▨		🟦	🟦

Suspicious ▨
Confirmed 🟦
High Toxin 🟥

Fig. 4. Annual mean (±1σ) BGA concentrations (top left), microcystin concentrations (top right), and the number of confirmed blooms (bottom left) reported in Seneca Lake by the HABs Shoreline Surveillance volunteers. The number of Finger Lakes with BGA blooms since 2012 (bottom right, by permission DEC). The DEC has yet to release the 2019 HABs data.

Lakeshore residents with private water systems should use bottled water during BGA outbreaks along their shoreline[5] because their private water supply systems are challenged to remove BGAs from the water without bursting 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.

WEEKLY OFFSHORE WATER QUALITY MONITORING AND BUOY RESULTS

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 common in the past.

Since the early 1990's, water temperature and nutrient concentrations have changed in Seneca Lake. Surface water temperatures measured by CTD since 1995 indicate that Seneca Lake has warmed over the past two decades (Fig. 5). The warming was not uniform but instead occurred in a step like function with a few years occasionally deviating from the overall trend. Of interest here, the past five years of bloom sightings correspond to some of the warmest water temperatures in the lake compared to the past two decades.

Secchi depths, total phosphorus, soluble reactive phosphate, nitrate, total suspended solids and chlorophyll-a concentrations have also changed since 1991 (Fig. 6). 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[6]. Pertinent to this report, larger concentrations and larger variability in each year's data was observed over the past decade, especially the largest values in each year, i.e., the upper whisker of the box and whisker plots. Larger concentrations of TP and SRP occurred during 2014, and shallower Secchi depths, and larger TSS and chlorophyll concentrations occurred during 2015. The unusually high concentrations are interpreted to reflect significant additions of phosphorus and sediments from runoff events. The 2014 and 2015 timing correspond to the initial detection of BGA blooms in the lake. The historical data suggest that the addition of extra phosphorus, the limiting nutrient

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

[6] **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.

in the lake, and the onset of warmer water pushed Seneca Lake over a tipping point in 2015 that triggered subsequent BGA blooms. Nitrate did not significantly change, perhaps because it is not the limiting nutrient. Any algal uptake of phosphorus and nitrogen would impact phosphorus concentrations to a larger extent than nitrate concentrations. Once these excess nutrients are in the lake, nutrient recycling is typically effective enough to regenerate the nutrients required for BGA blooms in subsequent years. These limnological precursors to the onset of BGA blooms are also observed in the water quality data from neighboring Finger Lakes[7].

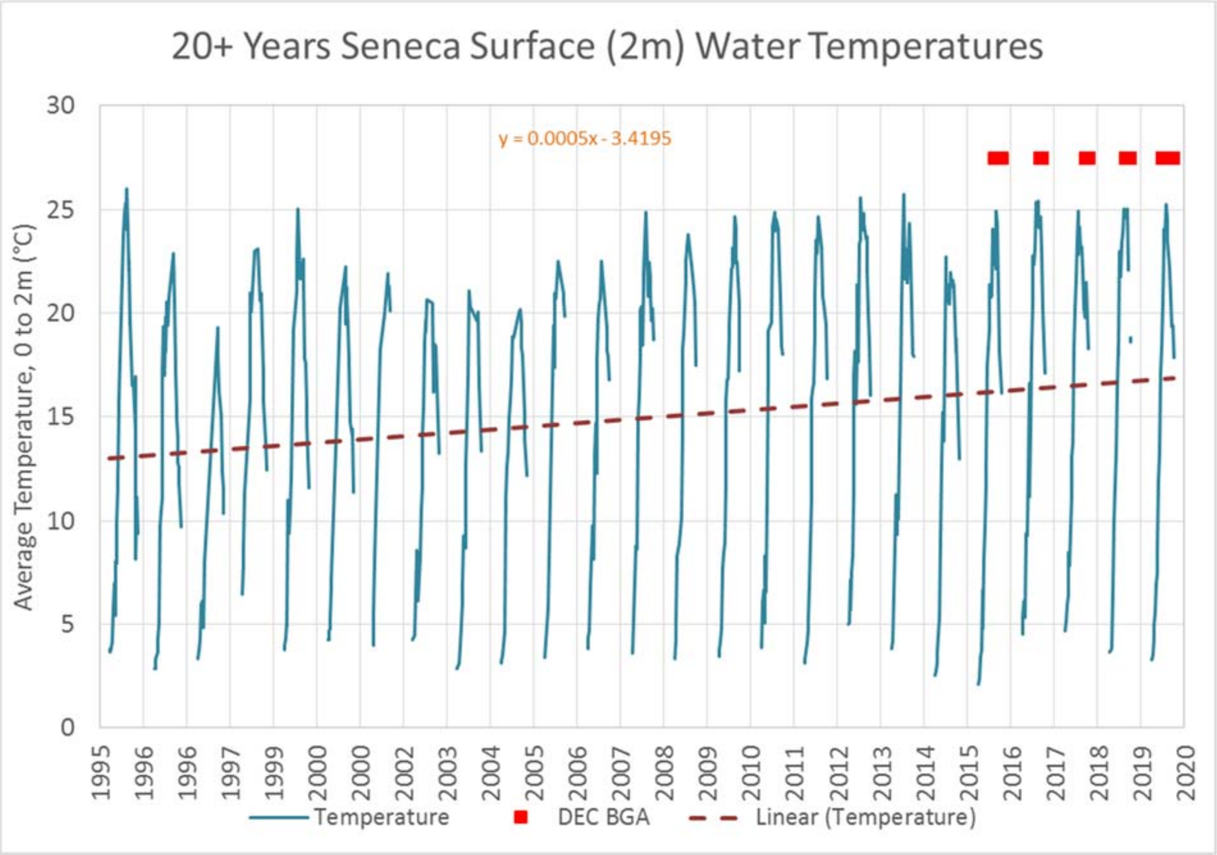

Fig. 5. Historical surface water temperatures from Seneca Lake measured by CTD.

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

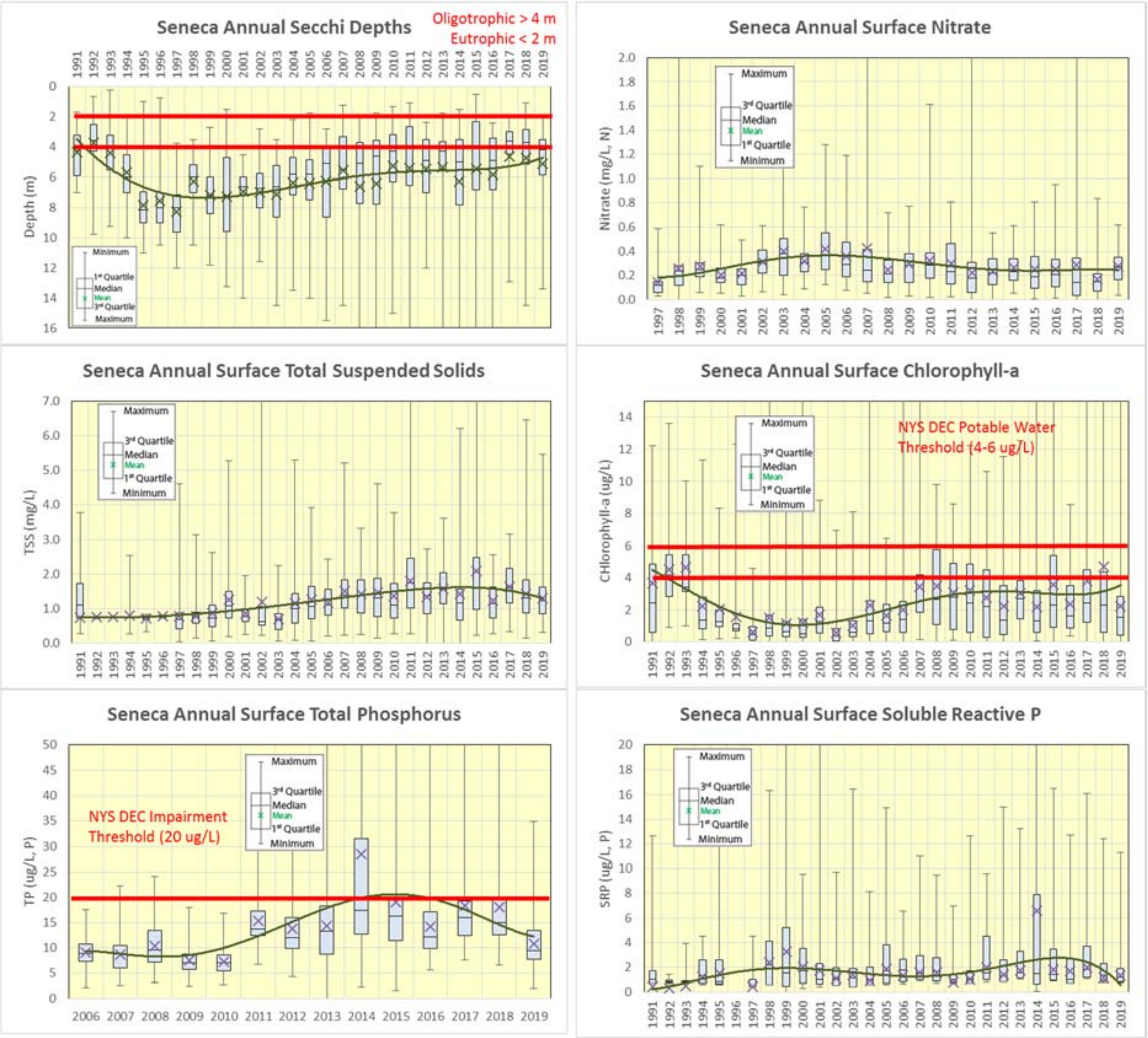
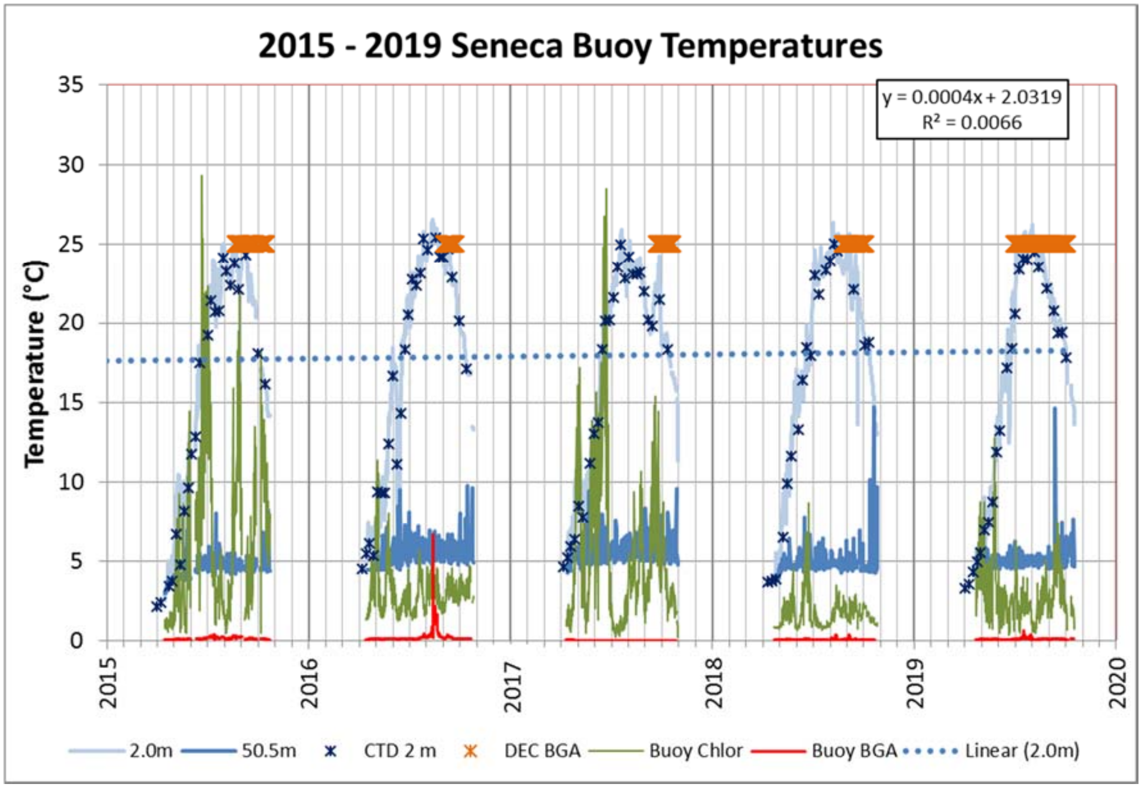
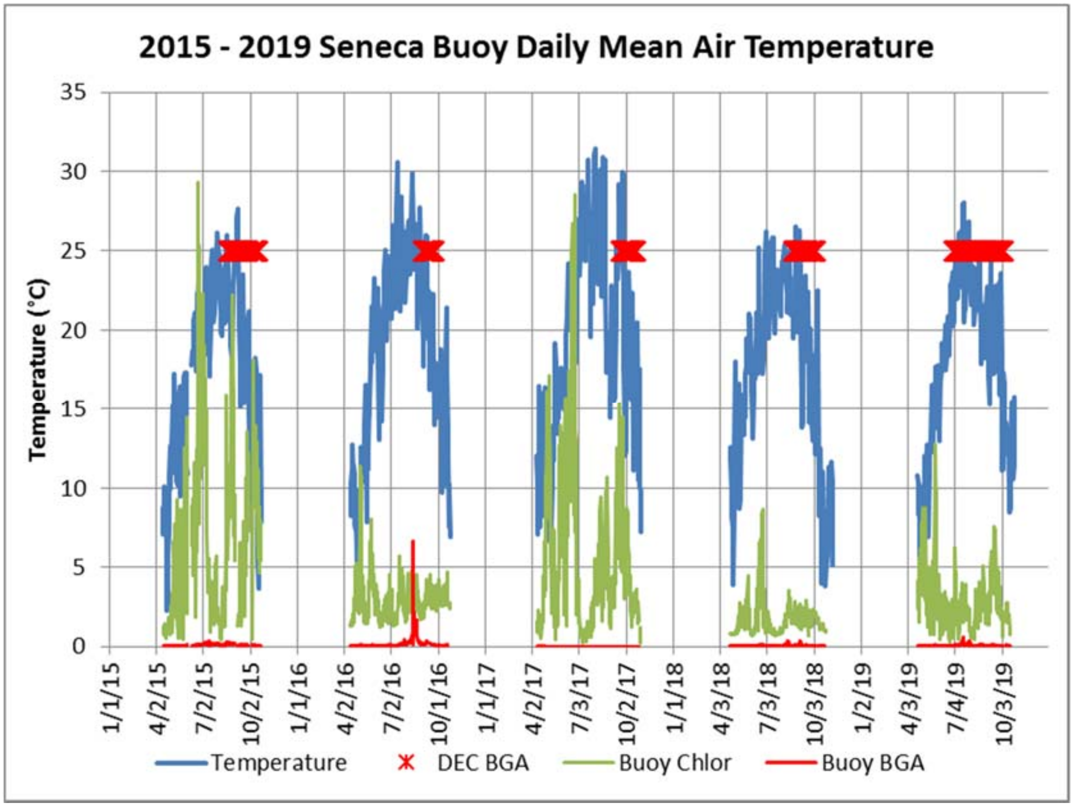


Fig. 6. Historical Secchi depths, nutrients and chlorophyll data from the HWS/FLI Seneca Lake monitoring program. The box in the box and whisker plots contain 50% of the available annual data. The lower and upper whiskers correspond to the minimum and maximum values of the available annual data.

Buoy Lake Temperatures: The FLI Monitoring Buoy provides higher resolution water quality and meteorological data than the weekly surveys. Shoreline BGA blooms occurred in warm water, 20 to 24°C (70 – 75°F) over the past five years, temperatures suitable for BGA bloom development (Fig. 7). However, in every year but 2019, blooms did not appear until a week or two after the warmest water temperature was observed. This indicates that warm water by itself does not trigger bloom activity. The time lag between the warmest lake temperatures and the first blooms may reflect the time required for sufficient bacterial growth and decomposition and release of nutrients to the environment. BGA activity may have started earlier in 2019 because more rain fell in the spring of 2019 than the other years. The correspondingly larger delivery of nutrients early in the season may have jumpstarted the BGA blooms. Alternatively, SLPWA volunteers were better at detecting blooms and/or looked for blooms earlier in the season. BGA blooms were not detected after the surface water cooled below 15°C (60°F).

Buoy Total Algae and BGA Fluorescence: Minimal correlations were observed between the buoy fluorescence and DEC BGA bloom dates (Fig. 7). The lack of a correlation is not surprising because the buoy measures open water parameters, and the bulk of the BGA blooms occur at shoreline locations. The buoy detected higher algal concentrations and more frequent offshore algal blooms in 2015 and 2017 compared to 2016, 2018 and 2019. More rain fell in 2015 and 2017, and increased nutrient loads from its runoff probably stimulated more algal growth during the impacted years. BGA were rarely detected at the buoy site. The absence may reflect the 1 m shallowest depth for the buoy sensor, and BGA blooms typically float near or at the surface. Alternatively, smaller and/or less frequent blooms occurred offshore compared to nearshore areas. Perhaps an automated camera should be deployed on the buoy to monitor the presence or absence of BGA at this offshore site.




2015 - 2019 Seneca Buoy Daily Mean Air Temperature
Temperature (°C)
35
30
25
20
15
10
5
0
1/1/15
4/2/15
7/2/15
10/2/15
1/1/16
4/2/16
7/2/16
10/1/16
1/1/17
4/2/17
7/3/17
10/2/17
1/1/18
4/3/18
7/3/18
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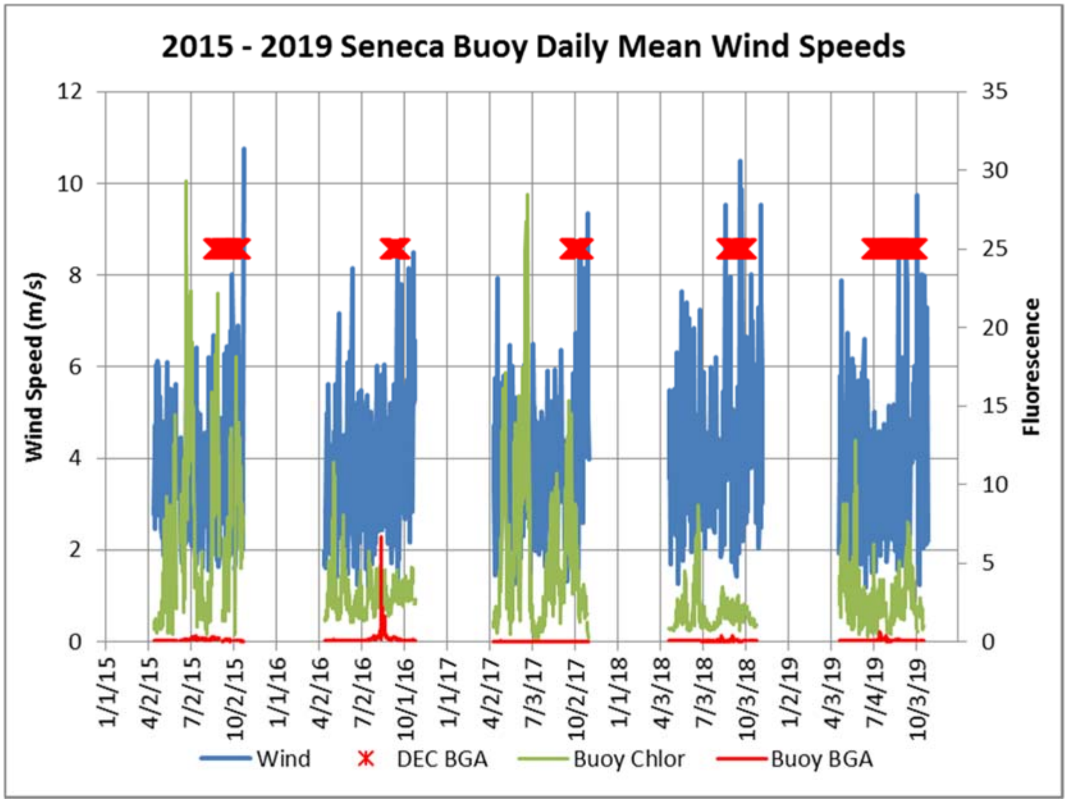
10/3/19
Temperature
DEC BGA
Buoy Chlor
Buoy BGA


2015 - 2019 Seneca Buoy Daily Mean Wind Speeds
Wind Speed (m/s)
12
10
8
6
4
2
0
Fluorescence
35
30
25
20
15
10
5
0
1/1/15
4/2/15
7/2/15
10/2/15
1/1/16
4/2/16
7/2/16
10/1/16
1/1/17
4/2/17
7/3/17
10/2/17
1/1/18
4/3/18
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Wind
DEC BGA
Buoy Chlor
Buoy BGA

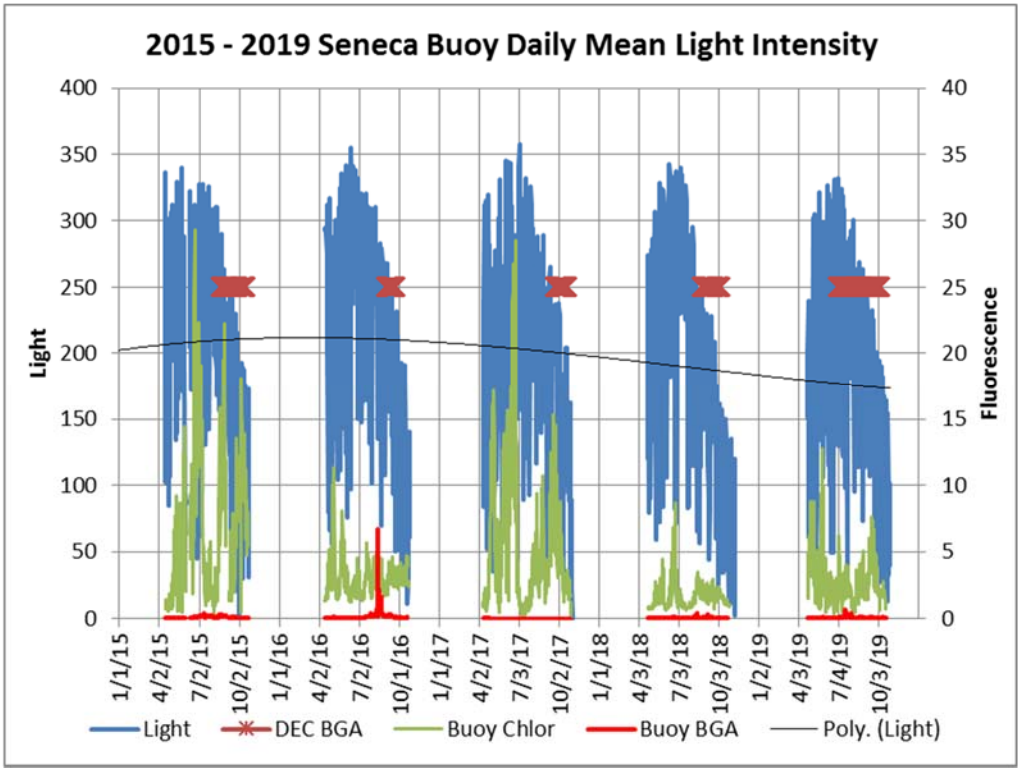
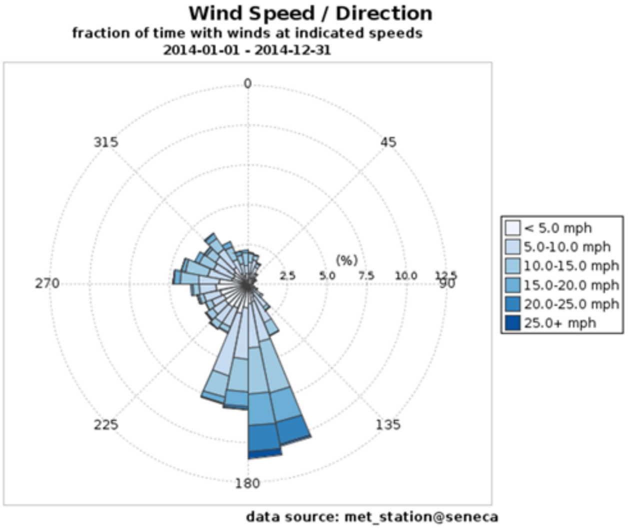


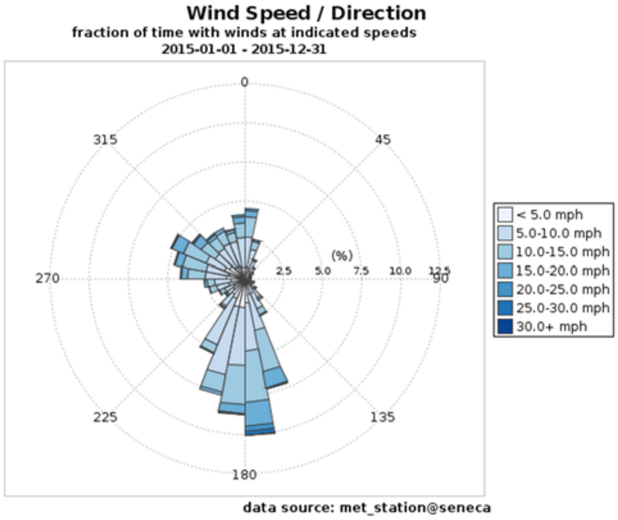
Fig. 7. Five years of surface and bottom water temperatures, total and phycocyanin (BGA) fluorescence, and daily mean air temperature, wind speed and light intensity data from the Seneca Lake FLI Buoy. The weeks Seneca Lake was on DEC's Notification Page are also shown. SLPWA's HABs database was used for 2019.

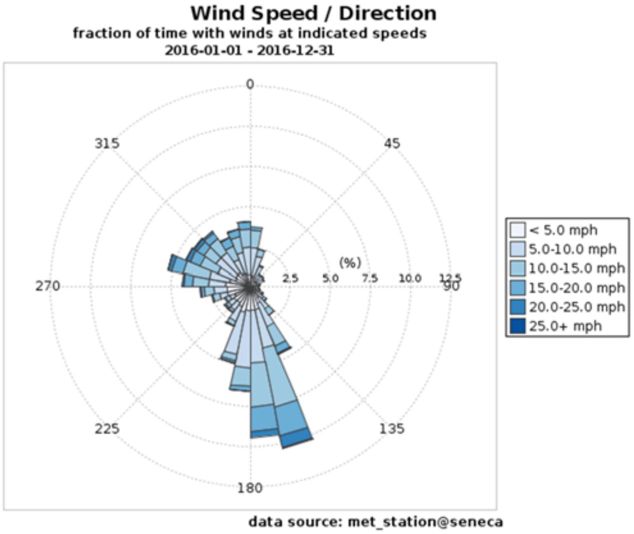
Buoy Air Temperature: Like water temperatures, the shoreline BGA blooms commonly occurred a few weeks after peak (23 to 24°C, 70-75°F) air temperatures (Fig. 7). Colder air temperatures in the fall, i.e., 10°C (50°F), coincided with seasonal end for BGA blooms. Thus, blooms prefer warm air and water temperatures, and are terminated by cold air and water temperatures. The parallel nature for air and water temperatures is not surprising because both air and water temperatures are linked to and ultimately forced by changes in solar insolation.

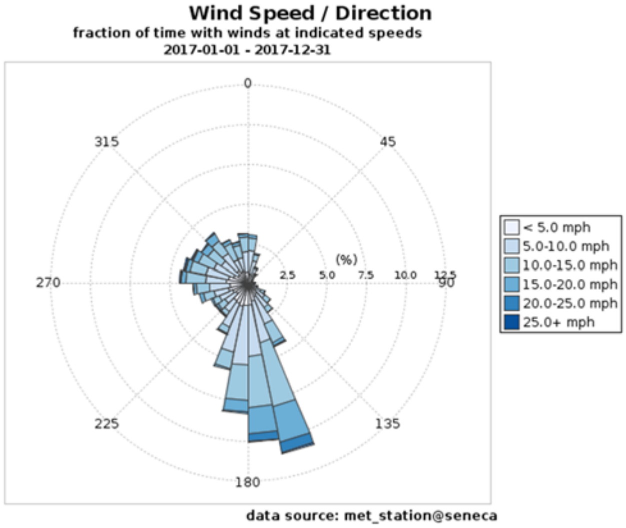
Buoy Sunlight Intensity: The first BGA blooms for the season happened after summer solstice, and BGA blooms were no longer detected in this study when mean daily insolation (sunlight) decreased from just above 340 $\mu E/cm^2$ in mid-June to below 150 $\mu E/cm^2$ by mid to late October (Fig. 7). Warmest water and air temperatures also peaked after summer solstice and all three typically 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 and nutrient levels. Thus, warmer air and water temperatures sometime 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.

Buoy Wind Speed & Direction: The summers of 2015, 2016, 2017 and 2019 were not as windy as 2018 (Fig. 7 & 8). 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). Fewer calm to light-breeze days and more days with wind speeds above 15 mph were detected during 2018. The increased wind speeds in 2018 compared to other years parallels fewer detected blooms. This suggests that BGA bloom development is more likely during calm or light-breeze days. However, BGA blooms were 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. These very large wind speeds probably mixed any BGA throughout the entire epilimnion and towards open water.









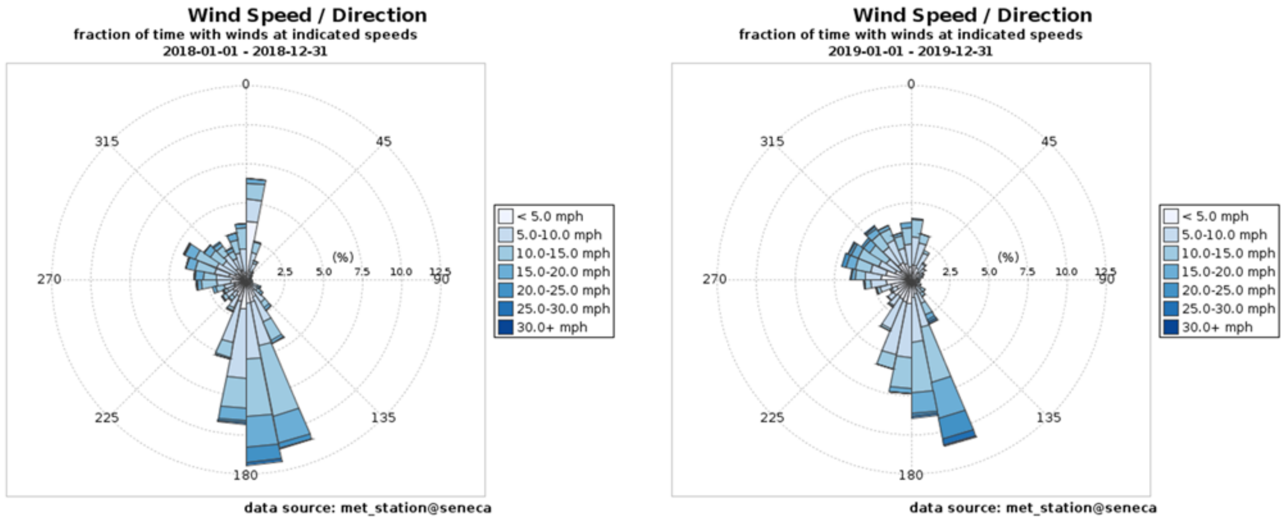
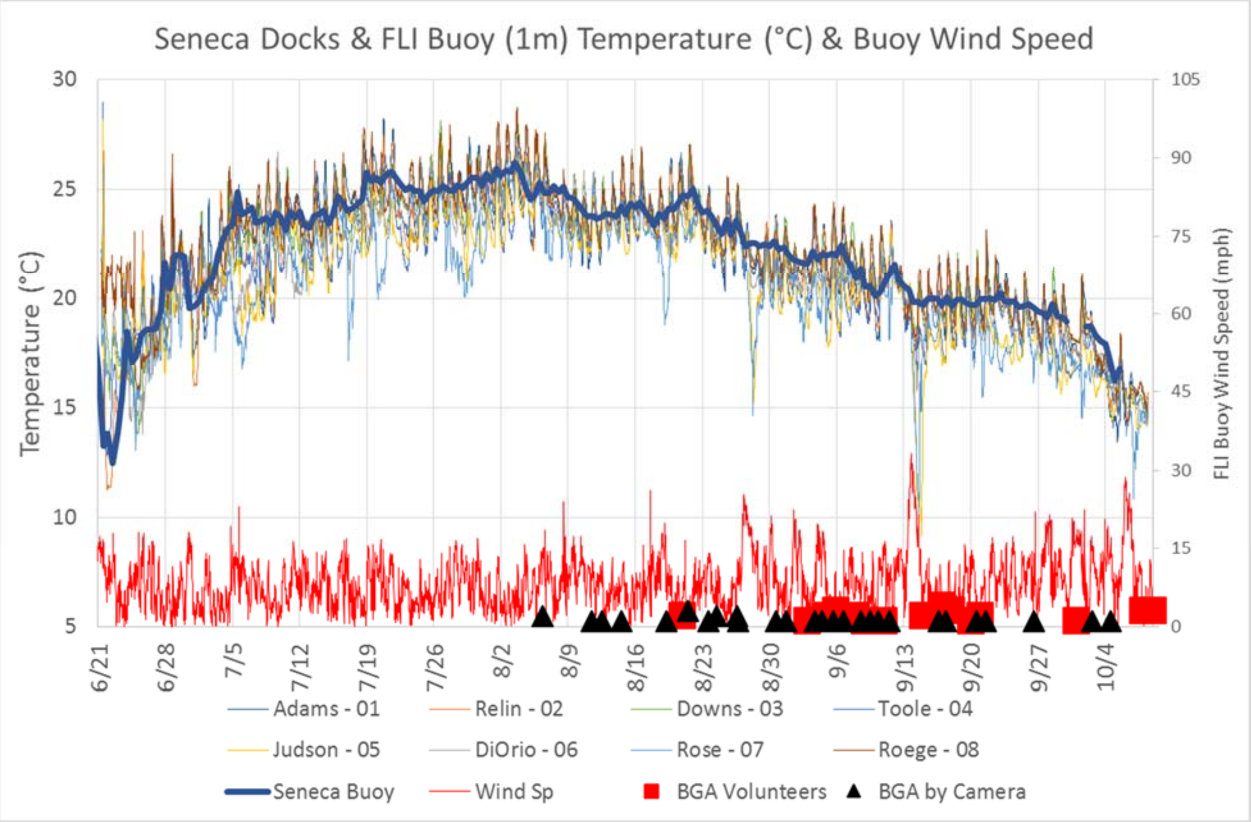


Fig. 8. Wind rose diagrams showing wind direction and speed distributions for 2014 (upper left), 2015 (upper right), 2016 (mid left), 2017 (mid right), 2018 (bottom left) and 2019 (bottom right) from the Seneca Lake FLI Buoy.

The dominant wind direction measured at the buoy was typically from just east of south, with the next most common wind directions from the west and northwest, and occasionally from the northeast over the past six years (Fig. 8). These directions are consistent with the majority of the BGA detections along the northern and northwestern margins of Seneca Lake (Fig. 3). 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 even 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 along the downwind shoreline. The nutrients released by bacterial decomposition of the accumulated organics by these winds can then stimulate the next BGA bloom.

NEARSHORE WATER TEMPERATURES

Surface water temperatures revealed nearly consistent temperature records among the eight nearshore temperature loggers (deployed at 1 m depth) and surface water (1m) temperatures detected offshore by the buoy (Fig. 9). The three southern sites, SW (Rose), SE (Judson) and SEC (Toole), experienced the largest change in daily temperatures. The water was typically cooler than the northern sites and the monitoring buoy, cooling most noticeably after a wind event. The lake floor at these southern sites descends quickly into very deep water and lacks an extended nearshore shelf observed at the other nearshore sites. Perhaps internal seiche activity and/or runoff brought colder hypolimnetic (bottom) water to these sites. The other nearshore sites typically revealed larger temperature swings and slightly warmer temperatures. The differences are expected, as extensive shallow water masses are easier to warm (and cool) than deeper water masses during sunny (or cloudy) days.



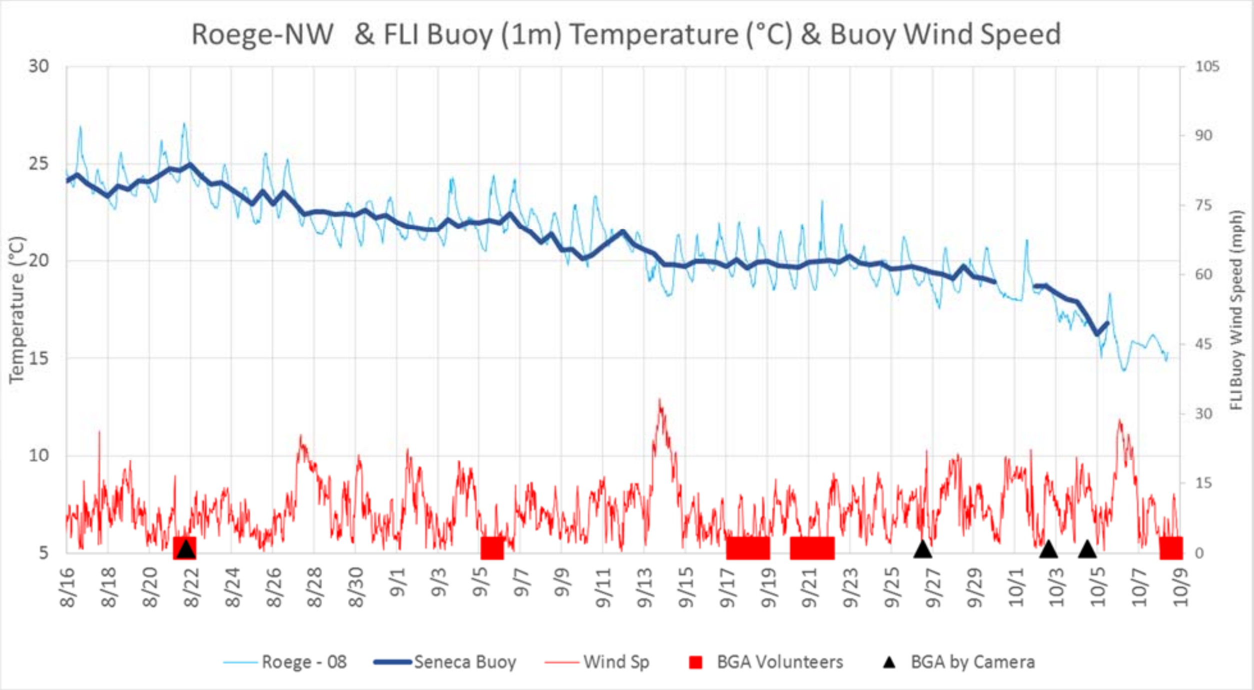


Fig. 9. The 2019 nearshore and buoy surface water temperatures, nearshore BGA blooms and mean daily wind speeds measured at the buoy (above). Data from the NW site (Roege) were also plotted separated for clarity (below). Data from every site is available in the report's data repository.

As observed since 2017 in Owasco Lake, the 2019 August and early September shoreline BGA blooms in Seneca Lake were typically preceded by a decrease (up to 5°C) in temperature. Lake-wide temperature declines in the surface water may reflect cooler air, cloudier conditions, and/or wind/storm events that generate surface waves and internal seiche activity ultimately mixing some colder hypolimnetic water into the epilimnion. This suggests that waves and internal seiche activity might be the first step in propagating BGA blooms. These same events could also introduce nutrient-rich hypolimnetic waters to the nearshore areas and release nutrients buried in nearshore sediments from decaying macrophytes and other organic matter. Runoff can also introduce nutrients to the shoreline areas and might fertilize BGA blooms.

Not every dip in temperature resulted in BGA blooms, especially those dips earlier in the summer. The delay may reflect the time required to sufficiently increase the nutrient concentrations in the hypolimnion and nearshore sediments to promote BGA blooms, because bacterial decay is faster in warmer temperatures. The macrophytes also need time to grow, mature and die. Once they die in the early fall, or get uprooted by wind events, they contribute to the stockpile of biomass, and thus nutrients, in nearshore areas.

The mixing scenario is consistent with data recorded by an YSI/Xylem EXO2 water quality sonde deployed at the NW Site (Roege) at 1m water depth in 2017 and 2018 (Fig. 10). For example, 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 lake floor sediments and made the water column turbid. Other notable wind events (e.g., 9/7, 9/8, 9/14, and 9/20) were blowing offshore, and minimized 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 within the sediments. These events were typically followed by a HAB event detected by the HABs volunteers. 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 offshore of the shoreline. This may suggest that BGA are present in the sediments and bloom under optimal conditions (i.e., nutrient augmentation, warm and calm waters), subsequently accumulating at the lake’s surface. The mid-day warmer (less dense) water would assist bloom buoyancy and lake surface accumulation.

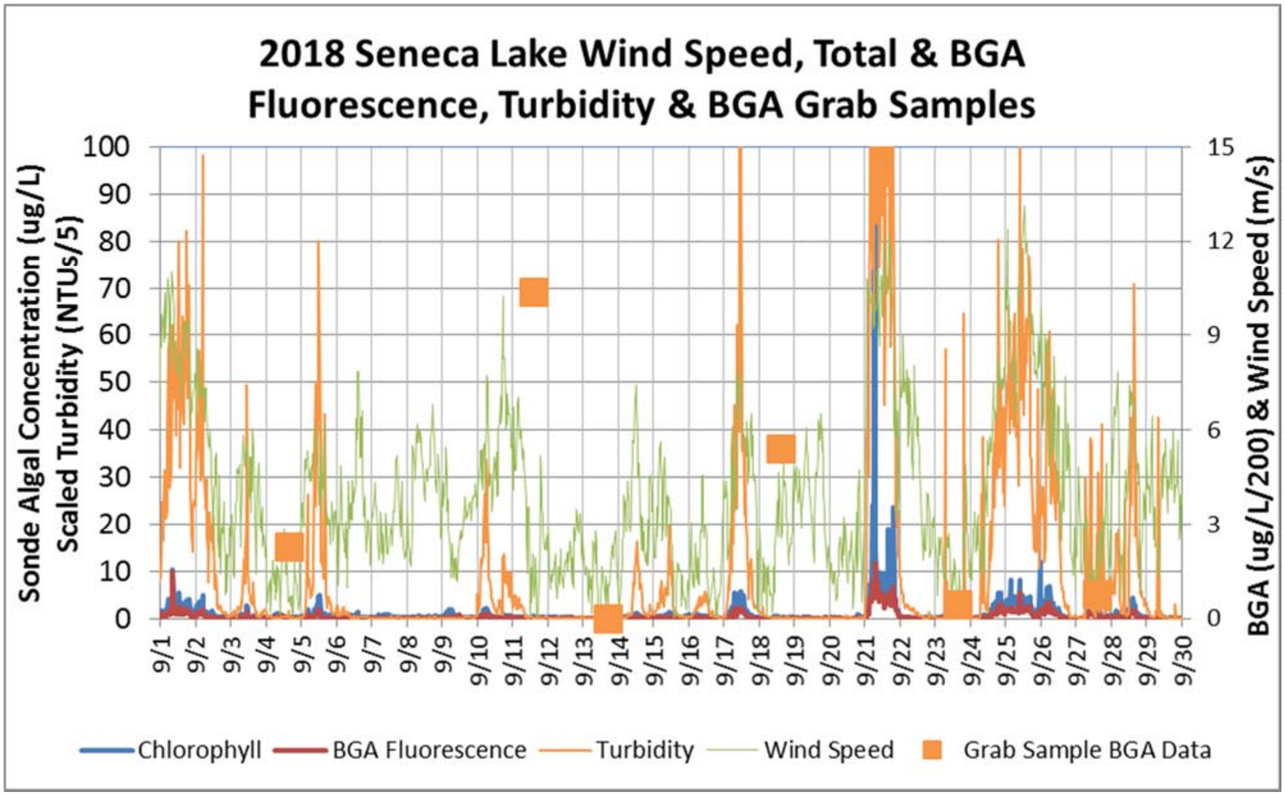


Fig. 10. Water turbidity, total and BGA fluorescence measured at the NW site, Emerson Cove, Seneca Lake by an YSI EXO2 sonde. BGA concentrations at this site were from the Seneca HABs Surveillance team (with permission). Wind speed was measured by the Seneca Lake monitoring buoy, just offshore of this shoreline location.

FLI SENSOR NODES:
The FLI Sensor Node is a student designed and built, low cost, data logger designed to record an array of environmental variables. Each self-contained unit integrates an Arduino processor, SD memory card, solar panel, associated electronic components that can log up to four commercial sensors at an estimated cost of $400 (without sensors). The FLI Sensor Node reads each sensor and saves the data on an SD card at preset time intervals. A prototype was deployed in Seneca Lake, at the NW site (Roege), to test the sensor's suitability in the field. Unfortunately, the deployed unit had sporadic power, memory and other issues.

The recoverable temperature data (~two weeks) revealed significant daily oscillations in temperature with amplitudes ranging from 1 to 4°C of the mean (Fig. 11). The water warmed during the day and cooled during the night, following the availability of sunlight. Similar daily temperature oscillations were detected at the other nearshore sites in the lake (Fig. 11). Interestingly, daily oscillations were not detected at the Buoy site. However, the 12-hour sample rate precluded detection of daily and shorter term oscillations. Similar daily temperature cycles were detected at the nearshore sites and the USGS Buoy site in Owasco Lake, as well.

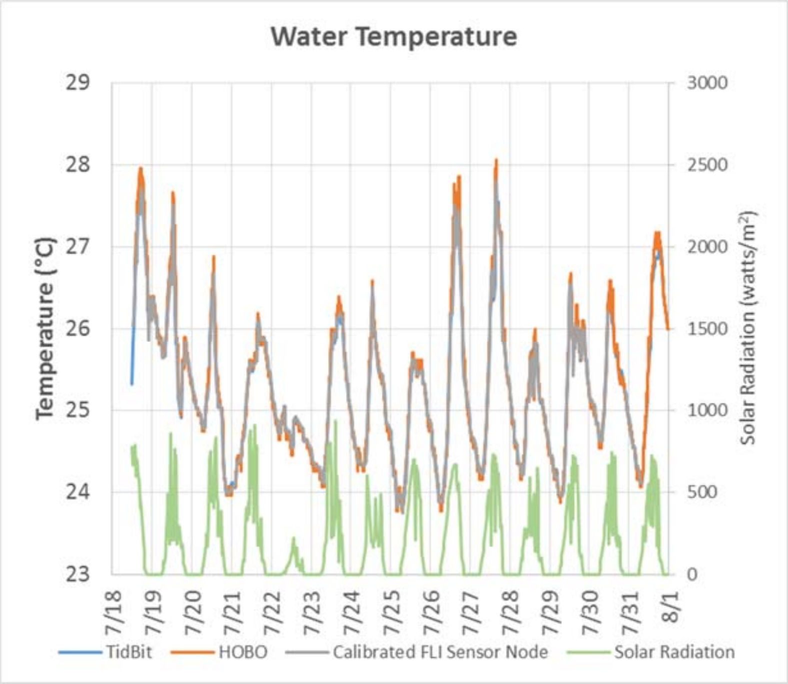


Fig. 11. Dockside FLI Sensor Node, TidBit and HOBO surface water temperatures at the NW site (Roege). The FLI temperatures were calibrated using a linear transformation to the Tidbit temperature data (r^2 of 0.97). Solar insolation measured at this site is also shown.

The thermistor string typically revealed a daily onset and decay of thermal stratification of the water column. The exception was when strong winds were blowing onshore (Fig. 12). During stratification, the 1-m thick, water column, temperatures warmed by ~4°C from the lake floor to near the lake's surface during the day. In contrast, the surface temperatures were essentially uniform and thus not stratified at night. The onset and decay of thermal stratification is consistent with warming by the sun during the day and cooling by radiative heat transfer to the atmosphere at night. When the wind was blowing, the water column stayed at a uniform temperature, i.e., waves kept the water column well mixed. This suggests that the magnitude of the daily temperature oscillations discussed above might also be due to the deployment depth of the thermistor at each site as well as the extent of shallow water conditions at the site.

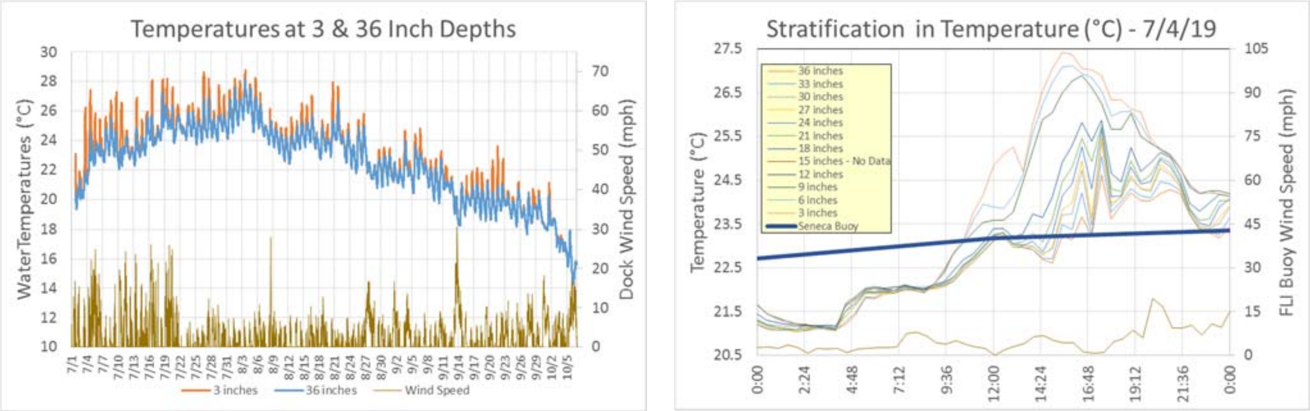


Fig. 12. Daily onset and decay of thermal stratification in the water column. The bottom and surface thermistor data are plotted over the entire field season (left) and all the logger data were plotted for 7/4 (right).

The uncalibrated and recoverable dissolved oxygen (DO) FLI Sensor Node probe also revealed daily oscillations in DO concentration that co-varied with water temperature (Fig. 13). Sufficient independent DO data were not available to calibrate the DO sensor voltage output. Regardless, the available data are informative. 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 however 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. Photosynthesis and respiration by macrophytes and phytoplankton can also affect DO concentrations. When biological activity is intense enough, oxygen is produced through photosynthesis; at night, biological activity uses oxygen from the water column (respiration by all organisms). The covariance between the temperature and DO fluctuations indicates that biology had a major impact on nearshore dissolved oxygen concentrations and suggests that respiration is important in nearshore areas. This suggests that nearshore bacterial decay could be a (or the) source of nutrients for blue-green algae growth. Similar co-variance of water temperature and dissolved oxygen was detected by an EXO2 sonde deployed at this site in previous years (Fig. 14). It suggests that commercial sondes with temperature, dissolved oxygen, turbidity and fluorescence sensors should be deployed in the future to investigate if these daily cycles are common everywhere in the lake, and if these cycles parallel changes in BGA bloom intensity and frequency.

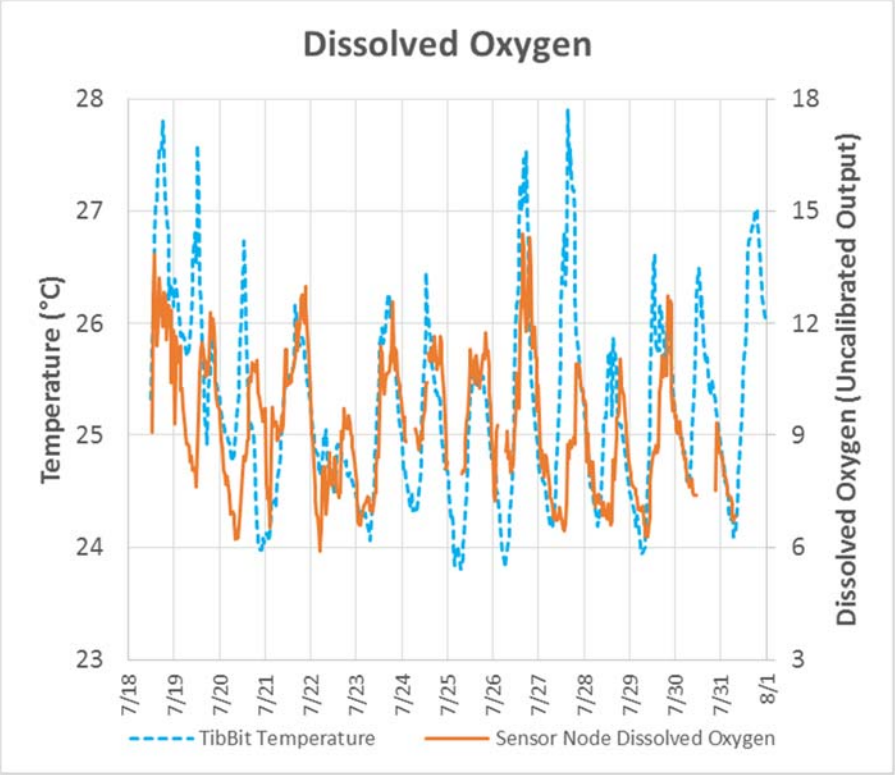


Fig. 13. FLI Sensor Node dissolved oxygen concentrations co-varied with water temperatures. The FLI Sensor Node dissolved oxygen output was not calibrated.

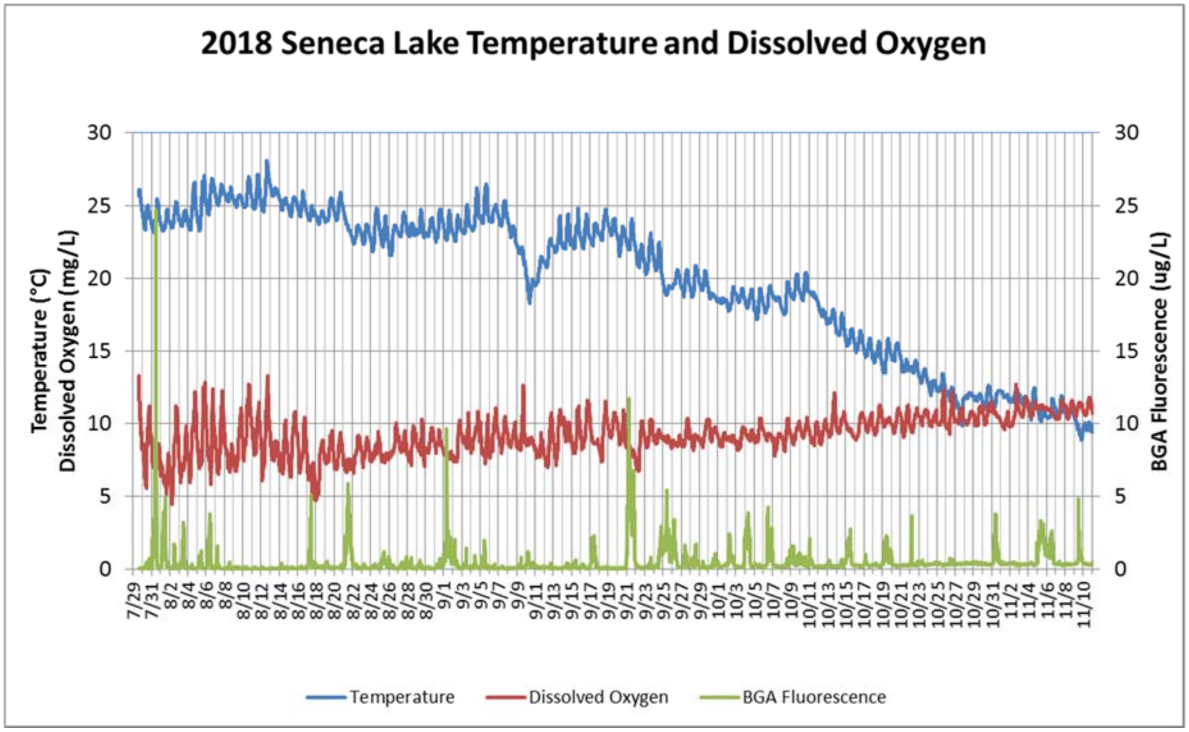


Fig. 14. Seasonal deployment of an YSI EXO2 Sonde at the NW Site (Roege) during 2017 and 2018 (2018 data shown here) also revealed seasonal daily oscillations and co-variance of water temperature and dissolved oxygen concentrations.

AUTOMATED CAMERAS:

The Brinno cameras faithfully recorded ~2 x 3 meter images of the lake every 10-minutes from 7 am to 6 pm from 6/23 through 10/8, a 108 day deployment in 2019. The cameras detected from 1 to 9 BGA appearances at each site (Table 1, Fig. 15). BGA concentrations were not concurrently measured to calibrate the image results; thus BGA detections by the camera cannot officially be called blooms but instead appearances. Experience suggests that the imaged BGA probably were not concentrated enough to be a bloom, however.

Table 1. Brinno Automated Camera Results

Camera Results (in days)	NW Roege	NWC Downs	SWC DiOrio	SW Rose	NE Adams	NEC Relin	SEC Toole	SE Judson
Blooms Detected (unknown conc.)	5	1	4	8	9	4	3	7
Clear Water (bottom was visible)	49	11	69	16	66	38	32	11
Turbid Water (bottom not visible)	41	16	38	89	42	68	74	93
Glare Impacted Image	0	19	3	13	8	5	0	16
Camera Malfunctioned	17	74*	0	0	0	0	1	1
SLPWA Volunteers (#Blooms)	9	8	4	7	1	0	2	5
Calm Winds	31	88	24	17	22	17	21	19
Sunny Skies	66	43	55	65	36	75	67	66

*faulty camera, power issues. It might have gotten wet and developed an electrical short early in the field season.

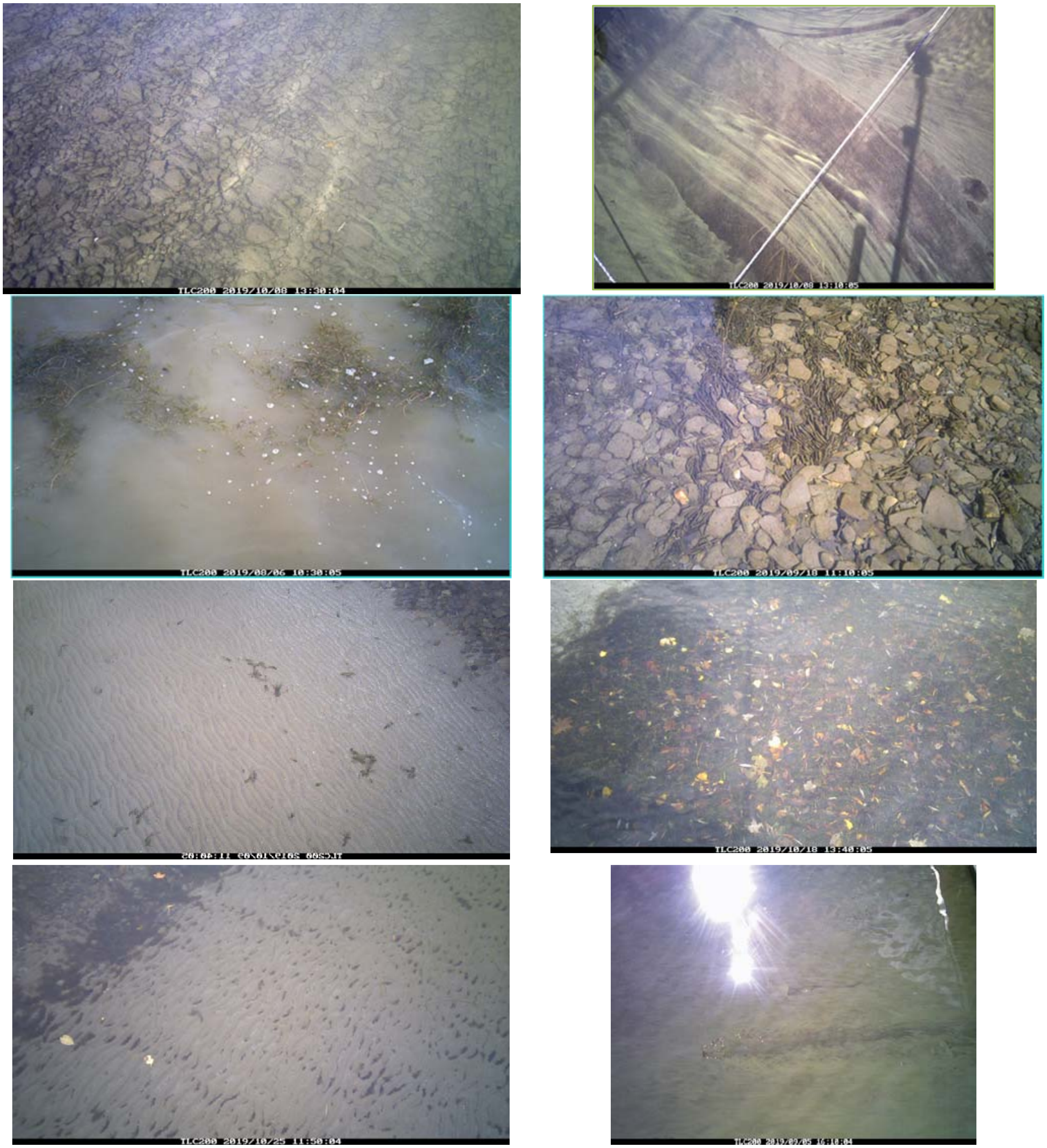


Fig. 15. Example camera images revealing BGA appearances (top photos), turbid and clear conditions (2nd row), a sandy bottom subsequently covered by leaves and organic debris (3rd row) to be subsequently sweep away by the next major set of waves (lower left). Note how glare impacted image quality and a twig influenced BGA movement at an Owasco Lake site (lower right).

Seneca Lake Pure Waters Association HABs volunteers detected a similar number of blooms in the surveillance "zones" adjacent to the camera, but blooms were typically detected on different dates by the different methods. Perhaps the SLPWA HABs volunteers missed blooms during other times of the day and/or other days of the week, and/or they surveyed entire zones along the shoreline and reported blooms outside of the camera's 3x4 meter field of view. Most importantly, the cameras imaged a portion of the lake that was far enough from the shoreline to miss the shoreline hugging blooms at these sites. It suggests that cameras should be deployed at a higher elevation and image a portion of the shoreline in the future. Spatial heterogeneity of BGA blooms has commonly been detected by drone (Fig. 16).

The images also differentiated between turbid (lake floor not visible) and clear water (lake floor visible) episodes, and occasionally detected fish, ducks and other animals. Glare from the sun did impact a portion of the afternoon images, especially when a camera pointed west or south (Downs, Judson & Rose), and suggests that cameras must be orientated to the north in future deployments.

Fig. 16. Patchy BGA blooms along the shoreline adjacent to the NW site. Each arrow points to a BGA bloom along the shoreline.

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 (lower right photo, Fig. 15). 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.

WEATHER STATION DATA:

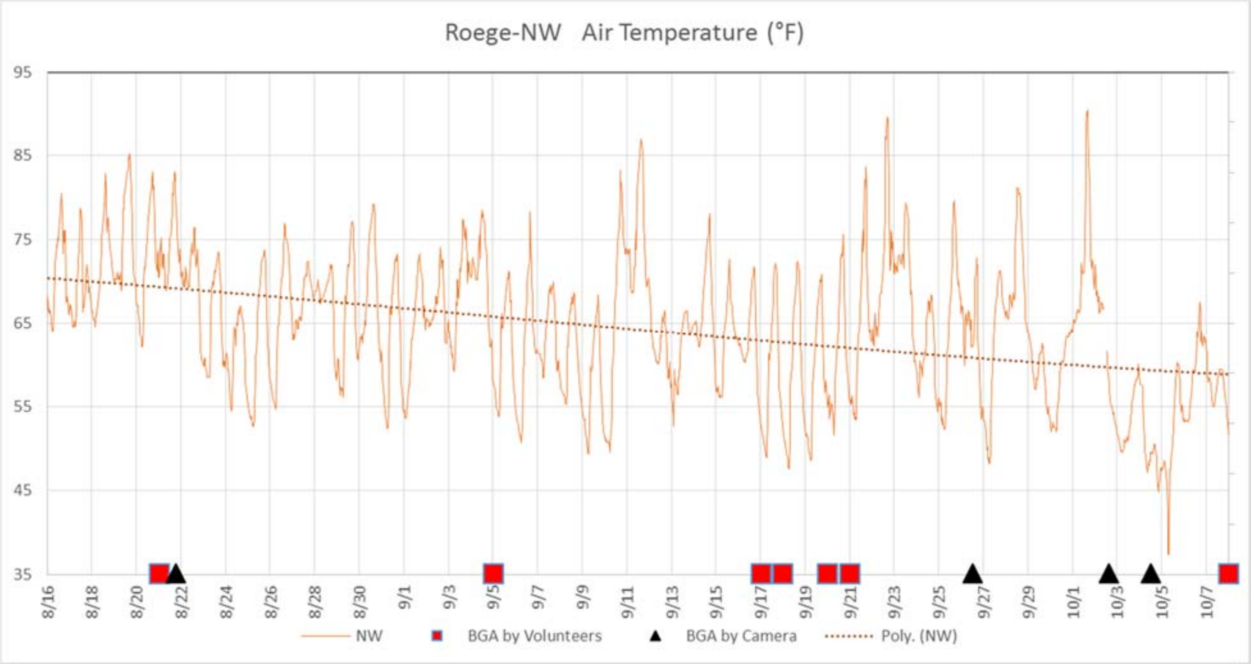
Air temperature, rainfall, solar radiation, wind speed and direction data are consistent with BGA bloom hypothesis. Data from the NW site (Roege) are shown (Fig. 17), and data from the other sites are available in the data repository. Cool air temperature, sunny skies, declining wind speed and some rainfall preceded most BGA appearances at the eight sites. For example, the mean wind speed during blooms was slower than the mean for the entire deployment (Table 2). Some exceptions exist. Perhaps all of the appearances did not fit the hypothesis because not all of the appearances were concentrated enough to be blooms. Nutrient availability is another complicating factor.

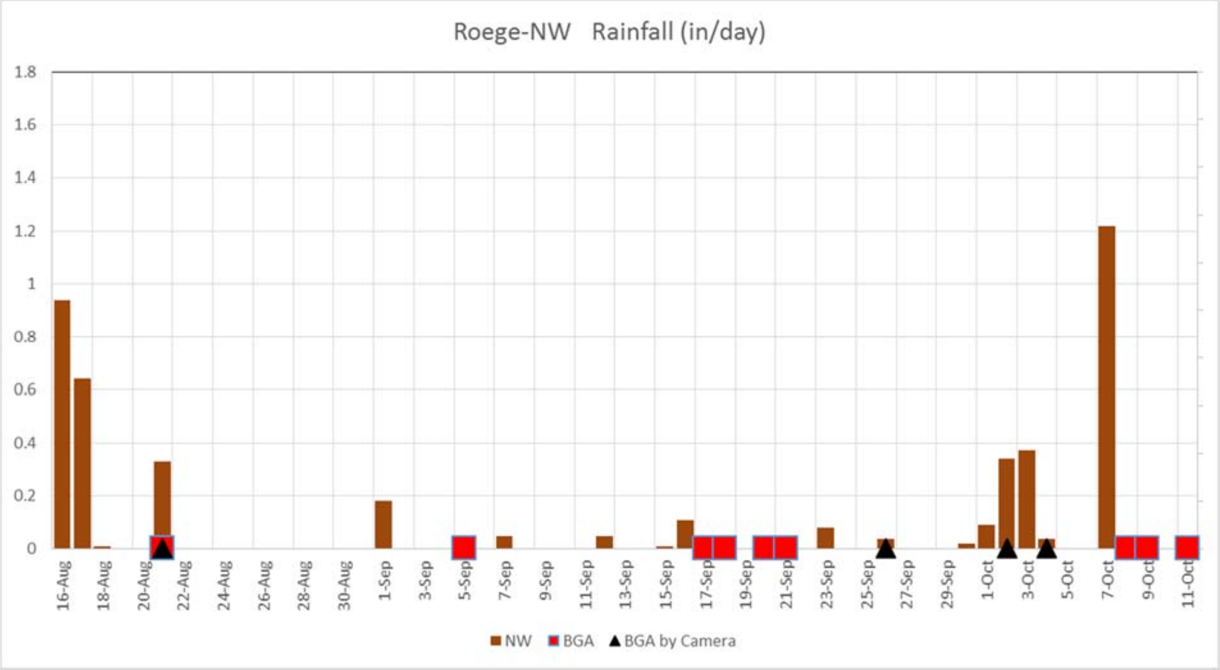
Table 2. Mean wind speeds (mph) during BGA blooms and over the entire field season.

Site	BGA Blooms	Season	Site	BGA Blooms	Season
NW-Roege	1.2	2.3	NE-Adams	0.4	2.6
NWC-Downs	0.7	2.4	NEC-Relin	0.4	0.6
SWC-DiOrio	0.0	2.1	SEC-Toole	1.1	1.9
SW-Rose	0.6	1.8	SE-Judson	0.4	2.2

Interestingly, the mean wind velocities were significantly slower at all the nearshore sites compared to the FLI buoy (Fig 18). The most frequent wind direction significantly differed at every site as well (Fig. 19). The shoreline orientation at each site probably modified non-onshore wind directions and wind speeds, and may dictate which shoreline locations will experience subdued regional winds and which do not. Onshore winds clearly impact water clarity, i.e., turbid *vs.* clear water, as mentioned above. The local variability in winds provide a plausible explanation why the water column is either turbid (windy) or clear (calm) on the same day at different sites. It also suggests another interesting speculation. If one shoreline is experiencing calm and sunny conditions, and a bloom appears, the other shorelines may not develop a bloom because it may be experiencing onshore winds. It may explain why BGA blooms appear along different segments of shoreline on different days. Additional sites should be monitored in the future to statistically confirm this hypothesis.

Rainfall also varied from site to site (Fig. 20). The variability was significant, from no rain at a number of sites to nearly 2 inches of rain at another site on the same day. In general, however, more sites detected rainfall when more rain fell in any given day was detected at the sites. The variability is due to numerous factors including localized, intense thunderstorms, orographic lifting to lake effect enhancements.


Roege-NW Air Temperature (°F)
95
85
75
65
55
45
35
8/16
8/18
8/20
8/22
8/24
8/26
8/28
8/30
9/1
9/3
9/5
9/7
9/9
9/11
9/13
9/15
9/17
9/19
9/21
9/23
9/25
9/27
9/29
10/1
10/3
10/5
10/7
NW
BGA by Volunteers
BGA by Camera
Poly. (NW)


Roege-NW Rainfall (in/day)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
16-Aug
18-Aug
20-Aug
22-Aug
24-Aug
26-Aug
28-Aug
30-Aug
1-Sep
3-Sep
5-Sep
7-Sep
9-Sep
11-Sep
13-Sep
15-Sep
17-Sep
19-Sep
21-Sep
23-Sep
25-Sep
27-Sep
29-Sep
1-Oct
3-Oct
5-Oct
7-Oct
9-Oct
11-Oct
NW
BGA
BGA by Camera

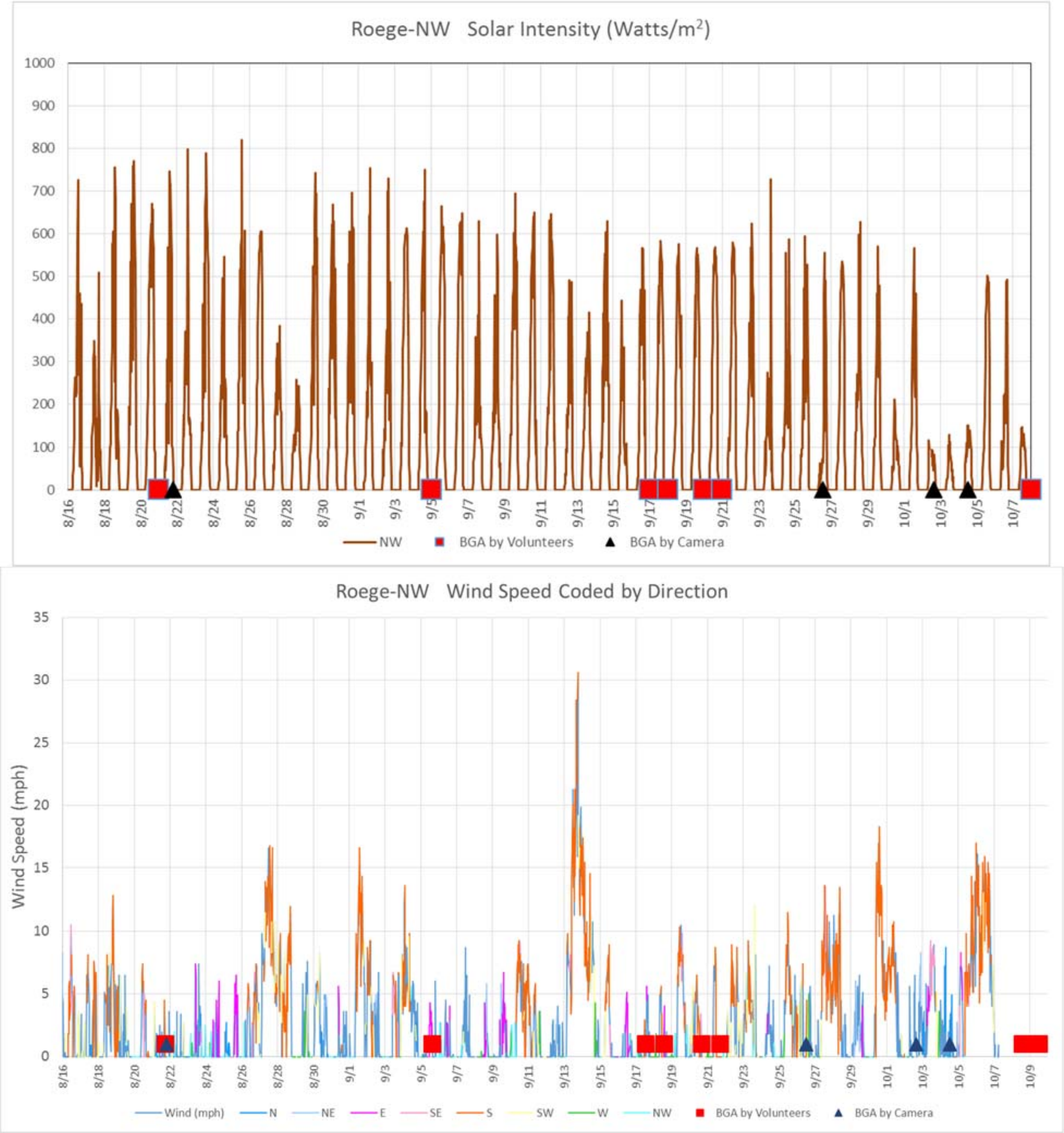


Fig. 17. Dockside air temperature, daily rainfall, solar intensity and wind speed data from the NW site (Roege). Wind speed is color coded by its direction. The red boxes mark dates when BGA were observed by the SLWPA HABs volunteers, the black triangles mark dates when BGA were imaged by the camera at the site. Plots for the other sites are located in the data repository.

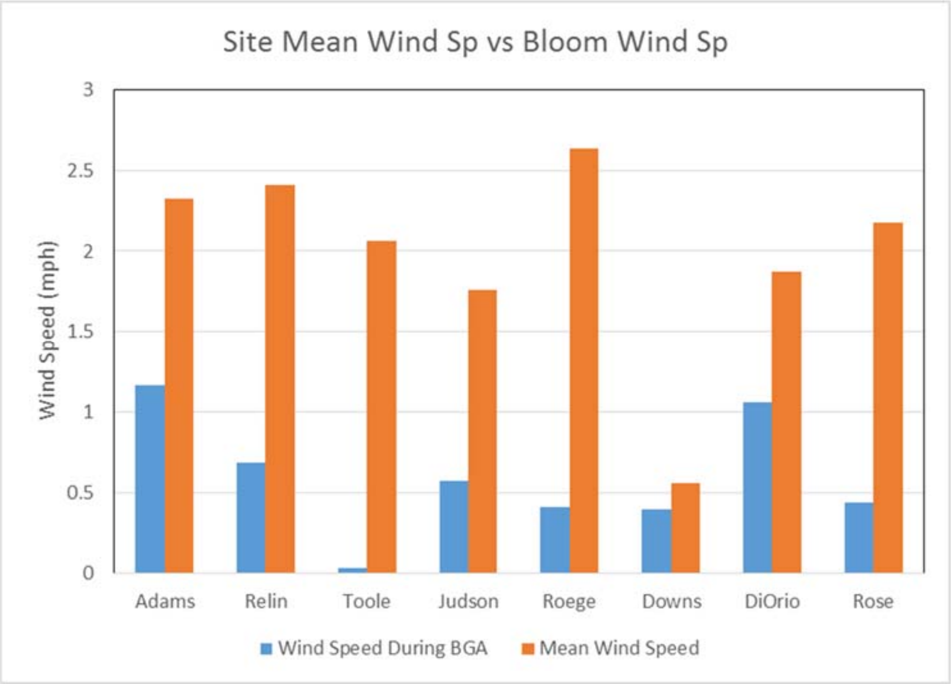


Fig. 18. Mean wind speed during detected blooms and over the entire field season at each site.

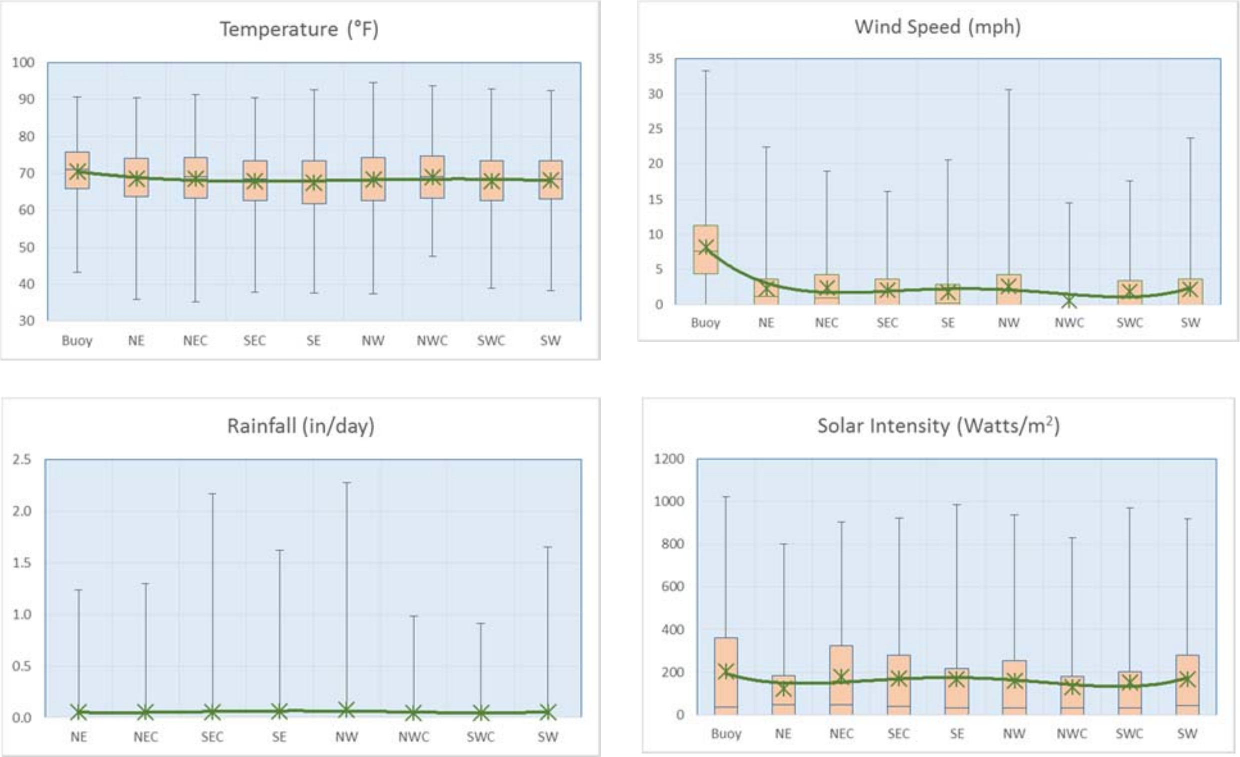
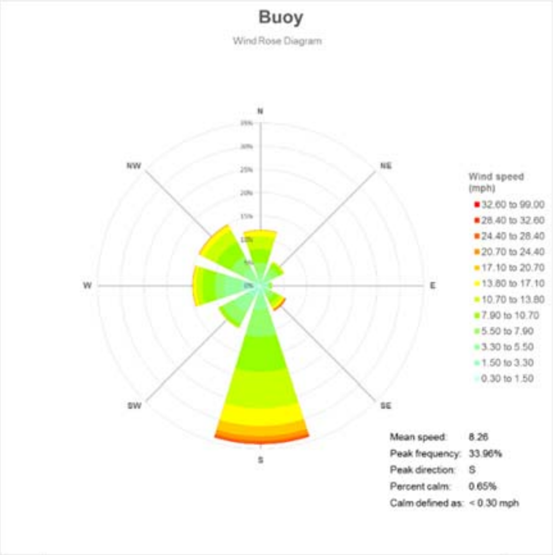
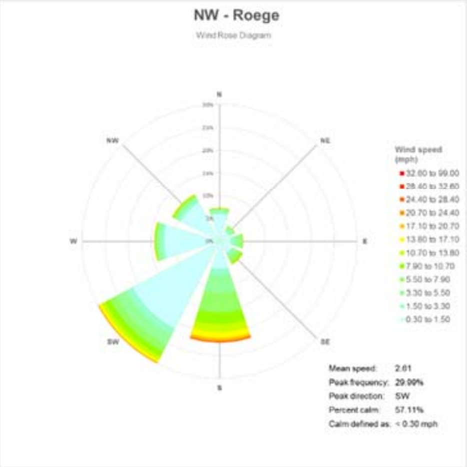
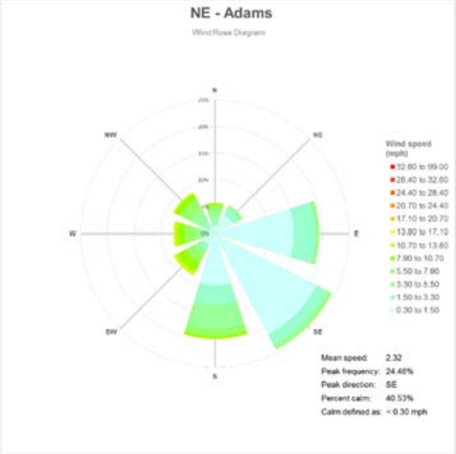
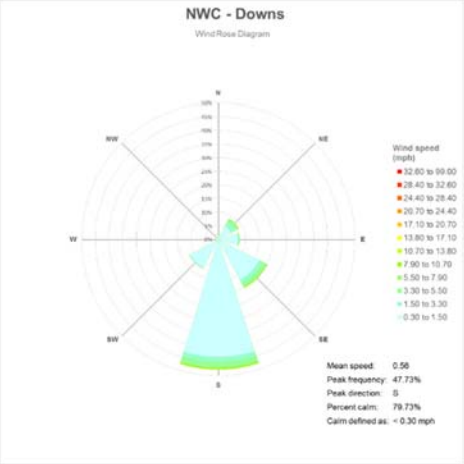


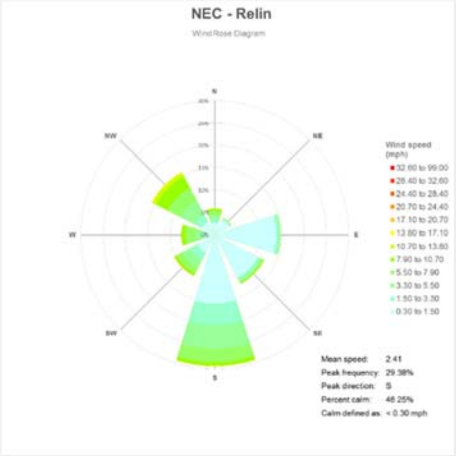
Fig. 18 cont. Box and whisker plots of air temperature (upper left), wind speed (upper right), rainfall (lower left) and solar intensity (lower right) at the eight sites and the FLI Monitoring Buoy. The buoy does not detect rainfall.


Buoy
Wind Rose Diagram
N
NE
E
SE
S
SW
W
NW
Wind speed (mph)
32.60 to 99.00
28.40 to 32.60
24.40 to 28.40
20.70 to 24.40
17.10 to 20.70
13.80 to 17.10
10.70 to 13.80
7.90 to 10.70
5.50 to 7.90
3.30 to 5.50
1.50 to 3.30
0.30 to 1.50
Mean speed: 8.26
Peak frequency: 33.96%
Peak direction: S
Percent calm: 0.65%
Calm defined as: < 0.30 mph


NW - Roege
Wind Rose Diagram
N
NE
E
SE
S
SW
W
NW
Wind speed (mph)
32.60 to 99.00
28.40 to 32.60
24.40 to 28.40
20.70 to 24.40
17.10 to 20.70
13.80 to 17.10
10.70 to 13.80
7.90 to 10.70
5.50 to 7.90
3.30 to 5.50
1.50 to 3.30
0.30 to 1.50
Mean speed: 2.61
Peak frequency: 29.99%
Peak direction: SW
Percent calm: 57.11%
Calm defined as: < 0.30 mph


NE - Adams
Wind Rose Diagram
N
NE
E
SE
S
SW
W
NW
Wind speed (mph)
32.60 to 99.00
28.40 to 32.60
24.40 to 28.40
20.70 to 24.40
17.10 to 20.70
13.80 to 17.10
10.70 to 13.80
7.90 to 10.70
5.50 to 7.90
3.30 to 5.50
1.50 to 3.30
0.30 to 1.50
Mean speed: 2.32
Peak frequency: 24.46%
Peak direction: SE
Percent calm: 40.53%
Calm defined as: < 0.30 mph


NWC - Downs
Wind Rose Diagram
N
NE
E
SE
S
SW
W
NW
Wind speed (mph)
32.60 to 99.00
28.40 to 32.60
24.40 to 28.40
20.70 to 24.40
17.10 to 20.70
13.80 to 17.10
10.70 to 13.80
7.90 to 10.70
5.50 to 7.90
3.30 to 5.50
1.50 to 3.30
0.30 to 1.50
Mean speed: 0.56
Peak frequency: 47.73%
Peak direction: S
Percent calm: 79.73%
Calm defined as: < 0.30 mph


NEC - Relin
Wind Rose Diagram
N
NE
E
SE
S
SW
W
NW
Wind speed (mph)
32.60 to 99.00
28.40 to 32.60
24.40 to 28.40
20.70 to 24.40
17.10 to 20.70
13.80 to 17.10
10.70 to 13.80
7.90 to 10.70
5.50 to 7.90
3.30 to 5.50
1.50 to 3.30
0.30 to 1.50
Mean speed: 2.41
Peak frequency: 29.38%
Peak direction: S
Percent calm: 46.25%
Calm defined as: < 0.30 mph

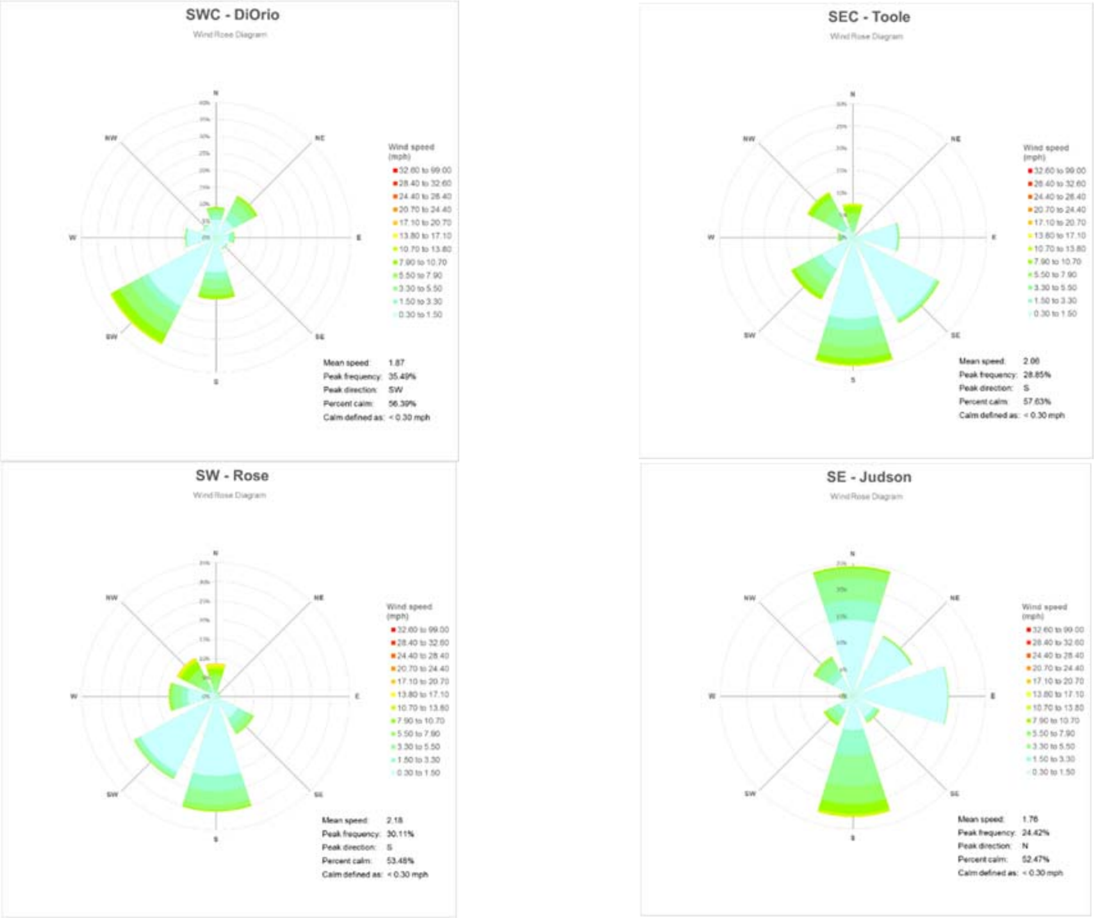


Fig. 19. Rose diagrams of wind speed and direction at the eight sites and the FLI Monitoring Buoy.

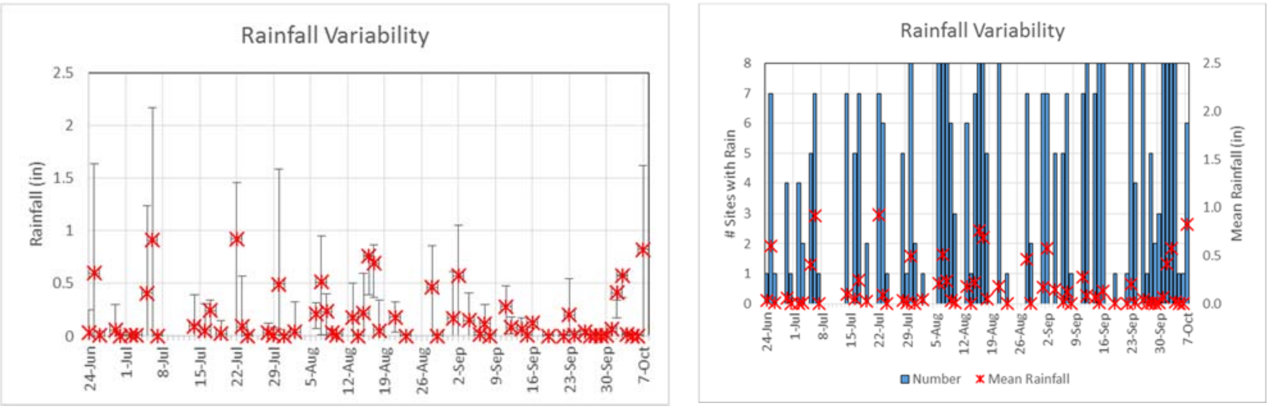


Fig. 20. Rainfall variability between sites. The mean, and minimum and maximum range for rainfall on any given day (left), and the mean rainfall and number of sites with any rain on any given day (right)

NEARSHORE ALGAL CONCENTRATIONS AND ALGAL GROUPS:

The bbe FluoroProbe surface water, grab sample, data revealed the dominance of diatoms and cryptophytes with lesser amounts of green algae and blue-green algae throughout the survey (Fig. 21). At the nearshore sites, mean epilimnetic total fluorescence concentrations averaged

2.7 μm/L and only exceeded 10 μg/L (mesotrophic/eutrophic threshold) in three of 70 samples during the project. BGA concentrations averaged 0.9 μg/L, and ranged from 0 to 7.6 μg/L at the nearshore sites. Otherwise BGA concentrations were low, only exceeding 2 μg/L in four nearshore samples. BGA (cyanobacteria) concentrations were higher in September and October, as expected. No noticeable change in total chlorophyll or BGA chlorophyll concentrations were detected on the same day when BGA were also detected by the HABs Volunteers or by the automated cameras (denoted by blue arrows). This is surprising but may reflect the spatial and temporal variability in bloom concentrations, even along the length of a dock. The majority of the offshore data revealed more chlorophyll than the nearshore sites (Fig 22). In open water all of the algae must be free-floating forms to gain enough sunlight for photosynthesis. In contrast, algae can also live attached to the lake floor and other surfaces in the nearshore area, because sunlight reached the lake floor. Thus, if both regions had an equal quantity of biomass, the nearshore biomass would be split between the water column and the lake floor, resulting in smaller nearshore algal concentrations in the water column.

NEARSHORE NUTRIENT AND TOTAL SUSPENDED SOLIDS CONCENTRATIONS:

Total phosphorus (TP), soluble reactive phosphate (PO_4), total nitrogen (TN), nitrate/nitrite (NO_3/NO_2), ammonium (NH_4), and total suspended solid (TSS) concentrations at each nearshore site, and offshore concentrations were typical for Seneca Lake (Fig. 22). Minimal site to site and day to day variability in the limnological parameters was observed (Fig. 23). Total and soluble reactive phosphorus concentrations were slightly larger and significantly more variable at the nearshore sites than offshore. This suggests that biota at the offshore sites are limited by phosphorus and/or watershed sources such as streams and lawn runoff are responsible for loading phosphorus to shallow nearshore areas. . Nitrate/nitrite concentrations in each sample were always higher than ammonium concentrations. Interestingly, the NW site (Roege) had the largest nitrate concentration, and the NE site (Adams) had the largest ammonium concentration but large values did not corresponded to a BGA bloom at the site. The reason is unclear at this time but may reflect the total amount of ammonium released by bacterial decomposition of organic matter, and then removed by oxidation to nitrate at each site. The NW site (Roege) had significantly more suspended solids than the other nearshore sites, and all of the nearshores sites had larger suspended solids concentrations than the offshore data. This is expected as waves effectively stir up the bottom sediments along the shoreline, where the waves can erode and disturb lake floor sediments. The NW site experienced larger mean wind speeds, implying more water column turbidity. The other variables, nitrate/nitrate, total nitrogen, and BGA concentrations revealed little change in the available data, even when BGA blooms were or were not detected at the nearshore sites.

Nutrient concentrations at the nearshore sites were similar to the offshore data. This similarity is surprising because significantly more nutrients are required to supply the massive nearshore BGA blooms. However, greater biomass is present in nearshore areas so any available nutrients can also be rapidly assimilated by plankton, plants and bacteria. Carbon, nitrogen and phosphorus ratios in algae are consistently at the Redfield ratio, 106:7:1 by atom (or 40:7:1 by mass). It implies that a 10,000 μg/L nearshore BGA bloom contains over 200 μg/L of soluble reactive phosphorus. Soluble reactive phosphorus concentrations rarely exceeded a few μg/L in the water column, and thus are deficient by one to two orders of magnitude than what was assimilated by the BGA. The next likely source for sufficient nutrients is the sediments. It suggests that BGA growth utilized nutrients in the upper sediments or from the decay of macrophytes washed up along the shoreline. Once grown, they may buoyantly rise from the sediments to the surface of the lake to form a bloom when the lake is calm. This hypothesis is consistent with "growing" BGA from lake bottom sediment placed in a sunlit flask with some filtered lake water.

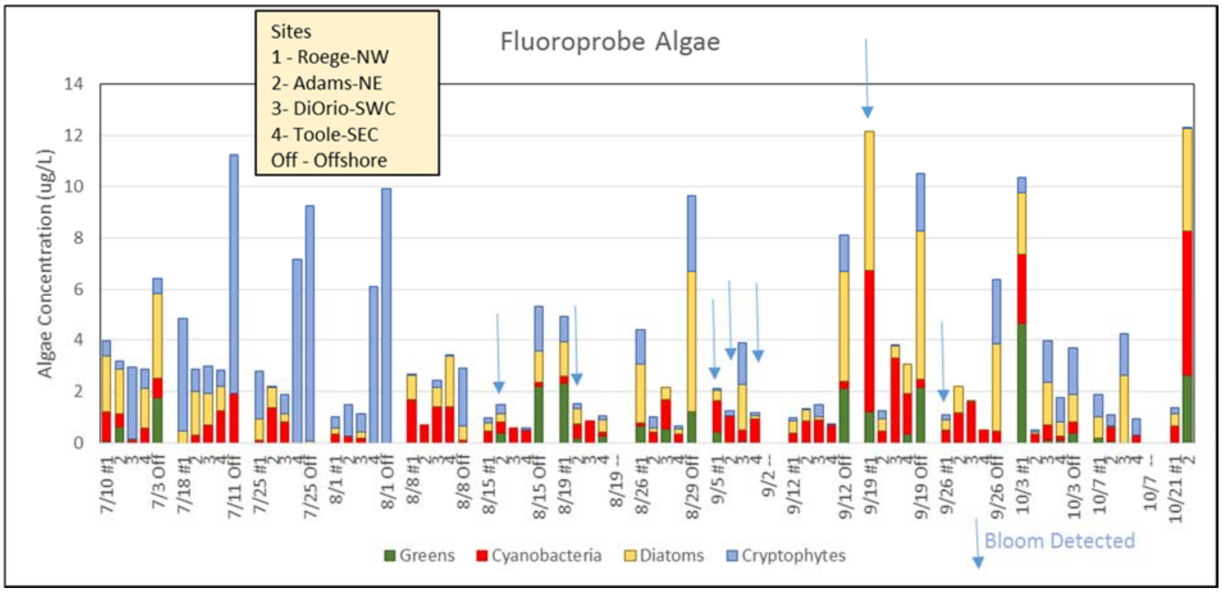


Fig. 21. bbe FluoroProbe algal group concentrations at each nearshore site and an offshore surface-water concentration (when available) on each survey date. Arrows indicate dates with detected blooms at the site.

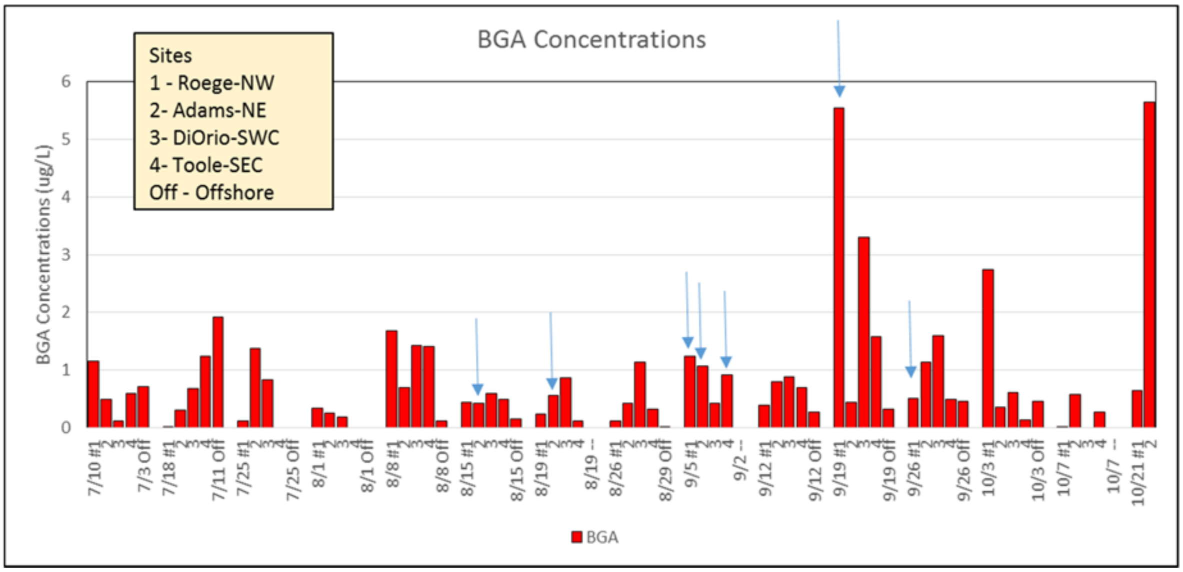


Fig. 22. Blue-green algae concentrations at each nearshore site and an offshore surface-water concentration (when available) on each survey date. Arrows indicate dates with detected blooms at the site.

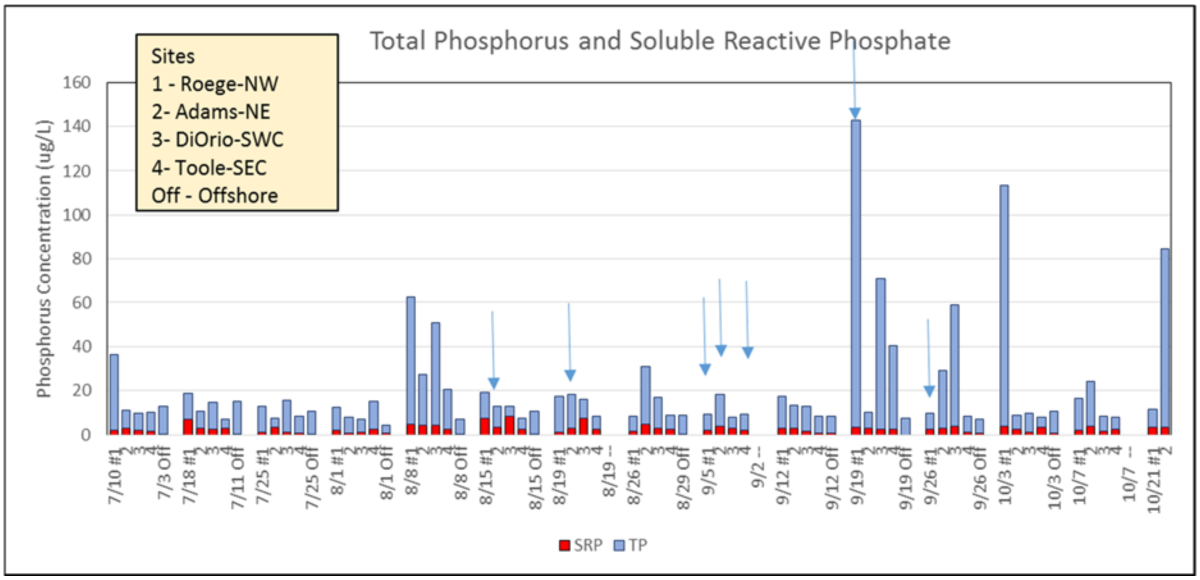


Fig. 22 cont. Total phosphorus (top of bar) and soluble reactive phosphate concentrations at each nearshore site and an offshore surface-water concentration (when available) on each survey date. Arrows indicate dates with detected blooms at the site.

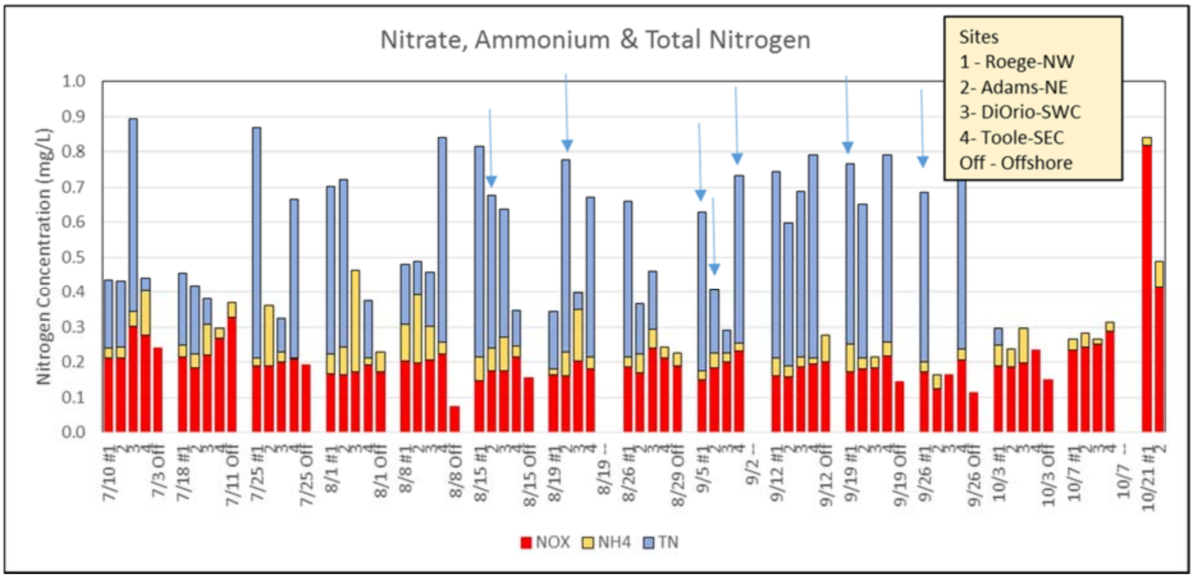


Fig. 22 cont. Total nitrogen (top of bar), nitrate/nitrite and ammonium concentrations at each nearshore site and an offshore surface-water concentration (when available) on each survey date. Arrows indicate dates with detected blooms at the site. The October dates are missing TN data.

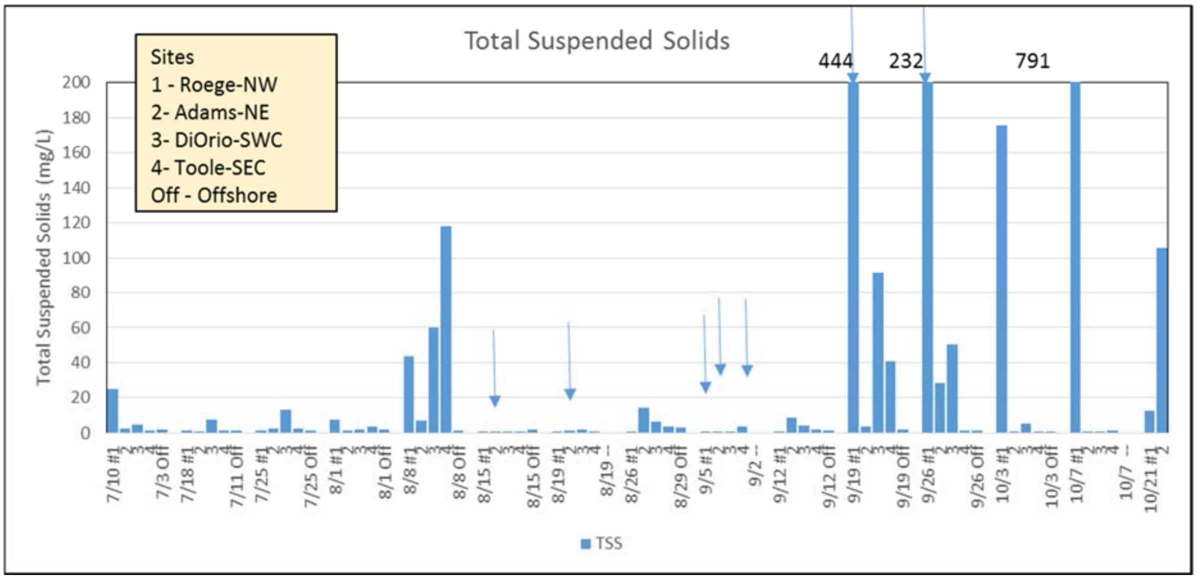


Fig. 22 cont. Total suspended solids concentrations at each nearshore site and an offshore surface-water concentration (when available) on each survey date. Arrows indicate dates with detected blooms at the site.

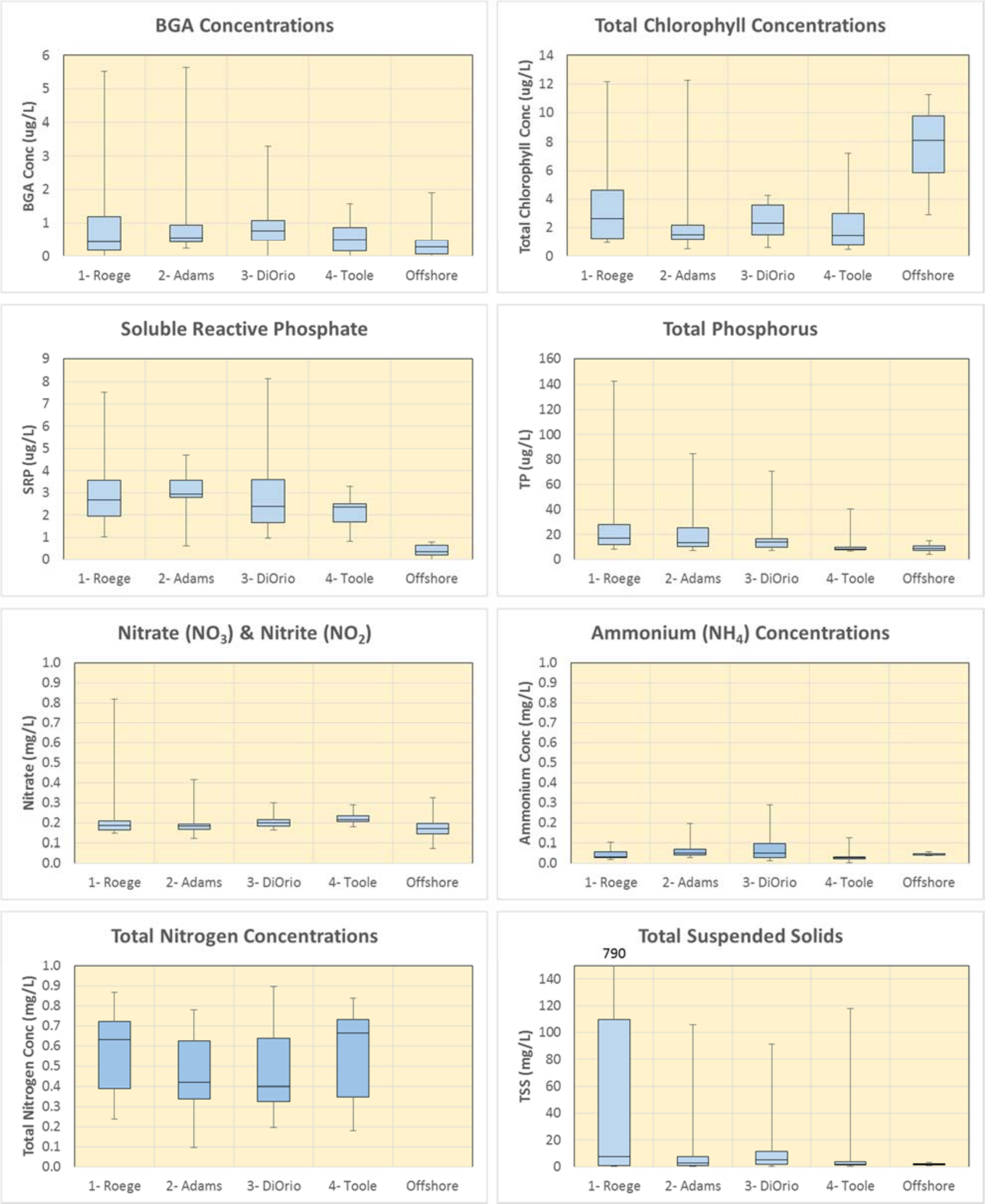


Fig. 23. Nearshore to offshore spatial comparison of the limnological data.

SUMMARY AND FUTURE RESEARCH:

- Surface water temperature across the lake typically decreased just before BGA blooms. The declines indicate that wind and/or storm events and the associated waves that likely caused the water temperature decrease also disturbed the sediments resulting in nutrients release to stimulate nearshore BGA blooms. The actual bloom typically (but not always) occurred until the next sunny and calm day.
- The prototype FLI Sensor Node had challenges in the field. When it worked, the data revealed significant, 2 to 4°C, daily oscillations in temperature. These oscillations were detected at every nearshore site. Sample frequency by the buoy was not fast enough to detect similar oscillations offshore.
- The FLI Sensor Nodes also detected daily oscillations in dissolved oxygen concentrations increasing during the day and decreasing at the night. This suggests that photosynthesis by algae and macrophytes during the daylight and respiration by organisms, especially at night, was important in the nearshore environment. Perhaps bacterial decay of organic matter would build up enough nutrients in the sediments to support the BGA bloom populations. This suggests that commercial sondes that measure temperature, dissolved oxygen, total chlorophyll and BGA chlorophyll should be deployed at numerous sites to test this relationship and any linkages to BGA blooms.
- 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. This suggests that a current meter should be deployed at one site (they are expensive) to investigate nearshore currents.
- The automated cameras detected BGA. The cameras detected blooms missed by local HABs volunteers; and conversely, the volunteers detected blooms missed by the cameras. The volunteer weekly surveys may have missed blooms at times (e.g., away from lake, not looking at lake). Volunteer survey of an entire shoreline zone may have also detected shoreline blooms outside of the camera's 2x3 meter field of view. This suggests that the cameras should be deployed at a higher elevation and/or closer to the shoreline where the largest blooms are observed. Automated image processing software would greatly increase the analysis of the movie files. Concurrent algal concentration data could provide a correlation between image quality and BGA concentrations as well.
- Automated cameras should be deployed underwater at a number of depths below the lake's surface and locations away from the shoreline to determine if BGA buoyantly rise from the sediments or migrate out away from the shoreline before a bloom.
- Wind speeds decreased and wind directions were different between nearshore areas, and between the nearshore areas and the mid-lake buoy data. The shoreline orientation most likely impacts the regional winds, and because each orientation is unique, each site is impacted by a unique wind field. Variability in winds along the shoreline suggests that one shoreline can experience calm conditions and a BGA bloom, whereas neighboring shorelines with different orientations may experience sufficient winds to retard bloom development at the lake's surface. The scenario provides a likely reason why surface blooms are localized in time and space. Nutrient availability probably impacts bloom development as well.
- The nearshore sites never had sufficient nutrient concentrations in the water column to support the observed BGA blooms in Seneca Lake. This suggests that nutrients are rapidly cycled and the sediments along the shoreline might be a recurring source of nutrients.

Nutrient concentrations and the flux of nutrients from the sediments to the water column should be measured in the nearshore sediments to investigate this speculation.

- These sites must be surveyed in the future to gather a large enough database to statistically model the wind, nutrient release, calm conditions, and BGA bloom hypothesis.
- The Seneca Lake weekly monitoring program and the FLI water quality monitoring buoy should be continued in the future to maintain an important reference dataset. The buoy faithfully records ecological change over time.

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WEATHER STATION, WATER TEMPERATURE AND FLI SENSOR NODE QA/QC

The weather station wind speeds, wind directions and air temperatures were periodically (35 times, ~ 4 times at each site) compared to data from a Kestral 5000 pocket weather meter and a cell phone compass. Even though the handheld and compass data were not measured at exactly the same time as the weather station recordings, the mean deviation in wind speeds was 0.04 mph, mean deviation in wind direction was 1.3° and mean deviation in air temperature was 2.0°C. The linear correlation between different data sources were $r^2 = 0.51$, $r^2 = 0.88$, and $r^2 = 0.89$, respectively. The low correlation for wind speeds could be due to, in part, the variability in the data measured by the weather station as the mean range in weather station wind speeds between the three closest readings was 3.3 mph. Unfortunately, the FLI Sensor node was not operating properly to compare the dissolved oxygen sensor to the measured, bi-weekly, titration data. The available FLI Sensor Node water temperature data was compared to the adjacent TidBit or HOBO data logger deployed at two sites. The r^2 were 0.98 and 0.93, and mean deviation of the temperature readings were 0.04°C and 0.001°C. Finally, a comparison of TidBit and HOBO water temperature data deployed at the same site resulted in an r^2 of 0.99 and a mean deviation of 0.02°C. Unequal deployment depths probably influenced the mean difference in temperature due to the observed daily onset and decay of thermal stratification by up to 4°C at these sites.