BLUE-GREEN ALGAE IN OWASCO LAKE, THE 2018 UPDATE.
THE 2018 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 in 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 an open-water comparison to the nearshore data.

This report details our findings from the second year of this three year award, and proposes recommendations to focus additional research efforts in the third year. The second year of research 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 collected data from this effort also increased our understanding of shoreline BGA blooms in the lake. The results of the OLWA project are detailed elsewhere[1] but pertinent information will be included in this report. Both projects complement and dovetail nicely with the lake/watershed monitoring effort supported by Cayuga County through the Owasco Lake Watershed Municipal Council. All three reports are available online at Halfman's web site (http://people.hws.edu/halfman/)[2]. A summary of our findings, future research and other recommendations are on pages 3 & 4.

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[1] Halfman, et al., 2018. Final Report on the Owasco Lake HAB Inhibiting Technologies Assessment. Submitted to Owasco Lake Watershed Association. Finger Lakes Institute, Hobart & William Smith Colleges. 57 pgs.

[2] Halfman, et al., 2018. The 2018 Water Quality Monitoring Report for Owasco Lake, NY. Submitted to Cayuga County & Owasco Lake Watershed Municipal Council. Finger Lakes Institute, Hobart & William Smith Colleges. 47 pgs.

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. Conclusions based on this work include:

- Algal growth is limited by phosphorus in Owasco Lake.
- Annual mean, open-water, total phosphorus concentrations are insufficient to support the amount of phosphorus required for the BGA shoreline blooms measured to date.
- Estimated annual phosphorus budgets for the lake revealed larger inputs than outputs.
- Nonpoint sources of nutrients from, e.g., runoff from agricultural areas, roadside ditches and construction sites, dominated the phosphorus loads to the lake. Over 95% of the total loads were delivered to the lake during precipitation events.
- Various best management practices should continue to be implemented and expanded to reduce nonpoint and point sources of nutrients, especially phosphorus, to the lake.

The HABs Mitigation Technology Assessment Project supported by Owasco Lake Watershed Association focused on samples collected from eleven homeowner’s docks along the shoreline. Findings from this project include:

- BGA blooms are transitory over both space and time, i.e., spanning across short segments of shoreline and lasting only a few hours.
- The BGA bloom transitory nature and potential linkages to meteorological events indicate that an array of water quality sensors that measure, e.g., fluorescence (total and BGA), turbidity, temperature, dissolved oxygen, and meteorological sensors that measure, e.g., wind speed, wind direction, air temperature, precipitation and light intensity, should be deployed at numerous sites to monitor these parameters every 30 minutes during the HABs season to better understand the limnological and atmospheric conditions associate with the appearance and disappearance of BGA blooms.
- The mitigation technology assessment was inconclusive because the weekly dockside samples never coincided with a bloom.

The first year of the Emerson award focused on the limnology and sediment character at six nearshore sites. Results include:

- BGA blooms favored warm, calm waters, and were detected in the late summer and early fall. The largest blooms were detected along the shoreline, highlighting the need to better understand the nearshore environment.
- Additional factors to support the meteorological linkages to BGA blooms discovered in 2017 require substantiation in 2018 and 2019.
    - Wind/Storm events released nutrients from the nearshore sediments, which in turn supported subsequent BGA blooms in nearshore regions.
    - The quantity and quality of organic matter in the shoreline sediments is sufficient for the detected bloom activity.
- The 2017 results prompted the HABs Mitigation Assessment Project with financial support from the Owasco Lake Watershed Association.

2018 SUMMARY, FUTURE RESEARCH & OTHER RECOMMENDATIONS:

Report Highlights

- Annual mean shoreline BGA bloom concentrations steadily rose from 2014 through 2017, and remained at the 2017 concentrations in 2018. Many of the shoreline blooms contained high concentrations of toxins. In contrast, BGA concentrations at the open-water and nearshore sites surveyed by this project were much smaller than the shoreline sites, up to 10,000 x's smaller.
- The 2018 nearshore temperature data again revealed that surface water temperature decreases preceded BGA blooms. This indicates that wind and/or storm events, that likely caused the temperature decreases, could provide additional nutrients to nearshore areas by runoff from land or sediment disturbance by waves and/or internal seiche activity, thus stimulating nearshore BGA blooms. The actual blooms occurred on the next sunny and calm day.
- Laboratory experiments indicate that sediment samples placed in sunlight and incubated in algae-free water with no added nutrient concentrations can still grow BGA blooms.

Future Research

- The 2017 and 2018 research highlighted a number of important relationships to test in 2019.
  - The relationship between wind and/or storm events and the hypothesized release of nutrients from the shoreline sediments (see dockside sensor nodes described below).
  - The relationship between the extent and type of macrophytes and the extent of zebra & quagga mussels at nearshore regions and the occurrence of BGA blooms. This requires detailed quadrant surveys of the lake-floor by SCUBA divers on multiple dates at the nearshore sites.
  - The bioavailability of nutrients in the sediments and the nutrient flux from the nearshore sediments to the water column, especially after sediment disturbance. This requires collection of short sediment cores, and nutrient flux testing in the lab.
- Sensor arrays should be deployed at multiple dockside sites to detect the pertinent changes in the atmosphere and the water column that are associated with BGA blooms.
  - At a minimum, the following meteorological and water parameters should be monitored: air temperature, light intensity, wind direction and wind speed; and water temperature, dissolved oxygen, turbidity, and fluorescence (total and BGA) at 30-munite intervals at a number of sites around the lake. Unfortunately, nutrients are challenging to measure electronically, and the floating nature of BGA blooms are challenging to be reliably detected by a BGA sensor deployed in the water at a fixed depth. Lakes levels change too much on multiple time scales due to precipitation, waves on windy days and lake level control at the outlet over the course of a field season. Instead, automated cameras should be deployed at each site to log photograph of the lake on a 30-minute basis. Periodic dockside photographs detected BGA blooms and turbid water in 2018.
  - Funds to purchase and deploy water quality EXO2 sondes (~$15 to 20K), and meteorological arrays (~$5K) at a number of shoreline locations, and display the data in near real-time on the web will be pursued, as funds that remain in the Emerson award are insufficient to support this ~$100,000 investment.
  - As an alternative, the HWS Physics Department, with support from FLI, has designed and built prototype FLI Sensor Nodes than more economically measure water temperature, and dissolved oxygen. Other sensors can be added to this platform and include light intensity, phycocyanin, total chlorophyll and turbidity ($500 to $5,000 /

Node depending on the sensors). The current FLI Sensor Nodes are designed to periodically measure each parameter, store the data on an SD card, and transmit the data via cellular technologies in near real-time to a web site for display and analysis. We hope to deploy a number of the Nodes, with automated cameras and meteorological arrays on docks around the lake to test the BGA genesis hypothesis developed over the first two years of this project.

Remediation Recommendations

- Lakeshore owners that draw drinking water from the lake need an affordable mechanism (or financial support) to reduce their risks from the BGA toxins. Perhaps municipal water should be extended to lakeshore properties to reduce health risks. Extending municipal sewer around the lake is also a good idea for nutrient source reduction.
- Aerators, ultrasonic vibrators, benthic mats and other in-lake strategies might provide stop-gap measures to reduce the extent of the BGA blooms until the nutrient loading issue is resolved. Unfortunately, the assessment of ultrasonic vibrators and aeration bubblers were inconclusive in 2018, mainly because the eleven test sites, that always experienced large BGA blooms in the past, never experienced a major bloom in 2018 during the weekly sample dates. Missing the few blooms in 2018 prompted the development of the FLI Sensor Nodes to continually monitor air and lake conditions.
- NEVER use herbicides to kill BGA because Owasco Lake is a drinking water source, and herbicides are also toxic to humans and other organisms including dogs.
- Nutrients should be removed from the lake, when feasible, especially from along the shoreline. For example, macrophytes should be harvested from the nearshore areas in the late summer before they start to decay. The macrophytes and attached algae that wash up along the shoreline should be gathered before they decompose. The BGA surface blooms should be vacuumed from the water before they disappear. All of the removed organic material could be composted, and not allowed back into the lake.
- Ultimately, the nutrient loading issues in the watershed MUST be resolved so that the lake is placed in a negative, nutrient load balance (i.e., nutrient losses must exceed nutrient additions). A negative balance MUST be sustained for a number of years before these issues will go away. The Cayuga County Water quality monitoring report addresses a number of nutrient loading reduction strategies, so they are not duplicated here.

METHODS

This project focused on the limnology and sediment character of six nearshore sites in Owasco Lake. The nearshore results will be compared to: (a) offshore data provided by the water quality and meteorological monitoring buoy, (b) identical limnological and sediment data collected at two mid-lake, offshore sites, and (c) additional data collected at eleven homeowner docks as part of the BGA mitigation technology assessment.

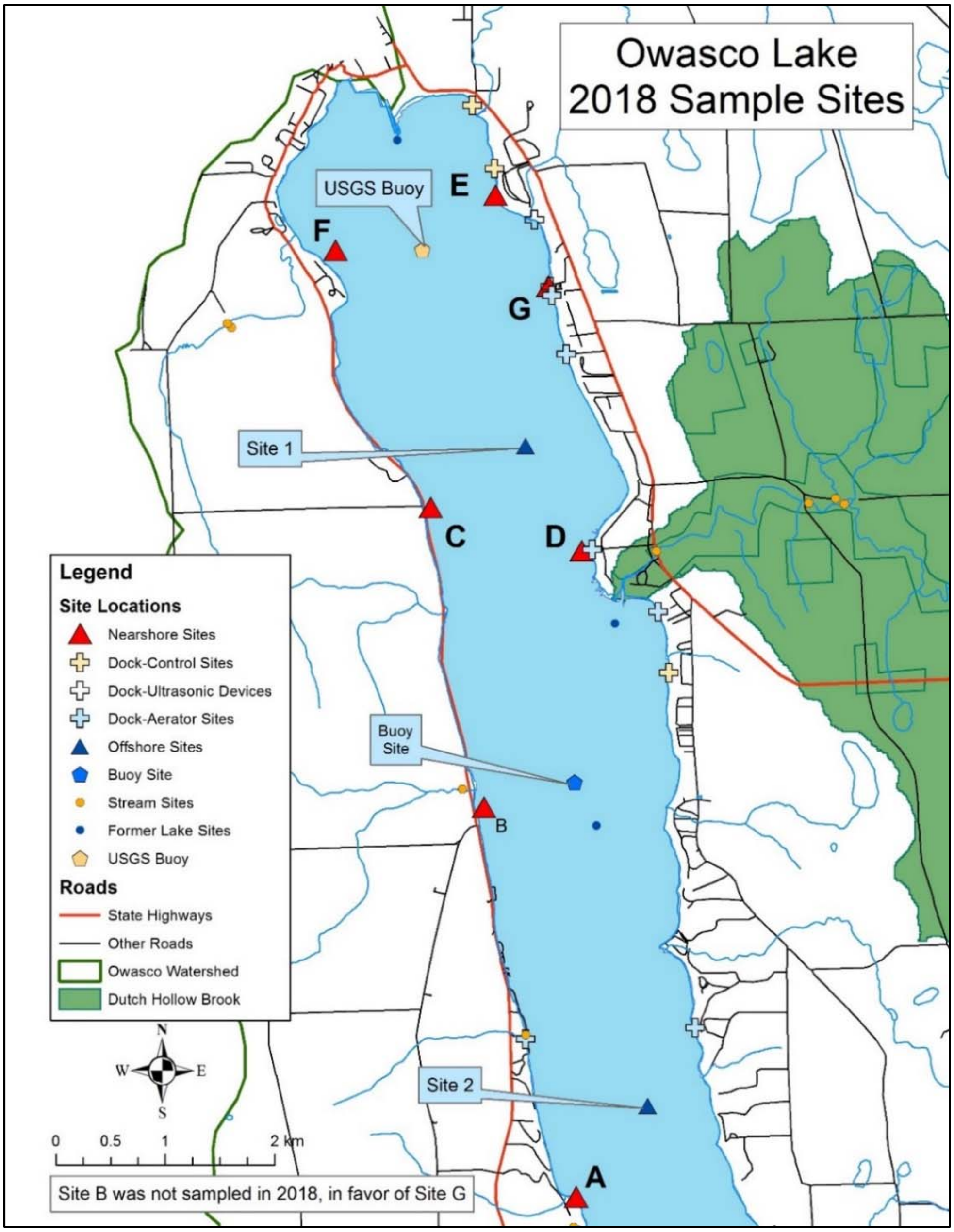
Site Locations: The 2018 fieldwork focused on six nearshore sites, Sites A, plus C through G (Table 1, Fig. 1). Site B, sampled in 2017, was discontinued, in favor of Site G, located just offshore of the Owasco Yacht Club. The switch provided a third site adjacent to a shoreline/dock survey site. All 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 2018 survey dates were: 6/5, 6/19, 7/3, 7/10, 7/24, 7/31, 8/7, 8/21, 8/28, 9/4, 9/11, 9/18 and 10/3.

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 Site?
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, discontinued
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	Yes
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 consisted of a CTD water quality profile, a bbe FluoroProbe profile, Secchi disk depth, vertical plankton tow (80-μm mesh), and surface water samples 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. 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. Phytoplankton was collected using an 80 µm mesh net towed from a depth of 20 m (or the lake floor if shallower) to the surface. The net contents were preserved in an alcohol-formalin solution and enumerated to genus level back in the laboratory under a microscope. Water samples were analyzed onsite for temperature (°C), conductivity (specific conductance, µS/cm), pH, 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.



Site B was not sampled in 2018, in favor of Site G

Fig. 1. The 2018 Owasco Lake nearshore, dockside, buoy and offshore survey sites.

One *ONSET* HOBO U20L-04 data logger was deployed attached to a dock leg near each nearshore site from 6/15 through 9/20. The logger at the Yacht Club stopped recording water temperatures on 9/16 because they took the dock out. 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.

For the nearshore sampling, sediment grab samples were collected using a ponar dredge at each site, and a subsample from each site was brought back to the lab to duplicate determine sediment concentrations of total phosphorus, water, organic matter and carbonate concentrations. Rake tosses were also completed at each site on each survey date to qualitatively determine the aquatic macrophyte (rooted / attached plant) assemblages, relative abundance and potential changes over time through the summer season.

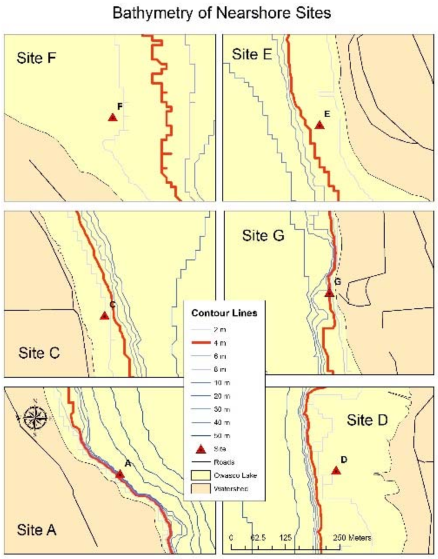


Fig. 2. The nearshore bathymetry. The contour interval shown is 2 m, in shallow water (< 10m), and 10 m in deeper water. Each map was drawn at the same scale. The two meter bathymetric contour is highlighted in red for comparison between sites.

Drone Flights: Drones were flown at an altitude of 50 m at the six nearshore and eleven dock sites to investigate the extent of nearshore macrophytes and BGA blooms (Fig. 3). The flight height was reduced from the 100 m flown in 2017 because some of the 100 m flights missed the BGA blooms along the nearshore areas. For this work, a DJI Phantom 3 Advanced drone with a Sony EXMOR gimbaled camera was used, which captured 12 megapixel digital images. Each image spanned an area of ~100 by 150 meters at a flight altitude of 50 m. Multiple (~15), overlapping nearshore images were collected at each site. Flights dates were: 6/5, 7/3, 7/10, 7/17, 7/24, 7/30, 8/6, 8/11, 8/20, 9/3, 9/5, 9/9, 9/14, 9/16, & 9/30, plus a few additional dates with partial site coverage due to high winds or rain. Drones collected one vertical and two oblique photos looking up and down the shoreline at the dockside sites starting on 7/30. Drones will no longer be flown in high winds (>10 mph) or in rainy weather.

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 4/25 through 10/29 (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). Data was collected every 1.5 meters down the water column starting at 1 m using a YSI/Xylem EXO2 water quality sonde. The buoy also recorded five-minute mean 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[3]. Buoy hardware and/or software issues prevented collection of water quality data from 4/17 – 5/7, 5/17, 5/26, 10/15, 10/18, and after 10/29 (the later dates due to lack of power resulting from the unrelenting cloudy/rainy weather); and meteorological data from 4/17 through 4/23.

Laboratory Analyses: Laboratory analyses for nutrient, chlorophyll-a, and total suspended sediment concentrations followed standard limnological techniques[4]. 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 pre-weighed, Millipore, 0.45 μm glass-fiber filters, and the filtrate was stored at 4°C until soluble reactive phosphate (SRP), nitrate and soluble reactive silica colorimetric analyses by spectrophotometer. The 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. Another known volume of lake water was filtered through a Gelman HA 0.45 μm membrane filter, and the filtered residue was kept frozen until chlorophyll-a analysis by spectrophotometer after pigment extraction in 90% acetone. 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. For the plankton enumerations, over 100 individuals were identified to genus (and typically species) level and reported as relative percentages. Multiple reagent blanks and standards were run with each analysis for a constant check on data quality.

Sediment total phosphorus content (μg/g dry wt.) was analyzed on ~0.1 g samples of dried (80°C overnight) sediment. The weighed sample was dispersed in distilled water, and phosphorus content determined using the total phosphorus procedure above. Because the sediment 2017 TP results underestimated the P concentrations because some of the phosphate adsorbed back onto particles during the laboratory analysis, less sediment was analyzed in 2018 to minimize the issue. Reabsorption was not observed in 2018. Sediment water, organic matter and carbonate weight percent (wt. % dry wt.) was determined by loss on ignition, first at 110°C for 2 hours to dry the sediment sample, then at 550°C for 1 hour to oxidize (remove) the organic matter, and finally at 1,000°C for 2 hours to oxidize the carbonates (mostly calcite, $CaCO_3$).

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. 4). 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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[3] http://fli-data.hws.edu/buoy/owasco/

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

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

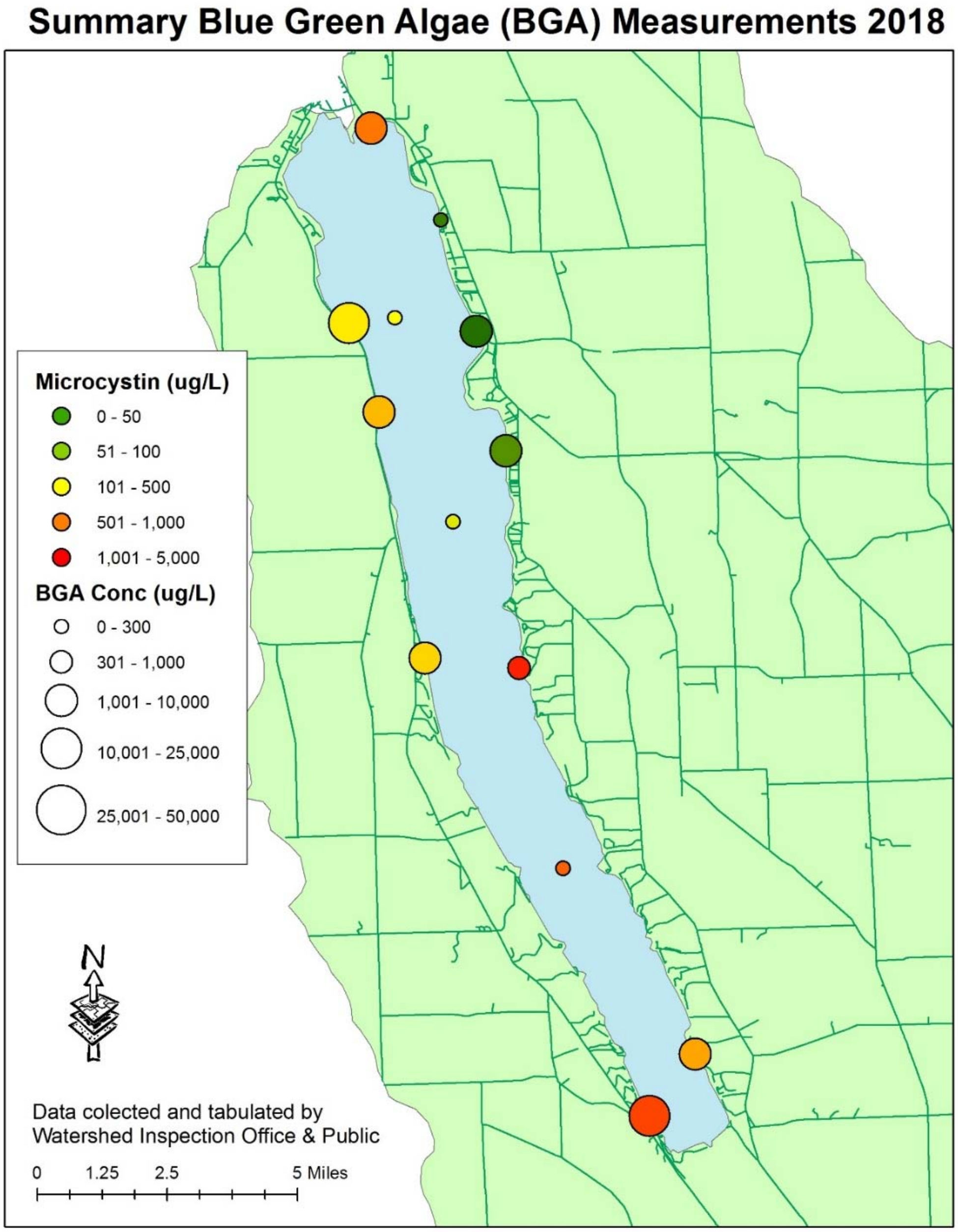

Fig. 4. Map of the 2018 BGA bloom and microcystin concentrations detected by the HABs Shoreline Surveillance volunteers (permission by the DEC). A greater percentage of blooms were detected along the western shoreline in 2018 than earlier years.

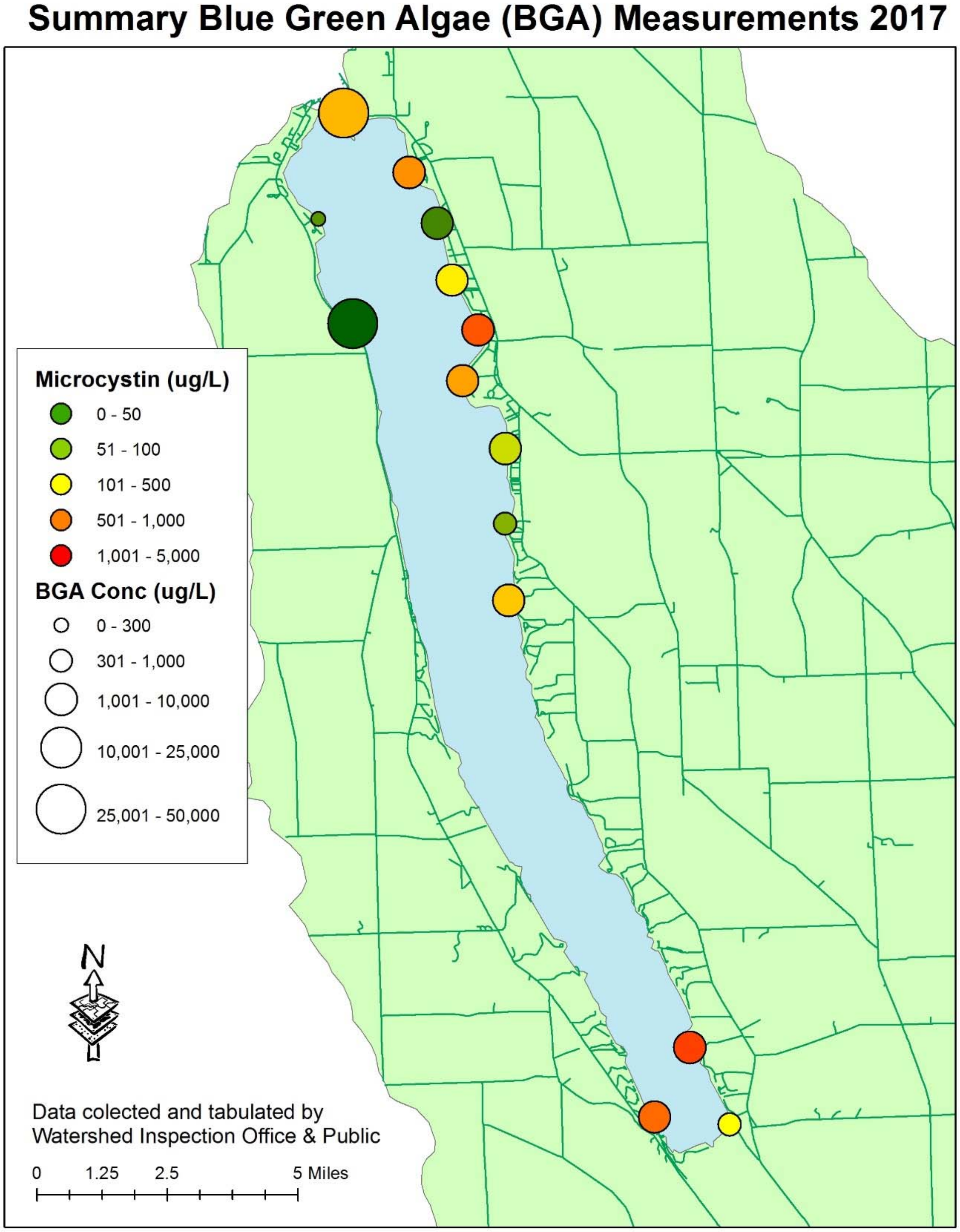

Fig. 4 (cont). Map of the 2017 BGA bloom and microcystin concentrations detected by the HABs Shoreline Surveillance volunteers (permission by DEC).

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 any 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 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* (*Anabaena)* 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[5]. 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[6]. 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.

Harmful algal blooms are not unique to Owasco Lake. In 2018, major BGA blooms were confirmed in all but one of the Finger Lakes (all but Canadice), and every Finger Lake in 2017 (Fig. 5). 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.).

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

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

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. 5). 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, although this may be an artifact of where individuals reported and/or searched for blooms. The distribution spread to the western shoreline in 2018 (Fig. 4). 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 five 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. 5).

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

Suspicious	▨
Confirmed	🟦
High Toxin	🟥

Fig. 5. 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).

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. Toxin concentrations between 0.3 μg/L and 1.2 μg/L were detected three times from 8/14 to 11/18 in the Auburn raw water and once in the Town of Owasco raw water[7]. These concentrations were just above the drinking water threshold of 0.3 μg/L for the most vulnerable populations. Both facilities draw water from Owasco Lake and distribute it to ~45,000 residents. However, all finished water concentrations were always below the EPA's drinking water threshold throughout 2018. This indicates that the recently installed upgrades and protocols to remove BGA toxins at these two municipal water supplies are working.

Lakeshore residents with private water systems should use bottled water during BGA outbreaks along their shoreline[8], 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.

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. 6). 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 temperatures section).

The nearshore sites revealed similar specific conductance on any given date as the surface water (upper 5m) mean specific conductance at the offshore sites (Fig. 6). Photosynthetically available radiation (PAR) was also similar across the lake. Light levels were sufficient (significantly above 1% surface light intensities) at the lake floor to support algal or attached (macrophyte) plant growth at every nearshore site.

The nearshore sites revealed similar or slightly less algae (CTD fluorescence) than the surface water (< 10m) mean fluorescence at the offshore sites (Fig. 6). 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. Some of the nearshore sites 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 and are related to shoreline blooms (Fig. 6).

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[7] http://www.cayugacounty.us/Community/Health/Environmental-Health/Blue-Green-Algae/drinking-water-sampling-data

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

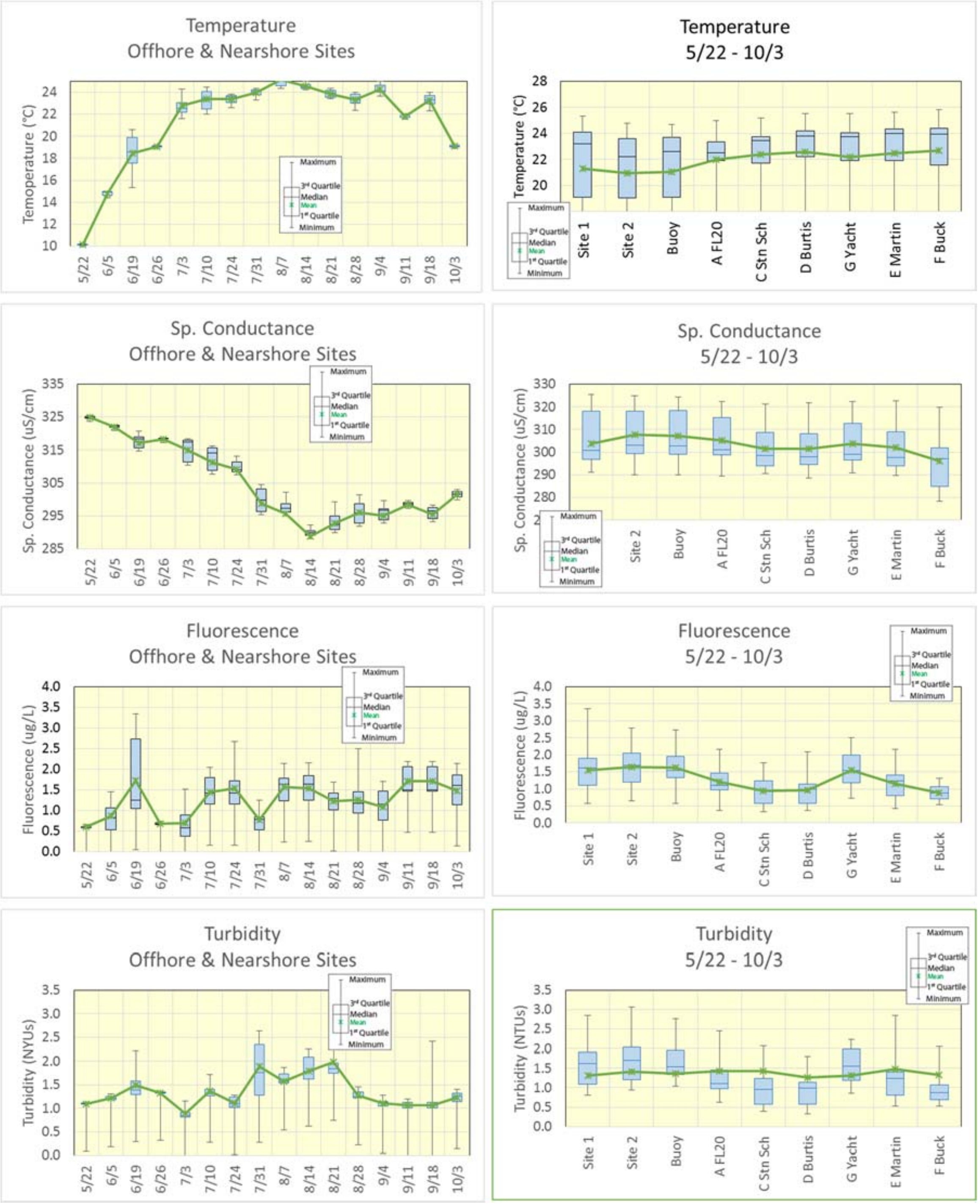


Fig. 6. Nearshore to offshore temporal (left) and spatial (right) comparison of 2018 CTD data. The CTD has its own fluorometer. The CTD was not used at the dock sites.

Unlike 2017, the 2018 turbidity CTD data revealed uniform or nearly uniform turbidities across all sites (Fig. 6). Survey dates in 2018 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. The 2018 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 data revealed the dominance of green algae, diatoms and cryptophytes throughout the lake (Fig. 7). Mean epilimnetic total fluorescence concentrations exceeded 10 μg/L (mesotrophic/eutrophic threshold) at one or more sites on seven of the thirteen surveys of the lake; but typically, the mean nearshore total fluorescence was below 10 μg/L. BGA concentrations increased through the late summer and early fall surveys, with typically more BGA at the nearshore than the offshore sites and the most BGA at the dockside sites. BGA concentrations at the nearshore sites did not exceed 1 μg/L, even though some of the sample dates coincided with confirmed blooms in Owasco. However, the sample sites were not adjacent to shoreline BGA blooms, where BGA concentrations were significantly larger (~1,000 to over 10,000 μg/L as measured by the HABs Shoreline Surveillance volunteers and the Owasco Lake Watershed Inspector's office). 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, mean offshore site data and mean dock site data were typically similar (Fig. 8a). A few exceptions are noted below. Total suspended solids concentrations were slightly larger at the dock sites than elsewhere, and probably reflected wave generated, lake-floor sediments. As in 2017, the 2018 B&W plot of Secchi disk depths is inconclusive because the Secchi disk hit the lake bottom at most of the nearshore sites and was never measured at the dock sites. Thus, Secchi depths shallower than the depth of the lake floor were only occasionally observed. The concentration of total phosphorus was slightly smaller offshore and slight larger at the dock sites than the nearshore sites but the bulk of the data (boxes) were always within the whiskers of every site, meaning that extreme concentrations were not observed in 2018. SRP concentrations were very small throughout the lake. The largest concentrations of soluble reactive phosphorus, i.e., the upper whiskers on the plots, were detected at five nearshore sites (A, C, D, F & G). This suggests that the nearshore environment occasionally has higher concentrations of nutrients.

Some temporal variability in the limnological parameters was noted through the 2018 field season (Fig. 8b). The total suspended sediment concentrations increased towards the end of the field season. Total phosphorus peaked in early September. The soluble reactive phosphorus peaked in early August and again in early September. The late summer early fall time frame is coincident with BGA blooms.

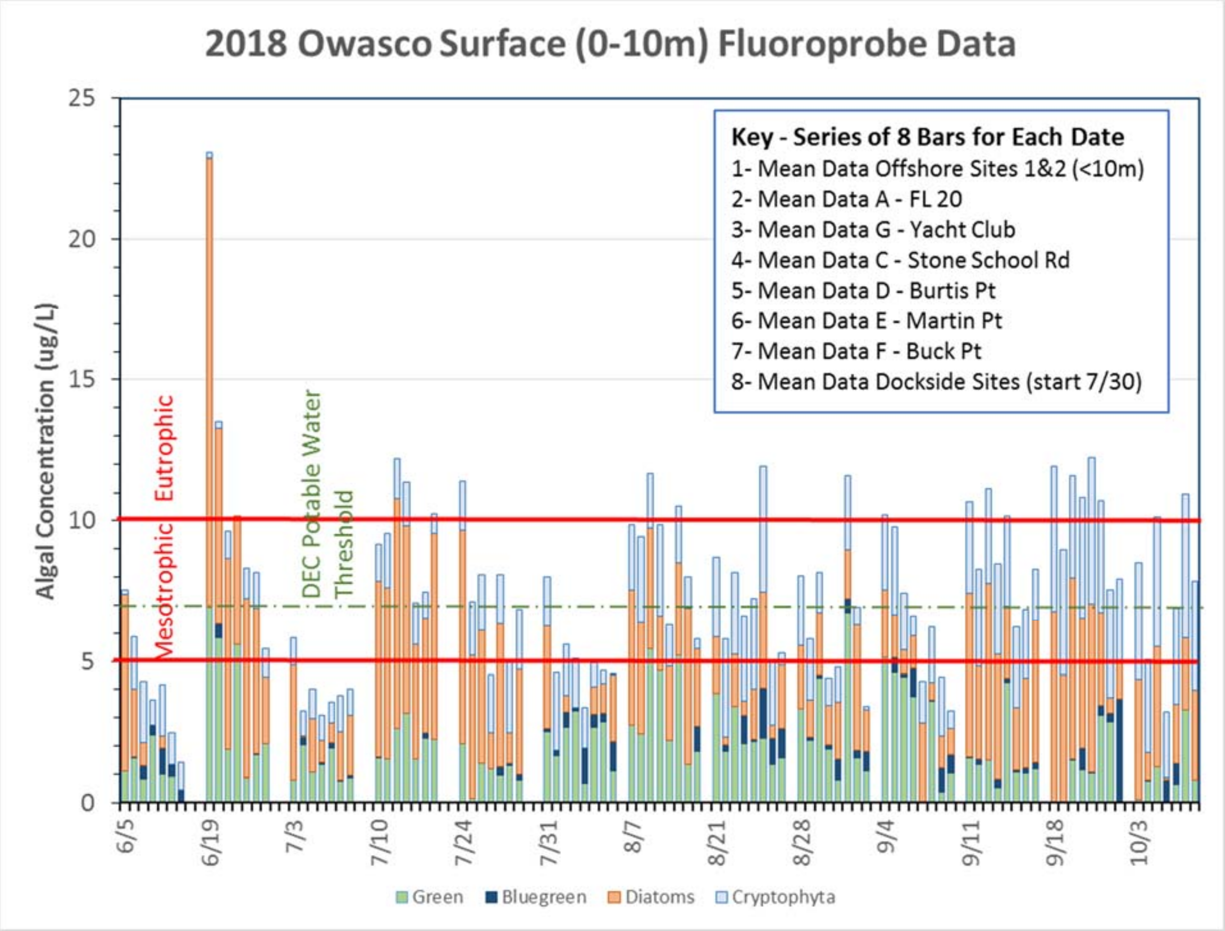


Fig. 7. bbe FluoroProbe data from each nearshore site (A, C-G, middle bars for each date) on each survey date. Two additional bars for each date depict mean data from the offshore sites on that survey date (1^{st} bar), and the mean data from the dock sites on the closest sampling date (last bar). The dock surveys started on 7/30.

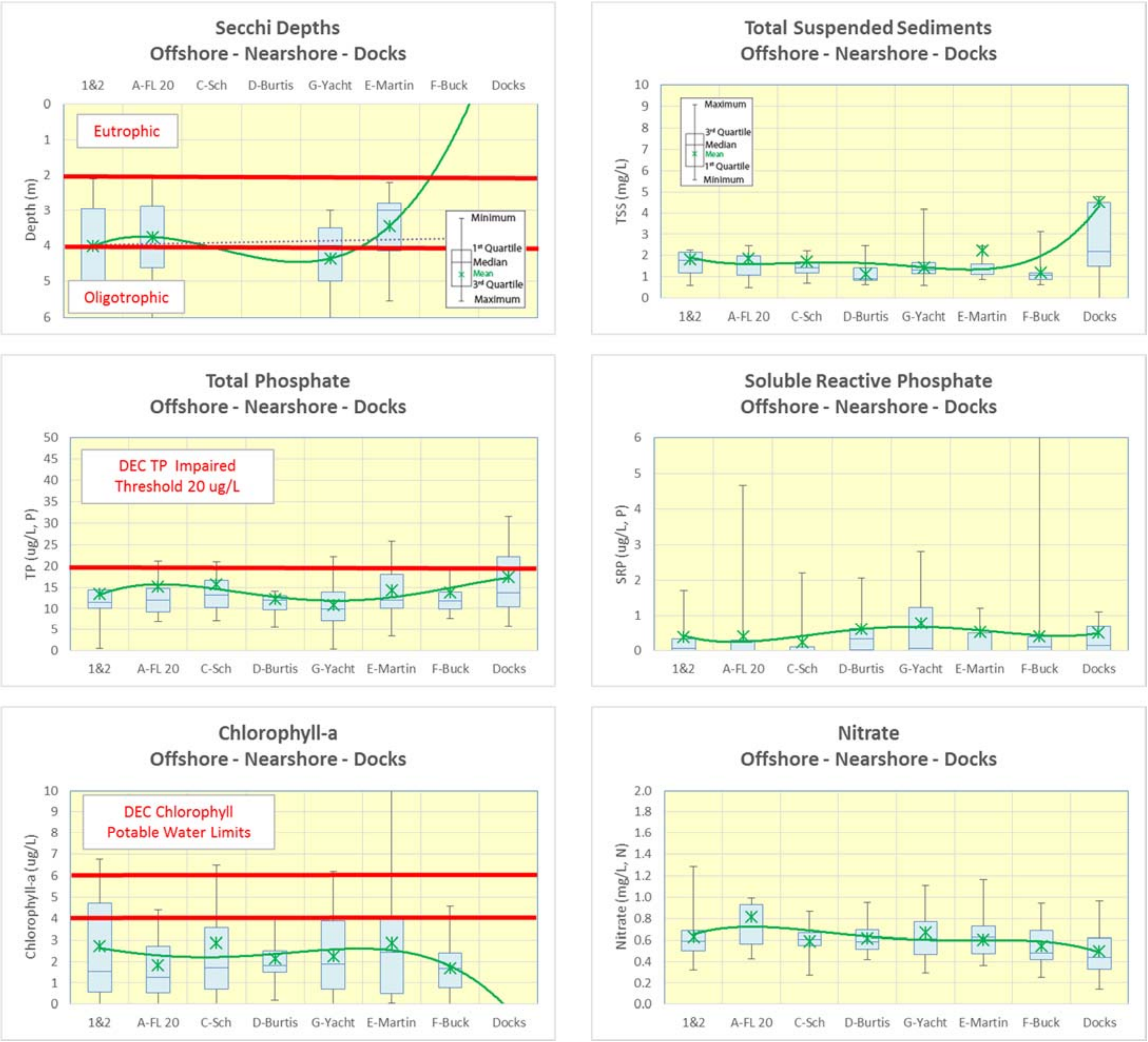


Fig. 8a. Nearshore, offshore and dock site spatial comparison of the limnological data. When appropriate, boundaries for oligotrophic, mesotrophic and eutrophic concentrations are indicated on the graph.

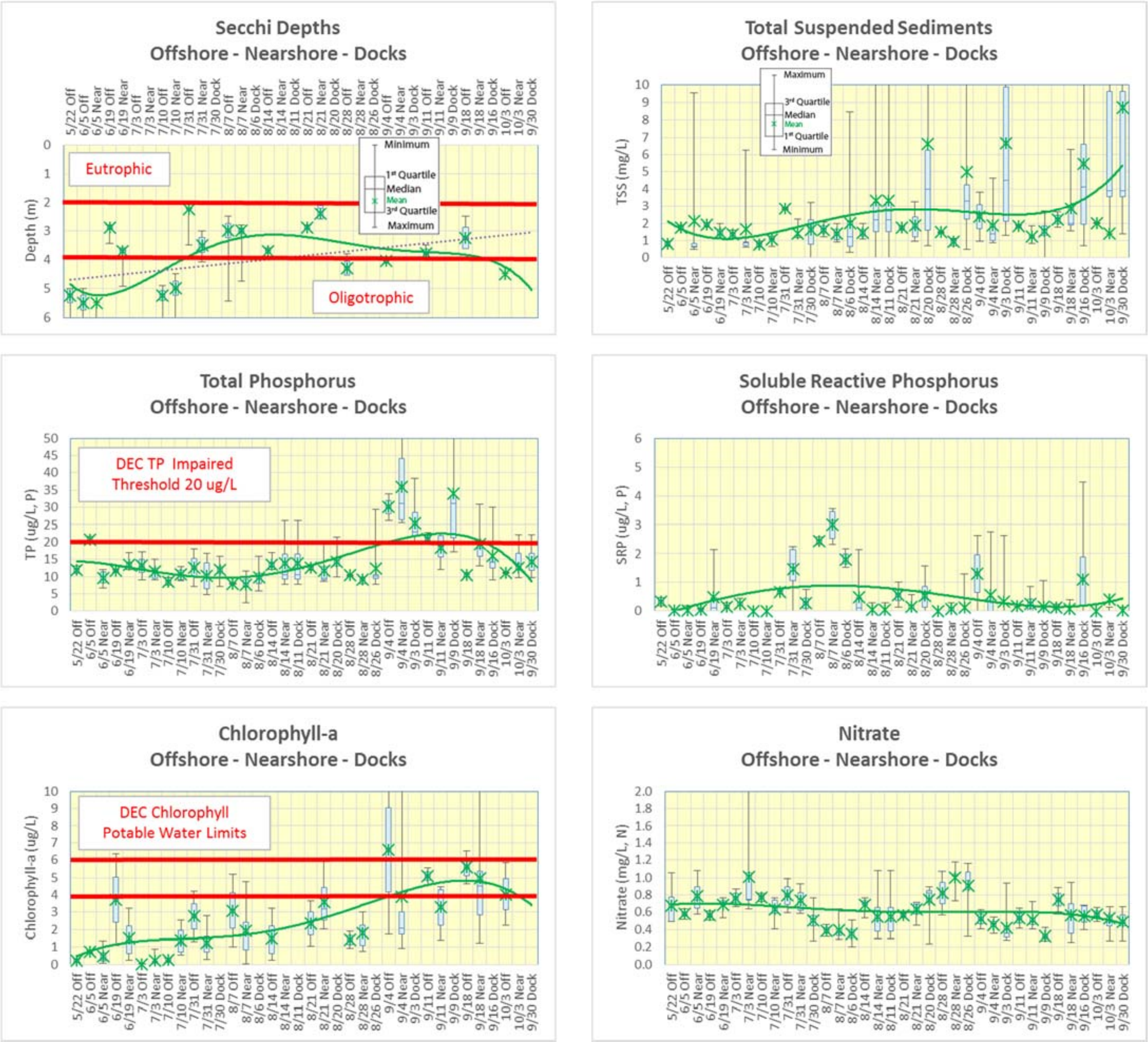


Fig. 8b. Nearshore, offshore and dock site temporal comparison of the limnological data. When appropriate, boundaries for oligotrophic, mesotrophic and eutrophic concentrations are indicated on the graph.

Plankton Data: The phytoplankton (algal) species in Owasco Lake during 2018 were dominated by diatoms, primarily *Synedra* and *Asterionella*, with smaller numbers of *Diatoma* and *Fragilaria*, (Table 4 in appendix, Fig. 9). Unlike previous years, *Synedra* replaced *Asterionelia* and *Diatoma* as the dominant taxa for most of the summer. The reason for the mid-summer *Synedra* dominance is unclear at this time as it had never dominated the algal population in the past. We openly speculate that the ecology of the lake may be changing. Besides blue-greens, other phytoplankton species observed include a few *Dinobryon* and *Colacium*. Zooplankton species were dominated by rotifers, namely *Keratella*, with some cladocerans, *Copepods*, and *Cercopagis*, the fishhook water flea. Zebra and quagga mussel larvae were also detected in the plankton tows. The September nearshore plankton tows have yet to be counted.

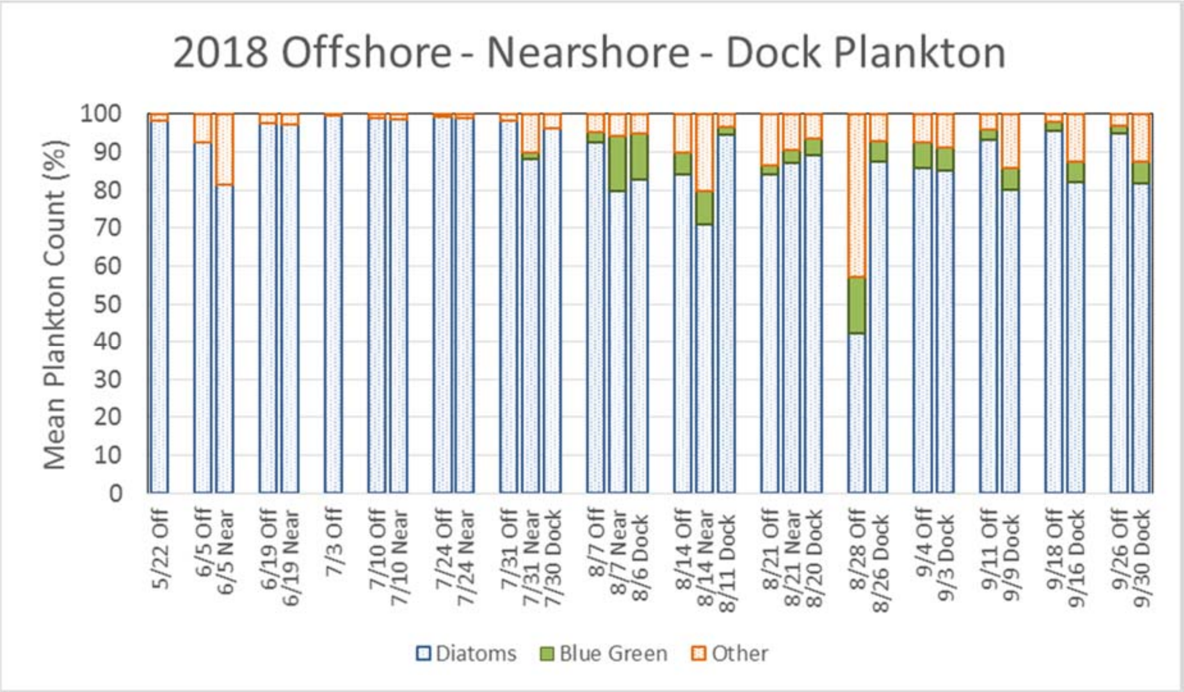


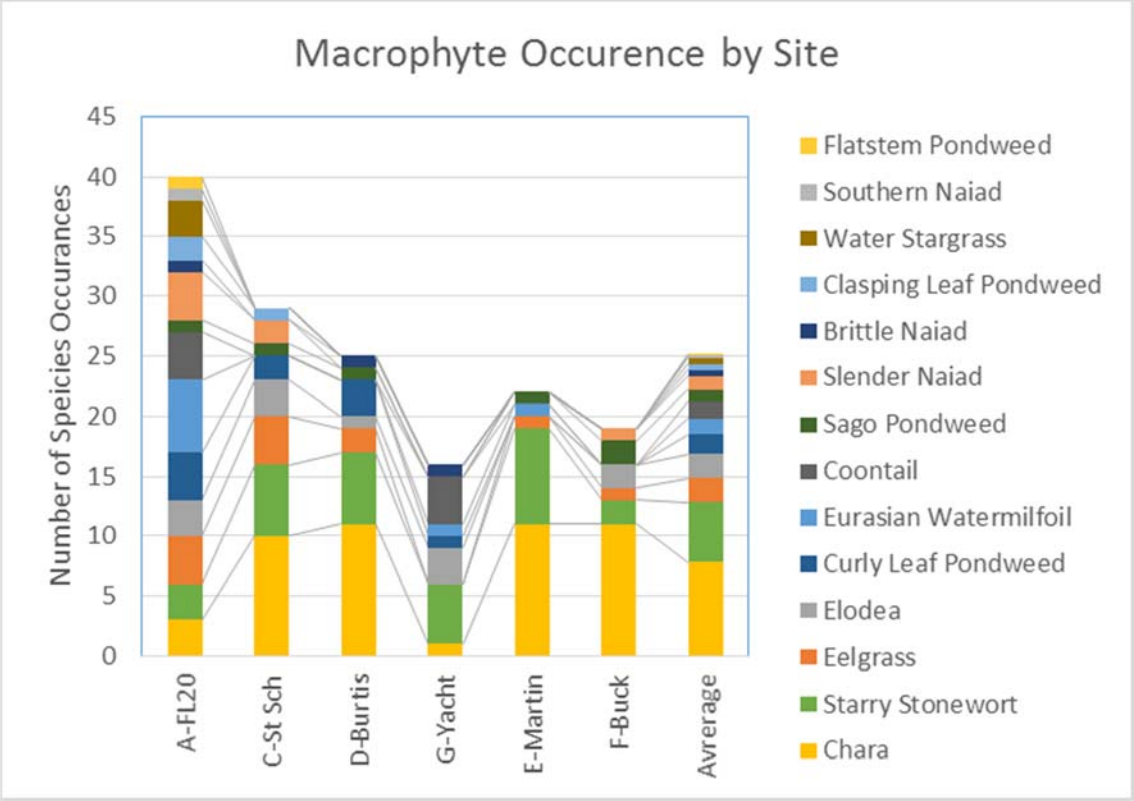
Fig. 9. Offshore to nearshore to dockside comparison of the plankton relative percentage by dominant groups.

Macrophyte Data: Fourteen species of plants were detected at the six nearshore sites at least once in 2018 (Fig. 10): Eurasian watermilfoil (*Myriophyllum spicatum*), eelgrass (*Vallisneria americana*), elodea (*Elodea canadensis*), Chara (*Chara spp.*), starry stonewort (*Nitellopsis obtusa*), curly leaf pondweed (*Potamogeton crispus*), coontail (*Ceratophyllum demersum*), water stargrass (*Heteranthera dubia*), brittle naiad (*Najas minor*), sago pondweed (*Stuckenia pectinata*), clasping leaf pondweed (*Potamogeton perfoliatus*), slender naiad (*Najas flexilis*), southern naiad (*Najas guadalupensis*), and flatstem pondweed (*Potamogeton zosteriformis*). Quadrants tosses were not deployed in 2018, but should be completed in 2019.

The macrophyte and attached microalgae detected the most often was Chara (*Chara spp.*), a macroalgae (Fig. 10). It was detected at every site at least once, and on all but one sample date at one site. The next most often macrophyte was starry stonewort (*Nitellopsis obtusa*), which was detected at every site during August and September. Curly leaf pondweed was abundant during the early part of the field season, June and July, but only at the shallower nearshore sites, B, D, E, and F. These three macrophytes also dominated the distributions in 2017. Water stargrass, brittle naiad, clasping leaf pondweed, southern naiad, and flatstem pondweed were only detected at one or two sites on one or two survey dates. Horned pondweed (*Zannichellia palustris*) and leafy pondweed (*Potamogeton foliosus*) were detected in 2017, but not in 2018; also, sago pondweed, clasping leaf pondweed, slender naiad, southern naiad, and flatstem pondweed were detected in 2018 but not in 2017.

- Site A, FL 20, had the largest diversity of macrophytes. All fourteen species were sampled at least once at this site.
- Site C, Stone School Rd, was dominated by Chara (*Chara spp.*) and starry stonewort (*Nitellopsis obtusa*) with some eelgrass, curly pondweed, sago pondweed, clasping leaf pondweed, and slender naiad.

- Site D, Burtis Point, was typically dominated by Chara species, curly leaf pondweed early in the summer and starry stonewort latter in the summer. Eelgrass, Elodea, brittle naida, and sago pondweed were also sampled at least once at this site.
- Site G, Yacht Club, was unique in that starry stonewort and coontail species were detected most frequently and Chara species were detected on only one survey. Eurasian watermilfoil, Elodea, curly leaf pondweed, and brittle naiad were also sampled at least once at this site.
- Site E, Martin Point, was dominated by Chara (*Chara spp.*) and starry stonewort (*Nitellopsis obtusa*). Eurasian watermilfoil, eelgrass, and sago pondweed were also sampled on different survey dates at this site.
- Site F, Buck Point, was dominated by Chara (*Chara spp.*). Five other species, eelgrass, elodea, starry stonewort, sago pondweed, and slender naiad were sampled once or twice at this site.



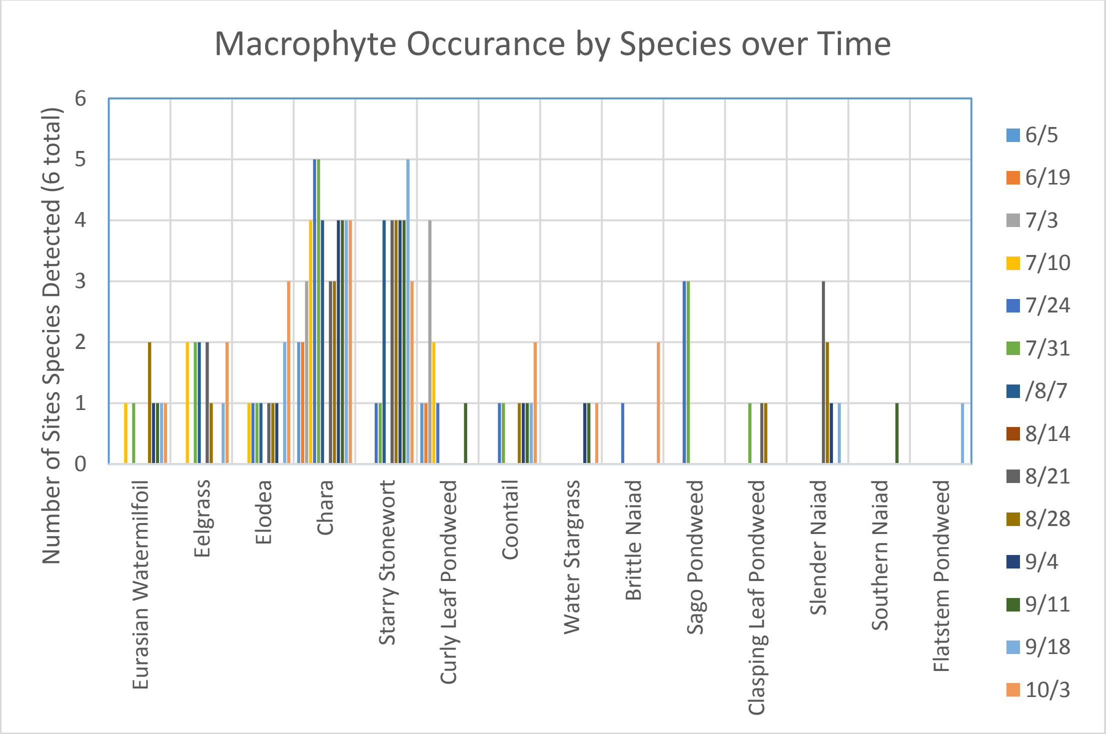


Fig. 10. Macrophyte distributions detected by rack tosses in Owasco Lake by survey site (above), and species over time (below).

Zebra & Quagga Mussels: The lake floor density of zebra and quagga mussels were not measured in 2018. We plan to measure them in 2019 because the "phosphorus nutrient shunt" could provide a critical source of nutrients to nearshore locations. The "shunt" refers to the mussel mediated transport of offshore nutrients to the nearshore environment. Zebra and quagga mussels filter feed on algae and other microorganisms that utilize offshore nutrients. What mussels do not digest is excreted to the nearshore water and sediments. The organic-rich excretions are decomposed by bacteria, "shunting" offshore nutrients to the nearshore region.

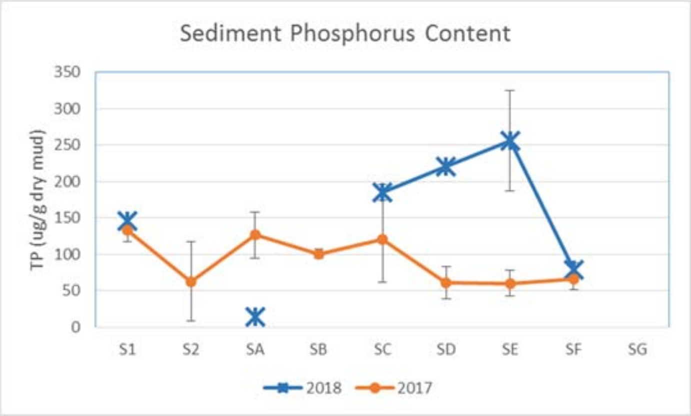
DRONE FLIGHTS

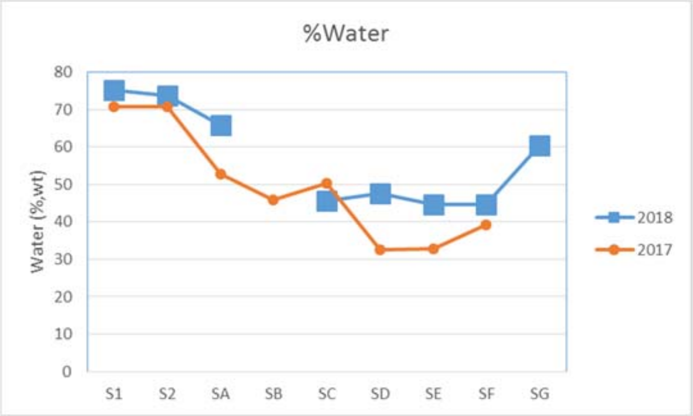
BGA did not bloom during our 2018 site visits and, therefore, were not readily detected in the drone images during the specific site visits in 2018. The largest BGA concentration measured by the dockside site visits was 68 µg/L, with a daily mean of 1.3 µg/L. In a few images, the bubbles from the aeration bubbler mitigation devices formed an outward propagating circle of capillary waves that appeared to push surface accumulations of BGA ~30 meters away from where the bubbles break the surface (Fig. 11). The detected change in BGA concentration was small, only ~20 µg/L, from the center of the circle to the BGA ring. This phenomenon is discussed further in the nearshore mitigation technology report. More progress was made on the linkage between the spectral signatures imaged by the drone, and various multi-spectral and hyperspectral sensors and algae concentrations. These details can be found in the 2018 Cayuga County report referenced at the beginning of this report.

Fig. 11. Drone images revealing circular BGA rings at the Yacht Club and Glenwood Rd. BGA mitigation sites.

SEDIMENT ANALYSES

The 2018 mean sediment total phosphorus concentrations ranged from 14 to 250 μg/g dry mud and did not reveal consistent offshore to nearshore trends (Fig. 12). In 2017 the Site A (FL-20) sediment sample was collected from a sandy gravel area. In general, coarse sediment areas typically have less organic matter and thus, less phosphorus. The 2018 TP sediment concentrations were typically larger than those detected in 2017. The increase probably reflected the 2017 lab challenges for the phosphorus analyses that artificially decreased the sediment TP concentrations. Duplicate sediment analyses showed some variability at each site, reflecting variability of the lake floor substrate, especially at Site E (Martin Pt.). The sediment TP concentrations are large enough to support a typical BGA bloom, assuming a mechanism is available to release these nutrients from the sediments to the water column.





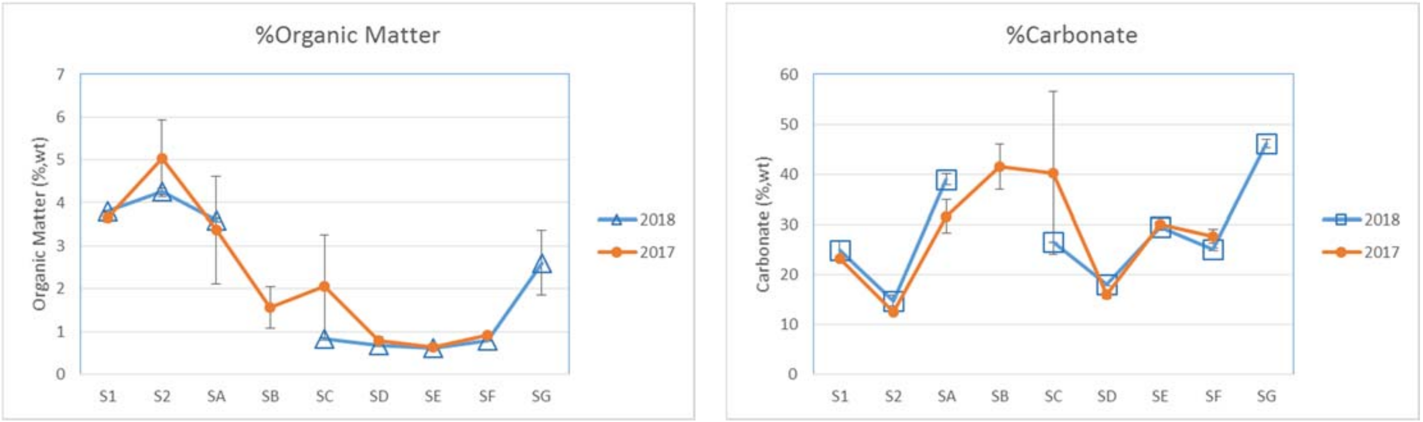


Fig. 12. Offshore (Sites 1 & 2) and nearshore (sites A, C-G) mean (±1σ) total phosphorus, sediment water, organic matter, and carbonate concentrations on samples collected in 2017 & 2018. Site locations: A- FL-20, C – Stone School Rd., D- Burtis Pt., G – Yacht Club, E – Martin Pt., and F – Buck Pt.

The nearshore sites had larger water contents (> 70%) than the offshore sites (40-50%) and less organic matter (1 to 2 % wt.) than the offshore sites (3 to 5 % wt.) in 2018. Organic matter is typically attached to fine grained particles, e.g., clays, and thus preferentially accumulates with the clays, i.e., in the deeper portions of the lake. The 2018 trends were consistent with the 2017 data. Sediments were recovered from a deeper depth (10 m) at Site G, and may explain the larger organic matter concentration compared to the other nearshore sites. The organics, once decomposed by bacteria in the sediments, may provide a source of nutrients to the water column, assuming a mechanism is available to release the nutrients.

Finally, the nearshore sites typically revealed more carbonate, 30 to 40 % wt., than the offshore sites, 10 to 20 % wt., except for Site D (Burtis Pt.) at 16 % wt. The carbonate source is typically twofold - (1) fine-grained, water-column, precipitates, i.e., whiting events, associated with intense algal blooms and (2) the remains of zebra, quagga and other carbonate shells. Very little variability was detected between duplicate carbonate analyses.

Organic Matter Decomposition: Bacterial decomposition (respiration) of organic matter in the sediment column releases nutrients to the sediment pore waters. The exact reaction is dictated by oxygen availability. If oxygen is available in the upper sediments, bacteria can consume this oxygen to decompose organics. This oxygenated decomposition can consume all of the oxygen within the upper few centimeters of the sediment column. Once bacteria are deprived of oxygen, they can continue to decompose organics in the anoxic sediments using other sources like oxidized forms of iron, manganese, sulfur and nitrogen. This oxic/anoxic boundary is typically a few centimeter below the lake floor, and creates an "oxygenated cap." In other words, an upper, oxygenated, brown (rusty color) sediment layer exists above a lower, anoxic, and black sediment. The "cap" is present when the hypolimnion (bottom waters) is oxygenated (typical for oligotrophic and mesotrophic lakes like Owasco Lake) and absent when the hypolimnion is anoxic later in the summer season (eutrophic lakes).

The "cap", when present, is critical to blocking the internal, sediment sourced, loading of phosphorus. The nutrients that accumulate in the pore waters typically diffuse upward towards the lake. If the oxygenated cap is present, dissolved phosphorus precipitates in this oxygenated layer and remain locked in the sediments. If the cap is absent, the dissolved phosphorus can diffuse into the lake and fuel additional algal growth (i.e., internal, sediment sourced, nutrient loading). An oxygenated sediment cap is typically detected in oligotrophic and mesotrophic lakes with oxygenated bottom waters, but not in eutrophic lakes with anoxic bottom waters. Bottom water dissolved oxygen concentrations just above the lake floor are depleted in Owasco Lake down to ~30 to 40% saturation just above the lake floor through the summer stratified season; however, anoxic conditions are not observed.

Even with oxygenated bottom waters, a number of mechanisms may provide access to the soluble reactive phosphorus generated and stored in nearshore sediments to the water column. Macrophyte roots tap into the anoxic sediments and utilize this sediment supported supply of nutrients for their photosynthesis. Waves and other turbulent motions can disturb the oxygen "cap" in nearshore sediments and potentially release bioavailable phosphates to the water column. Thus, more research is required to determine the actual flux of phosphorus from the sediments to the lake.

An accumulation of decaying macrophytes along the shoreline provide another localized source of nutrients as well. The decaying mats can smell like rotten eggs (hydrogen sulfide, H_2S, gas) depending on the oxygen content of the rotten mass. If oxygenated, bacterial respiration of organic matter consumes oxygen and releases carbon dioxide (a colorless and odorless gas). However, oxygen can be quickly consumed in localized areas of the biomass, e.g., stagnant piles of weeds along the shoreline, unaerated backyard compost piles, and in the sediment column, and become anoxic. Once anoxic, bacteria use other oxidants to oxidize organic matter, and release different gaseous byproducts like hydrogen sulfide (rotten egg smell) or methane (also colorless and odorless). This is why a stagnant pile of weeds along the shoreline, once disturbed, have an odor. A well-mixed, i.e., aerated, pile of compost does not emit a foul odor. The aeration mixes oxygen into the pile and provides a continual supply of oxygen for respiration.

Nitrogen can also be released from the sediments. The release of nitrogen is complicated because multiple forms of dissolved nitrogen exist. Nitrogen exists as nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), urea (and other excretions) and nitrogen gas (N_2). A few genera of BGA can use or fix nitrogen gas for metabolism. However, most algae use the other forms of dissolved nitrogen for photosynthesis. All algal prefer ammonium, the reduced form of dissolved nitrogen, as their nitrogen source for photosynthesis because the oxidation state of ammonium is identical to the oxidation state of nitrogen in organic matter. However, algae will use nitrate and/or nitrite, the oxidized forms, when ammonium is not available. To complicate matters, two bacterial reactions, nitrification and denitrification, convert nitrogen from one form to another. Nitrification oxidizes ammonium to nitrite and eventually nitrate. Oxygen must be present for bacteria to accomplish this task. In anoxic areas, denitrification reduces nitrates and nitrites to nitrogen gas, and the gas bubbles out of the aquatic environment to the atmosphere. The importance of these processes in Owasco Lake are also poorly understood and dictate additional research to determine the fluxes of the soluble forms of nitrogen to the water column.

BUOY DATA

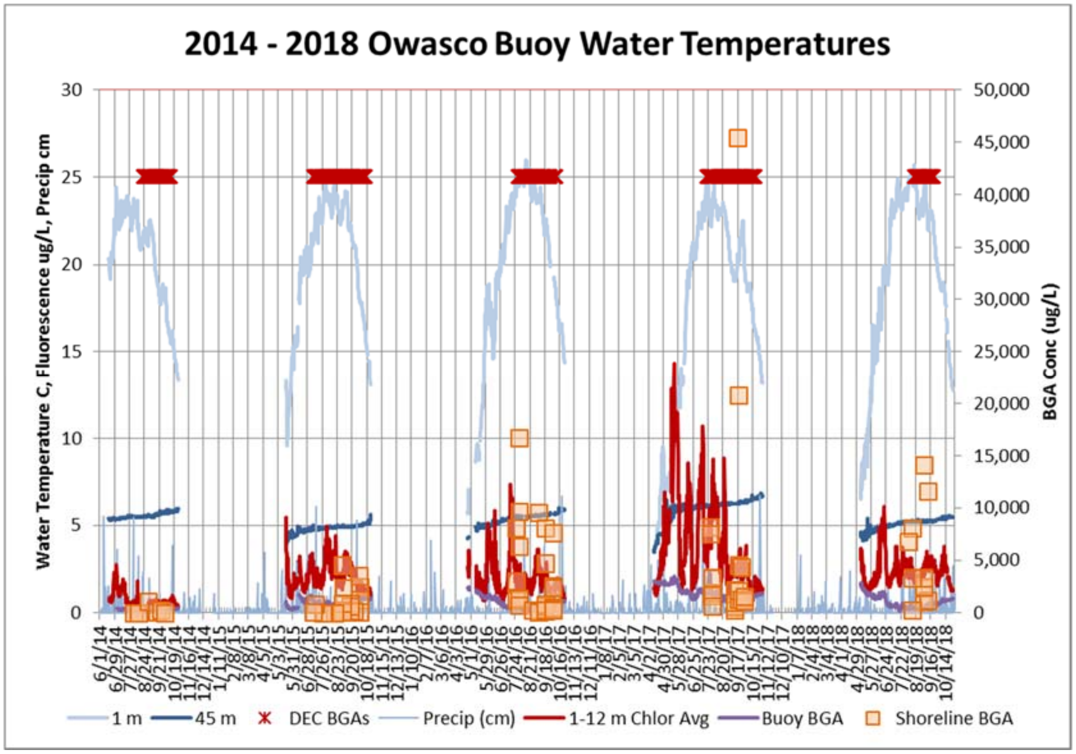
As outlined in the 2017 report, scientists have generalized that BGA blooms prefer the following conditions:

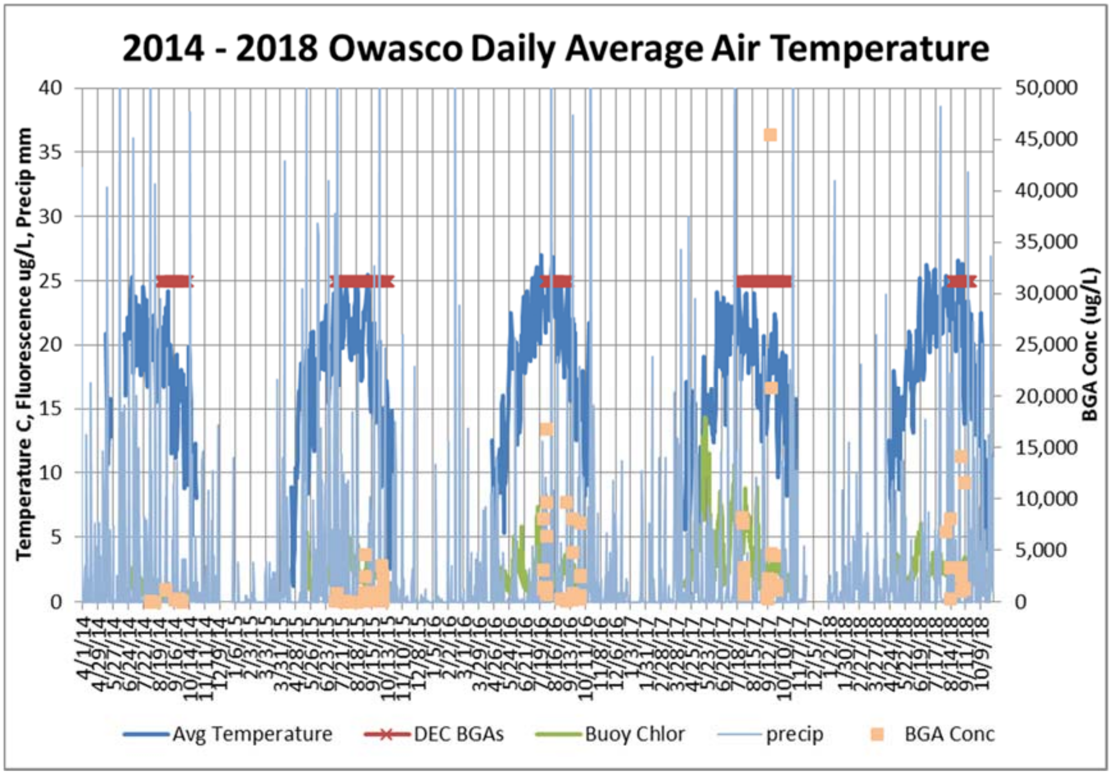
- warm water, temperatures between 15 to 30°C (60 and 80° F);

- 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 that BGA blooms were more commonly detected a decade ago. The last five years of buoy data have shed some new light on the occurrence and development of BGA blooms in Owasco Lake (Fig. 13). The 2017 results were confirmed and advanced by the 2018 data.

Buoy Total Algae and BGA Fluorescence: Minimal correlations were once again observed between the buoy fluorescence and nearshore BGA data (Fig. 13). 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.




2014 - 2018 Owasco Daily Average Air Temperature
Temperature C, Fluorescence ug/L, Precip mm
0
5
10
15
20
25
30
35
40
BGA Conc (ug/L)
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
4/1/14
4/29/14
5/27/14
6/24/14
7/22/14
8/19/14
9/16/14
10/14/14
11/11/14
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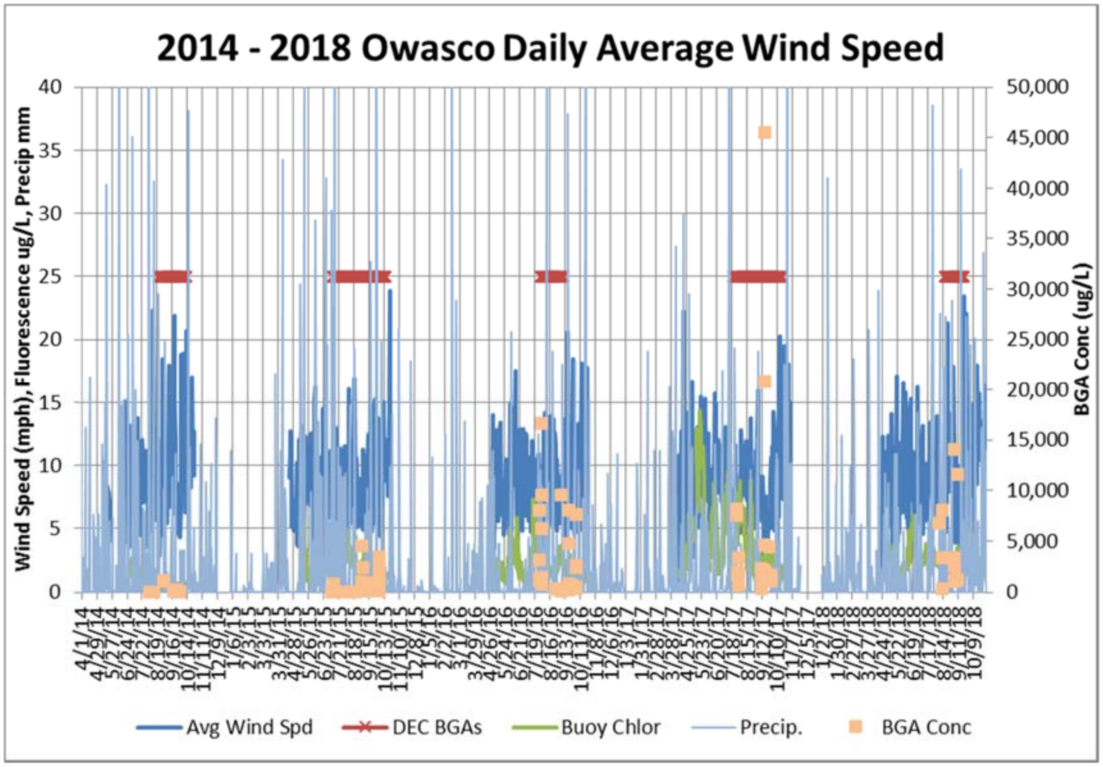
11/7/17
12/5/17
1/2/18
1/30/18
2/27/18
3/27/18
4/24/18
5/22/18
6/19/18
7/17/18
8/14/18
9/11/18
10/9/18
Avg Temperature
DEC BGAs
Buoy Chlor
precip
BGA Conc


2014 - 2018 Owasco Daily Average Wind Speed
Wind Speed (mph), Fluorescence ug/L, Precip mm
0
5
10
15
20
25
30
35
40
BGA Conc (ug/L)
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000
4/1/14
4/29/14
5/27/14
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6/20/17
7/18/17
8/15/17
9/12/17
10/10/17
11/7/17
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1/2/18
1/30/18
2/27/18
3/27/18
4/24/18
5/22/18
6/19/18
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Buoy Chlor
Precip.
BGA Conc

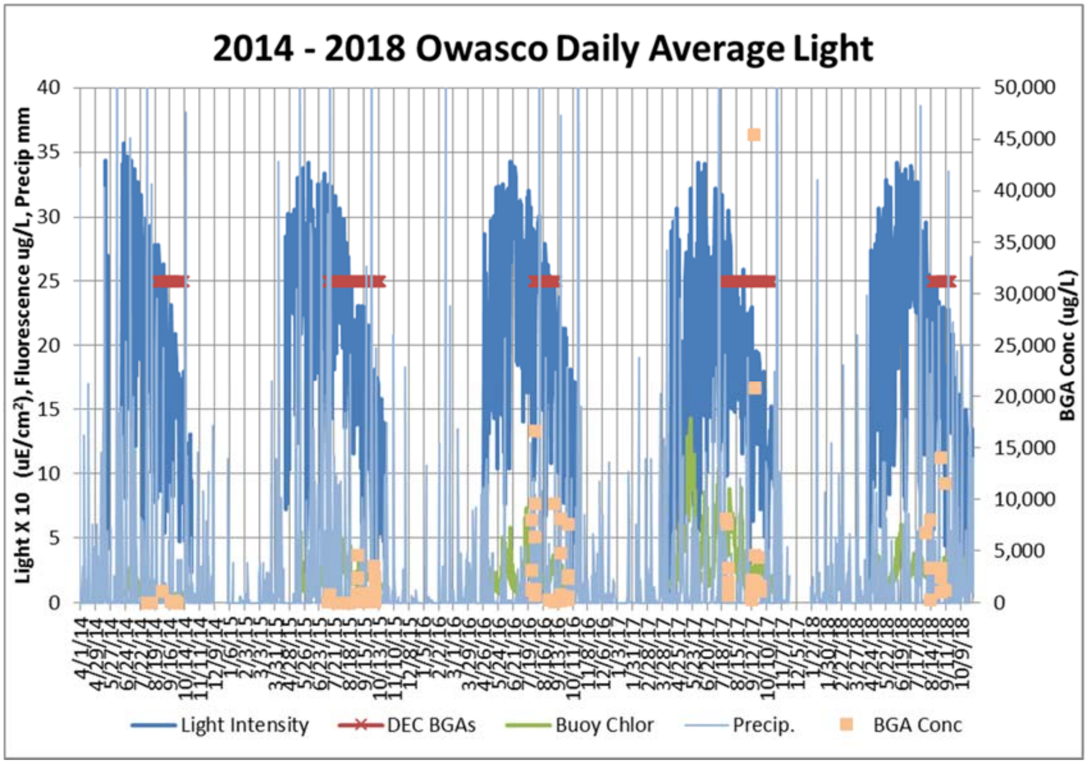


Fig. 13. Five years of water temperature, total and phycocyanin (BGA) fluorescence, and daily mean air temperature, wind speed and light intensity data. The weeks Owasco Lake was on DEC's notification web site, the measured concentration of shoreline BGA blooms and daily precipitation totals are also shown. (1 FNU ≈ 1 ug/L)

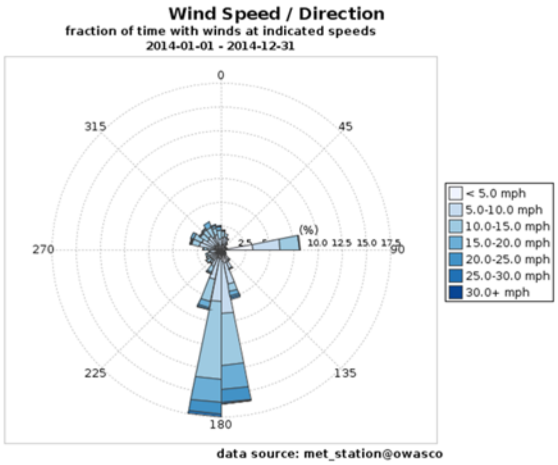
Buoy Lake Temperature: In all five years, shoreline BGA blooms occurred in warm water, 22 or 23°C (70 – 75°F, Fig. 13). However, in every year but 2015, blooms did not appear until a week or two after the warmest water temperature was observed, indicating that warm water by itself does not trigger bloom activity. The warm water does promote faster bacterial decomposition of the nearshore sediment organic matter, however. The persistent time lag may reflect the time required for sufficient bacterial decomposition. More rain fell in 2015 than the other years, and this massive delivery of nutrients may have jumpstarted BGA blooms in 2015. Cold water is detrimental to blooms as they were not detected after the surface water cooled below 15°C (60°F).

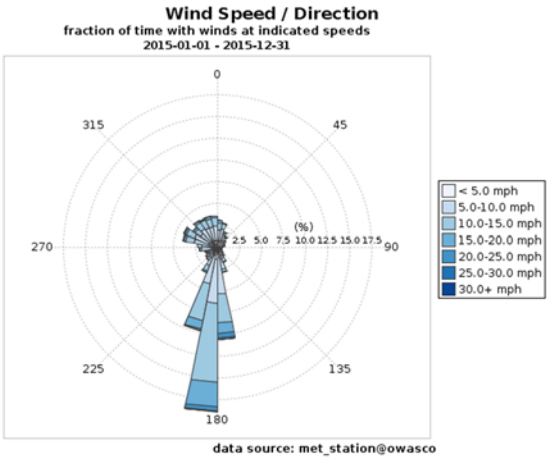
Buoy Air Temperature: Like water temperatures, the shoreline BGA blooms commonly occurred a few weeks after peak (23 to 24°C, 70-75°F) air temperatures (Fig. 13). Colder air temperatures in the fall, i.e., 10°C (50°F), appeared to terminate BGA blooms. Thus, blooms prefer warm air and water temperatures, 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 when mean daily insolation (sunlight) decreased from just above 340 μE/cm^2 in mid-June to below 150 μE/cm^2 by late September/early October (Fig. 13). 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 five years, shoreline BGA blooms typically appeared after a rain storm (Fig. 13). 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, the algae 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 to the lake to trigger the initiation of larger and more numerous BGA blooms along the shoreline in Owasco and all other Finger Lakes during the past five years.

Buoy Wind Speed & Direction: The summers of 2015, 2016 and 2017 were not as windy as 2014 and 2018, especially on days when BGA blooms were detected (Fig. 13). The mean daily wind speeds in 2015, 2016 and 2017 were at or below 10 mph (small waves) with only a few days with wind speeds above 15 mph (large waves with white caps). The years of 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 (very large waves with white caps) also coincided with the end of the bloom activity in 2015, 2016, 2017 and 2018, but not 2014. These very large wind speeds probably mixed any BGA throughout the epilimnion and towards open water.





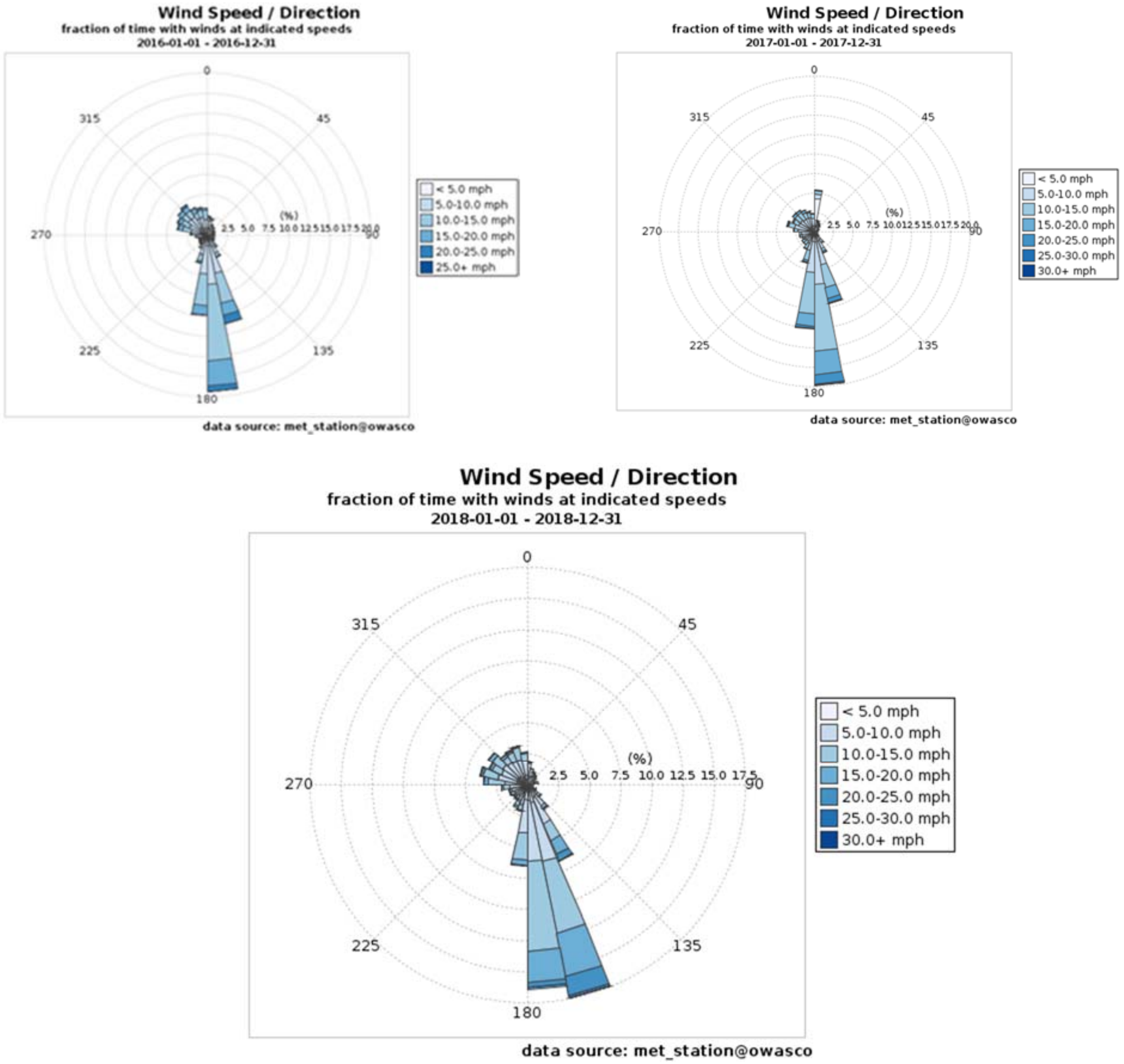


Fig. 14. Wind rose diagrams showing frequency of wind direction and speed for 2014 (upper left), 2015 (upper right), 2016 (mid left), 2017 (mid right) and 2018 (bottom) from the Owasco Lake buoy.

Please note: the 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 calibrated data was used in this report.

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 over the past five years (Fig. 14). These directions are consistent with the majority of the BGA detections along the northern and northeastern margins of Owasco Lake (Fig. 1). A slight eastward shift in wind direction was detected in 2018 compared to earlier years, and perhaps this shift is connected to a greater number of blooms along the western shoreline.

Previously, it was suggested that the dominant winds might push the 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 along the downwind shoreline. The nutrients released by bacterial decomposition of the accumulated organics can then stimulate the next BGA bloom.

NEARSHORE TEMPERATURES & BGA BLOOM HYPOTHESIS

Mean daily, surface water temperatures revealed nearly consistent temperature records among the nearshore data loggers (deployed at 1 m depth) and surface water (1m) temperatures detected offshore by the buoy (Fig. 15). 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 occasionally 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.

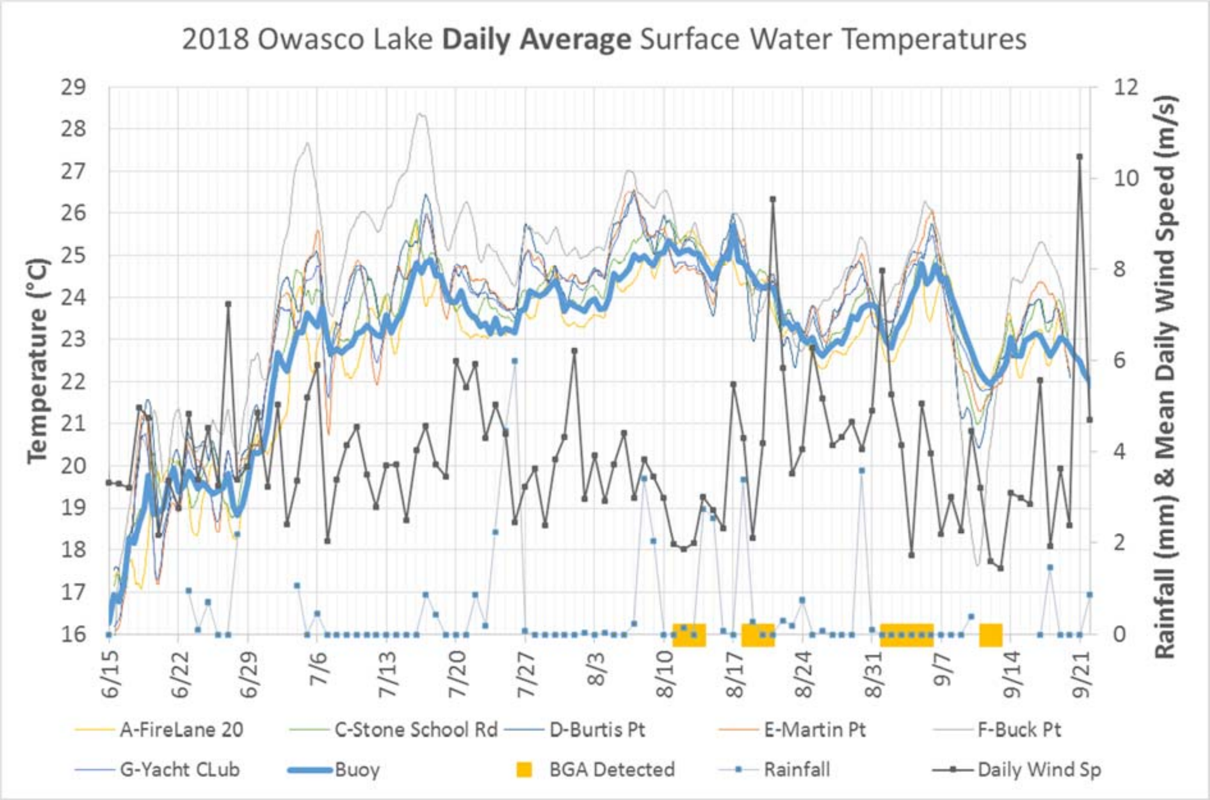


Fig. 15. Plot of nearshore and buoy 1m water temperatures, nearshore BGA blooms, rainfall and mean daily wind speeds.

As observed in 2017, the 2018 August and early September shoreline BGA blooms were typically preceded by lake-wide, multi-day, decrease (~1°C) in temperature. 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 nutrient to the shoreline areas from the watershed. These additional nutrients might provide sufficient nutrients to fertilize BGA blooms.

Unfortunately, not every dip in temperature 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, their biomass can also contribute to the stockpile of nutrients in nearshore areas.

The mixing scenario is consistent with data recorded by a YSI/Xylem EXO2 water quality sonde deployed on a dock at 1m water depth in Seneca Lake in 2017 and 2018 (Fig. 16). 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 the sensor was approximately 1 m below the surface. This could 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.

A DETAILED DOCKSIDE RECORD OF WIND SPEEDS & SUNLIGHT INTENSITY

Weekly wind and BGA concentration data measured at the eleven homeowner docks indicate that even moderate wind speeds and the associated gravity waves negatively impacted BGA concentrations. BGA concentrations never exceeded 1.5 µg/L, and averaged 0.5 µg/L, when wind speeds at the docks exceeded 1.5 m/s (3.5 mph, Fig. 17a). Clearly, BGA blooms are associated with calm days, as blooms were absent on windy days.

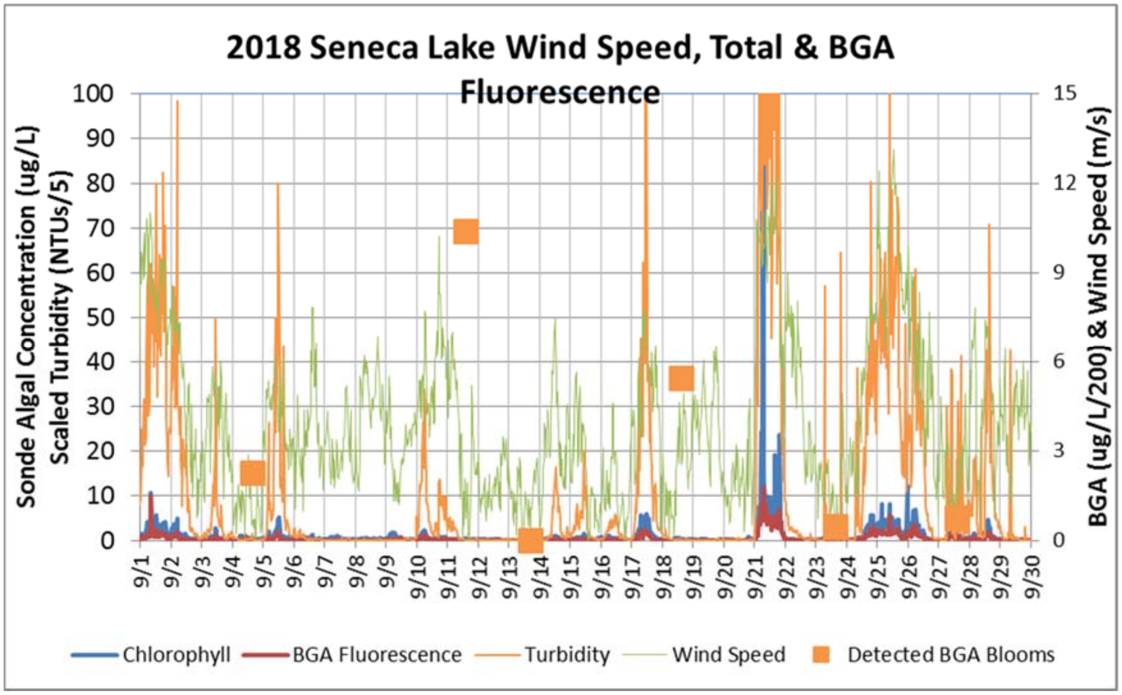


Fig. 16. Water turbidity, total and BGA fluorescence measured at a dock in Emerson Cove, Seneca Lake by a YSI EXO2 sonde. BGA concentrations at this site were from the Seneca HABs Surveillance team (with permission). Wind speed was measured by the Seneca Lake monitoring buoy, just offshore of this shoreline location.

Daily homeowner photographs of the shoreline detected blooms that were missed by the weekly dock samples. Additional blooms were detected by the Owasco HABs Surveillance volunteers at other locations in the lake. A compilation of the available daily bloom event record was compared to mean daily, wind speeds detected at the Owasco Lake buoy. Results show that BGA blooms prefer calm or near calm conditions (Fig. 17b & 18). The four suspected blooms detected on 8/21, a windy day, were from locations that were more protected from the south-southeasterly winds on 8/21 than the other sites. Wind speeds at the dock sites were not measured on 8/21, but wind speeds measured at each dock site on each survey date were always less that the buoy mean daily wind speeds.

A comparison of the daily bloom history to mean daily, sunlight intensity measured at the buoy and nearby rainfall data provide consistent correlations (Fig. 19). Light intensity dipped a few days before detected BGA blooms, probably due to cloudy/stormy weather and an occasional rain event (NY-CY-08, CoCoRaHS daily precipitation data). In these cases, the bloom appeared to wait until sunlight was more intense, e.g., sunny, cloud-free days. Thus, BGA blooms appeared to require the correct alignment of a number of forcing functions. A wind and/or storm event that release nutrients in shoreline areas, i.e., the event could have introduced nutrients from runoff and/or sediment disturbance by waves and/or internal seiche activity. The BGA then bloomed on the first subsequent calm and sunny day.

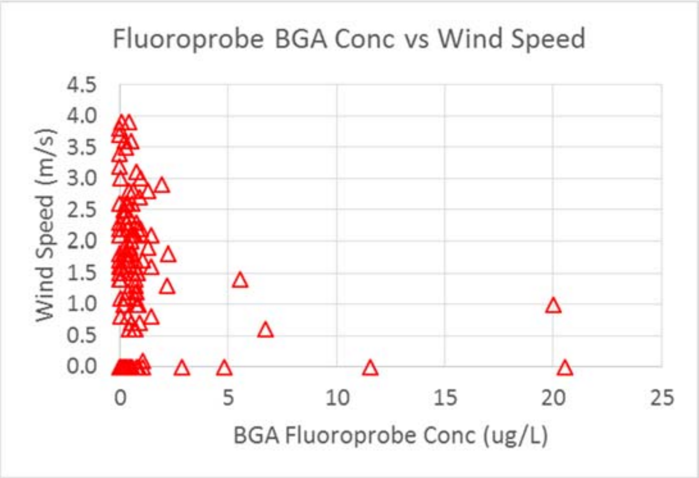


Fig. 17a. Wind speeds vs. FluoroProbe BGA concentrations measured at dockside locations indicate that even gentle winds (>1.5 m/s) appear to limit BGA accumulations.

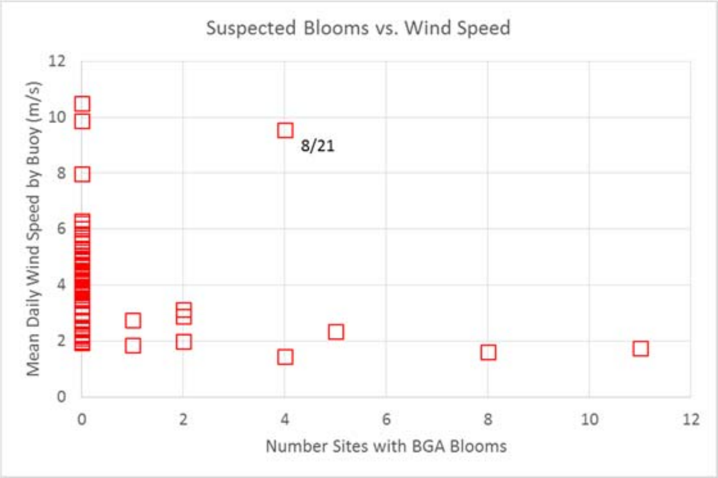


Fig. 17b. Buoy mean daily wind speed vs. suspected blooms detected in the homeowner photographs. Again, BGA accumulations are restricted to calm weather.

The following observations were also consistent with the bloom genesis hypothesis. Once an area has a BGA bloom, it usually experiences additional blooms. Accumulating BGA resting stage cells after each bloom might provide the spatial linkage, as they were probably deposited into the sediments underneath the previous bloom, waiting for the next ideal mix of nutrient-rich, calm and warm waters to foster the next bloom. This wait and bloom scenario could also increase the BGA concentrations in the shoreline areas from one bloom to next and from one year to next as the dead algae increase the sediment nutrient reservoir over time.

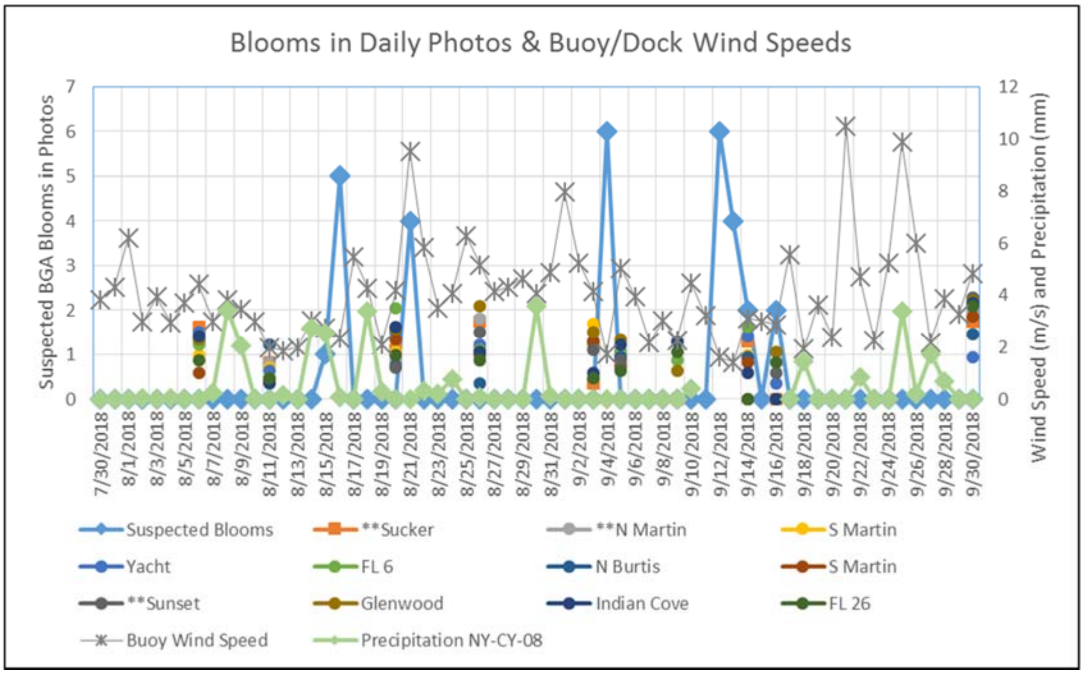


Fig. 18. Owasco Lake record of shoreline blooms, buoy and dockside wind speeds and daily precipitation data from a nearby weather station (NY-CY-08).

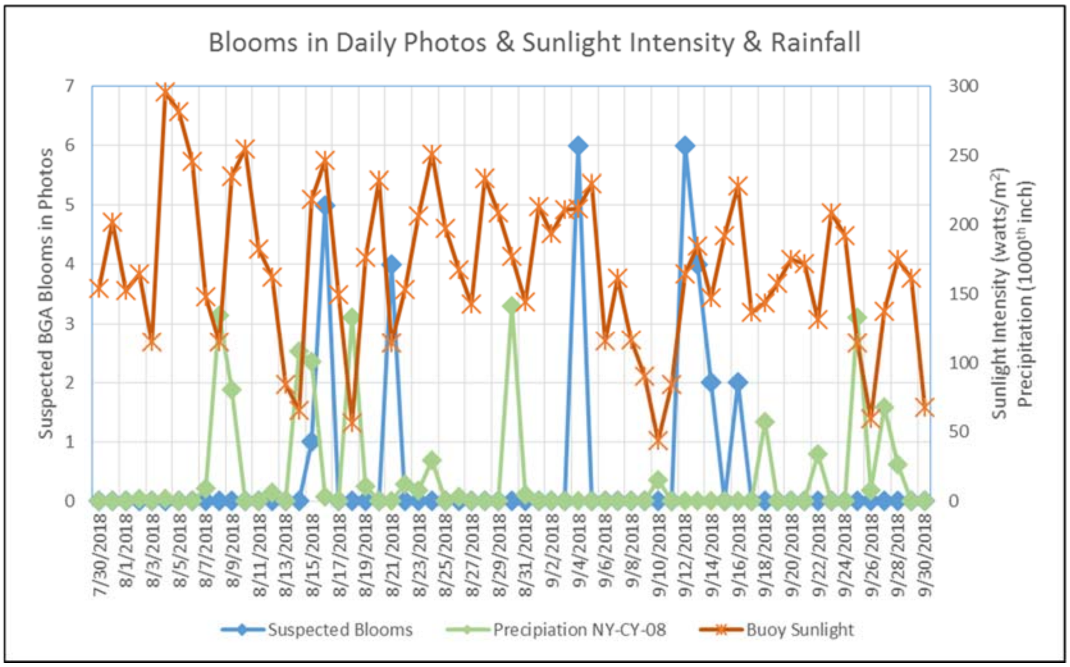


Fig. 19. Owasco Lake record of shoreline blooms, mean daily sunlight intensity measured by the buoy, and daily precipitation data from a nearby weather station (NY-CY-08).

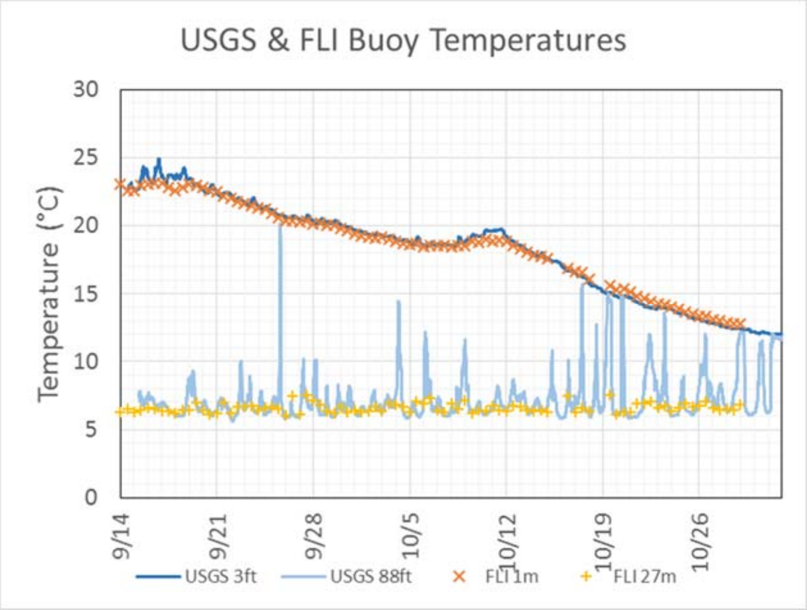
THE USGS BUOY DATA

The United State Geological Survey deployed a water quality monitoring buoy on 9/14, located about midway from the FLI Buoy to the northern shoreline of the lake in ~27 m of water (Fig. 1). Their buoy detected everything measured by the FLI buoy plus pH and dissolved organic matter, (fDOM). Other differences between the buoys are that the USGS buoy that collected data every 15 minutes at three depths (3ft (0.9m), 44 (13.4m) and 88ft (26.7m)) compared to FLI's 12 hour 1.5 m interval water column profiles (surface to bottom). Despite these differences, a comparison of the data collected by these two buoys when both were deployed (9/15 – 10/28) revealed consistent surface water trends for many of the parameters (Fig. 20). For example, the mean daily surface water temperatures only deviated by < 0.1°C. This deviation is less than the day-to-day variability observed by the nearshore temperature loggers.

The bottom-water temperature records revealed some significant differences between the two buoys. The USGS data revealed hour to day long, bottom-water increases in temperature. These warmer temperature spikes at times warmed the lake floor to surface water temperatures. These changes in bottom temperature are interpreted to reflect internal seiche activity, the see-saw tilting of the thermocline along the long axis of the lake after a substantial axis parallel wind event. Similar fluctuations were not observed at 27m (88ft) in the FLI buoy data. The difference can be explained by the dissimilar sample frequency, deployment location, and water depth at each location. The FLI buoy could easily miss any event shorter than its 12 hour sample frequency. The spikes themselves are attributed to internal seiche activity, which would have a greater influence at the more northern USGS site due to the tilting of the thermocline along the entire length of the lake. The tilt would extend the thermocline to much deeper depths closer to either end of the elongated lake. The timing of the thermal spikes was consistent with lake-parallel wind events.

The surface and bottom water turbidities reveal hour to day-long, spikes of increased surface and bottom water turbidity at the USGS site, and revealed a constant offset between the mean daily, background data, measured at the two buoy sites. The parallel offset between the background turbidities detected at both the surface and deep water depths was small, ~0.5 NTUs, and suggest a small difference in sensor calibration. Slightly larger background turbidities at the more offshore FLI site would not be expected under normal circumstances. The spikes of increased surface water turbidity by 1 or 2 NTUs are unique to the USGS data. The transitory spikes could have easily been missed by the semi-daily measurements at the more southern, mid-lake location of the FLI site. These surface water spikes may be attributed to sediment inputs from nearby streams and/or spatial inconsistences in algal blooms. Input from the lake floor is unlikely because concurrent spikes were rarely observed by the mid-depth nor the bottom water sensors.

Larger hour to day long spikes of increased bottom water turbidity (up to 10.5 NTUs) were also detected at the USGS site. These spikes are attributed to runoff from rain events and/or, more likely, sediment resuspension by strong winds and/or internal seiche activity. All three would have a greater influence at the USGS buoy because it was deployed in shallower water, and the bottom water sensor was positioned just above the lake floor. The depth at the USGS buoy is half of the depth of the FLI buoy site. A sediment source for the turbidity is likely because the mid-depth (44ft) and surface water sensors at the USGS site did not observe parallel turbidity spikes. This indicates that wind, i.e., waves and internal seiche activity, occasionally resuspended the bottom sediments at this nearshore, shallow water USGS buoy site.



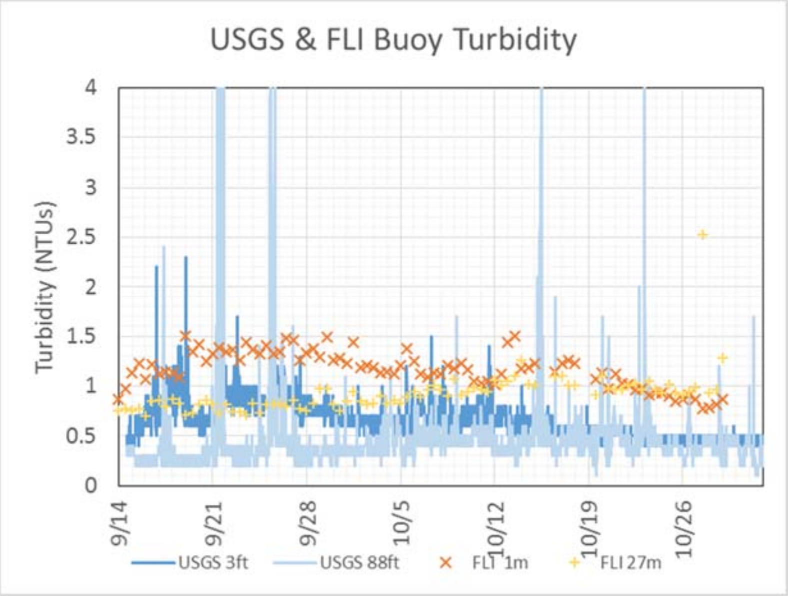


Fig. 20. USGS and FLI buoy surface and 88-ft depth temperature and turbidity data when both buoys were present in the lake. (1 NTU ≈ 1 mg/L)

BLUE–GREEN ALGAE LABORATORY GROWTH EXPERIMENTS:

The field data suggest that BGA grow from BGA resting stage cells and nutrients in the sediments. To test this, 2018 Owasco Lake sediment samples from each site were placed in separate flasks. Filtered lake water was added to each flask. The filtration removed any algae from the water sample. The starting nutrient concentrations in the lake water were insufficient to support blooms. Each flask was then stirred to emulate a turbid, wind-mixed, environment, and placed in the sunlight on a southern exposure windowsill in the lab. Within hours, the water cleared as the mud settled to the bottom of the flask. In a week or two, every flask experienced BGA blooms (Fig. 21). Other algal species, typically benthic diatom species, were also observed in some of the flasks. The simple experiment suggests that BGA can grow from the offshore and nearshore sediments in nutrient-poor water after a mixing event. The algae and nutrients must have originated from the sediments. It also suggests that a time lag is required to decompose enough sediment organic matter to support the subsequent growth of algae in the overlying water column. This simple experiment should be repeated again with detailed measurements of algal and nutrient concentrations over time.

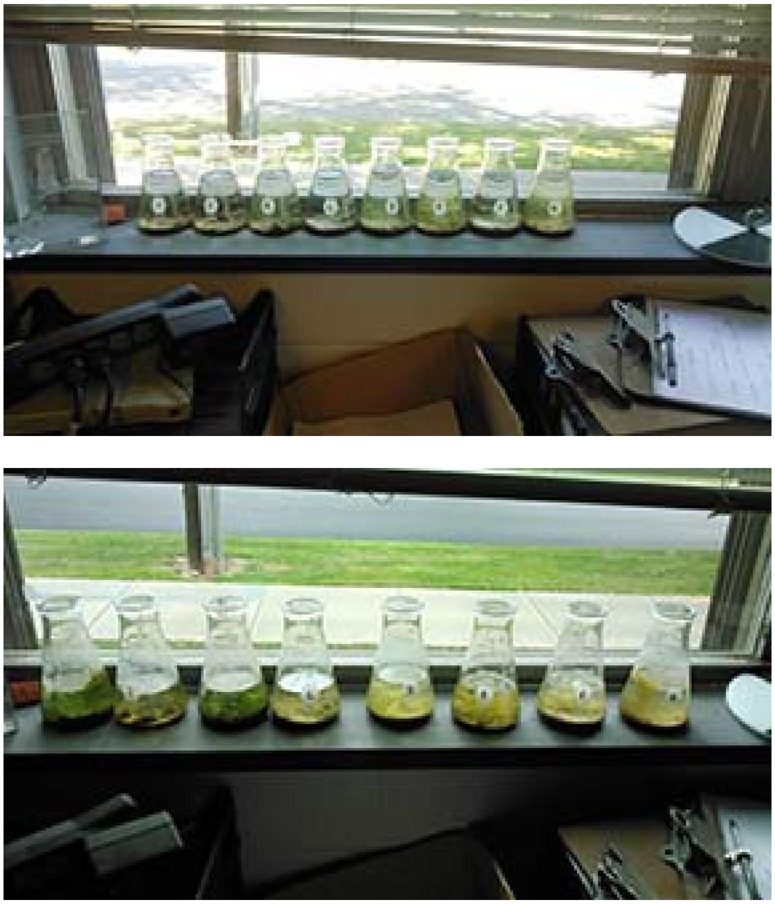


Fig. 21. BGA blooms from Owasco Lake sediments. Sediments from each site were immersed in separate flasks. Filtered (algae free) lake water was added. Then, each flask was swirled (to simulate a wave mixing event) and placed in the sunlight. The suspended sediments and water motions settled quickly (above). BGA blooms formed in each flask after a week or so (below).

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