Evaluation of macroalgae and aquatic plant harvesting as a means for improving water quality in Georgica Pond

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Executive summary

During the past several years, Georgica Pond, East Hampton, NY, USA, has experienced a series of significant water quality impairments and human health threats including toxic cyanobacterial blooms, anoxia, kills of aquatic and wildlife, and macroalgae blooms. In 2015, the precise nitrogen and phosphorus loading rates to Georgica Pond were quantified. At the same time, the hypothesis was put forth that the purposeful removal of macroalgae and aquatic plants from Georgica Pond could help improve water quality conditions. In 2016, NYSDEC permits were obtained to deployed an Aquatic Weed Harvester in Georgica Pond to remove the accumulation of macroalgae and aquatic plants across the entire system as a means of combating the delivery of nitrogen and phosphorus to the Pond and thus combating the late summer occurrence of toxic blue-green algae blooms. Harvesting began in June and persisted through early September with peak removal occurring during the months of July and August. A total of 55,740 lbs of macroalgae and aquatic plants was harvested through the season. This harvest represented only a small fraction of the annual nitrogen and phosphorus load to Georgica Pond (1% and 2%, respectively). Importantly, however, all of this harvest was concentrated between June 23 and September 8 of 2016. Prorating the harvest to these summer months, when freshwater delivery of nitrogen and phosphorus is minimal, this harvest represented up to 13% of the July-August nitrogen load and 23% of the July-August phosphorus load. While the nitrogen reduction is still far below the 80% reduction needed to meet US EPA target values, the 20% reduction in phosphorus was a significant portion of the 50% reduction required to meet US EPA target values for this element. Concurrent with the removal of the macroalgae and aquatic plants, environmental conditions in Georgica Pond during 2016 were significantly improved compared to prior years. Blue-green algae levels were an order of magnitude lower than the two prior years and these algae never bloomed to the exclusion of other algae. While Georgica Pond had the highest levels of blue-green algae in Suffolk County in August of 2014 and 2015, it had some of the lowest levels in 2016. In addition, unlike 2013 – 2015 when anoxia and kills of wildlife occurred in Georgica Pond, in 2016 dissolved oxygen levels stayed above 4 mg/L throughout the summer and kills of fish or other wildlife were not observed. While many inter-annual differences could have contributed to the improved environmental conditions in Georgica Pond in 2016, the significant reduction in nitrogen and phosphorus loading via the harvest of macroalgae and aquatic plants during the months when blue-green algae form blooms were likely to have played a key role in these improved conditions.

Introduction

Since 2013, the Gobler Laboratory has documented a series of significant water quality impairments in Georgica Pond including anoxia (no oxygen), fish kills, macroalgal blooms, blue-green algal blooms, and elevated levels of the cyanotoxin, microcystin. These events worsen during summer (July - September) and are most problematic during late August and into September. As a result of blue-green algal blooms with elevated levels of cyanotoxins, Georgica Pond has been sporadically closed to shellfishing during late summer and fall. In 2015, three independent nutrient loading models were created by the Gobler Laboratory to understand which nutrients and at what quantities were contributing to blooms of macroalgae and blue-green algae and subsequent water quality impairment in Georgica Pond. The models showed that levels of nitrogen and phosphorus entering Georgica Pond exceeded levels recommended by USEPA, with the primary transport process being groundwater. The transport of septic wastewater via groundwater was the largest source of nitrogen to Georgica Pond while fertilizer and sediments were the primary sources of phosphorus. It was noted that 50% and 80% reductions in phosphorus and nitrogen delivery, respectively, would be required to reach federal water quality standards.

Upon noting the dense macroalgae blooms that accumulated in Georgica Pond in 2014 and 2015, it was hypothesized by the Gobler Laboratory that the active removal of macroalgae could be a means to remove a significant amount of nitrogen and phosphorus from the system. The macroalgae overgrowing Georgica Pond had been primarily *Cladophora* and Sago pondweed *Stuckenia pectinata*. Once these algae grow dense enough, they contribute toward nighttime hypoxia and anoxia (low and zero oxygen). Moreover, its decay releases a large quantity of nutrients that likely fuel late summer, toxic blue-green algal blooms. Hence, removal of macroalgae could minimize blue-green algal blooms and low oxygen conditions. Preliminary tissue analyses indicated macroalgae contained high levels of nitrogen and phosphorus but low levels of toxic trace metals and cyanotoxins and it was noted that macroalgae re-grow continuously through the summer, meaning they could be continuously harvested. Hence, in early 2016 discussions were initiated with NYSDEC Marine Habitat Division on behalf of the East Hampton Town Trustees and permits were obtained to actively remove macroalgae from Georgica Pond in the summer of 2016. In addition, authorization to use the diesel powered harvester on Georgica Pond was obtained from the East Hampton Town Board.

The goal of this project was to establish the temporal dynamics of macroalgae removal and the elemental composition of macroalgae in Georgica Pond during the summer of 2016. This included analysis of the mass and elemental composition of macroalgae harvested from Georgica Pond which facilitated an assessment of the efficacy of macroalgae harvest from Georgica Pond as a nutrient mitigation strategy. Specifically, nutrient load models made in 2015 were used to determine what percentage of the total nitrogen and phosphorus loads were removed from Georgica Pond through the harvest of macroalgae.

Approach

Beginning in late May 2016, an Aquamarine Model H7-400 Aquatic Weed Harvester vessel was deployed in Georgica Pond by Solitude Lake Management from Shrewsbury Massachusetts. The vessel was launched at the Georgica Association boat launch on Georgica Association Road which is a boat launch region, meaning no shoreline modifications were required for the boat to be launch. This aquatic plant harvester is hydraulically-driven with reciprocating knives mounted on the harvesting head to cut aquatic vegetation. A GIS-tracking device provided by the Gobler laboratory was sent to the vessel to assess precise distance traveled by the vessel through the summer, although a technical malfunction prevented useful data from being generated by this device. The vegetation was transferred via its conveyor system onto the vessel's deck. The storage deck gradually filled up with harvested biomass which was then transferred to the shoreline and then transferred via trucks to the East Hampton Town transfer station where it was weighed and then composted. Harvesting continued through September when there are no longer dense yields of macroalgae and aquatic plants, which together can be referred to as macrophytes.

For each weekly harvest, sub-samples of the macrophytes were obtained, brought to the Gobler laboratory, dried at 60°C for 48 h, and re-weighed, establishing a ratio of wet-to-dry weight, and permitting later dry yields to be quantified. Subsamples of dried seaweeds were analyzed for elemental composition. Carbon and nitrogen content was directly quantified using a Thermo EA1112 elemental analyzer. In parallel, phosphorus was analyzed using persulfate oxidation, wet chemistry analyses. In addition, selected samples were analyzed for additional elements using an ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometer). Prior to analysis, ~1 g of dried seaweed sample was dissolved in 50 mL of hydrochloric acid that was analyzed. Levels of the cyanotoxin, microcystin, in the macrophytes were also quantified via an ELISA assay.

Utilizing the nutrient loading budgets established in 2015 by the Gobler Laboratory's study of Georgica Pond, the efficacy of the 2016 macrophyte harvest from Georgica Pond as a nutrient mitigation strategy was evaluated. Laboratory analyses of nitrogen and phosphorus attained were prorated to the weights of macrophyte measured at the East Hampton Town transfer station. The nitrogen and phosphorus loading models generated in 2015 were re-run adding the harvest of macrophyte as an additional loss term in these budgets. Models were run both monthly and annually to assess the seasonal and year-long impact of harvests. Since a large majority of the annual nitrogen and phosphorus loads are delivered to Georgica Pond via freshwater flow (groundwater, streams, run-off), nutrient delivery rates were also altered to account for the seasonal decline in freshwater flow during summer due to the high rates of evapotranspiration. Collectively, these model runs determined what percentage of the total nitrogen and phosphorus loads were removed from Georgica Pond by macroalgal harvest.

Water quality measurements made in 2016 were nearly identical to those made in 2013, 2014, 2015, and 2016, allowing inter-annual comparisons to be made. A Fluoroprobe (bbe Moldenke) was used to differentiate cyanobacteria from other phytoplankton groups on the basis of photosynthetic accessory pigments on discrete water samples. YSI EXO water quality probes were used to measure continuous levels of dissolved oxygen as well as blue-green algal biomass.

Findings

From June 23 through September 8, 2016, a total of 55,740 lbs of macrophytes was removed from Georgica Pond (Table 1). The macrophytes consisted largely of Sago pondweed for much of the summer, with *Cladophora* being the second most abundant macrophyte harvested with its abundance peaking in August. Harvested macrophytes were transferred from the harvesting vessel to land prior to being loaded onto a truck and weighed at the East Hampton Town Transfer Station. Sub-samples of harvested macrophytes were tested for water, nitrogen, and phosphorus content. Harvested macrophytes were, on average, 70% water weight (Table 2). Once dried the macrophytes were found to contain, on average, 3% nitrogen and 0.2% phosphorus meaning the harvesting removed 585 and 37 lbs of nitrogen and phosphorus (Table 2). This represented only a small fraction (1 and 2%, respectively) of the mean annual nitrogen and phosphorus load to Georgica Pond determined via nutrient budgets in 2015 (Table 2). Importantly, however, this harvesting was performed during the summer only when freshwater flow-derived nutrient loads are at an annual minimum, being roughly 50% of the annual, monthly average (Table 2; USGS monitoring; Steenhuis et al 1985). Focusing on the months of July and August only, it is estimated that the macrophytes harvested from Georgica Pond represented 10% and 20% of the nitrogen and phosphorus loads entering the Pond (Table 2). These months represent critical periods in the ecology of Georgica Pond as they are the times when blue-green algae blooms and anoxia developed in 2014 and 2015. It is well known that excessively high levels of nitrogen and phosphorus promote blue-green algae blooms which then lead to anoxia and that blue-green algae thrive on recycled nutrients that would be released from macrophytes and sediments. By removing the macrophytes, it is hypothesized that the lowered nutrient levels created conditions that allowed other phytoplankton to be more competitive with blue-green algae, as blue-green algal blooms are known to be promoted by excessive levels of nitrogen and phosphorus (Paerl et al., 2001; Gobler et al., 2016).

The differences in environmental conditions in Georgica Pond during the summer of 2016 when the harvesting occurred and prior monitoring years when it did not were stark. For example, in 2014 and 2015, levels of blue-algae exceeded the NYSDEC threshold value of 5 µg/L (on the telemetry buoy scale) from August through October and declined only after the cut to the ocean was opened (Figure 1). Moreover, those blooms reached and maintained immense densities of 30µg/L for extended period (Figure 1). In 2016, levels rarely exceeded 5 µg/L (Figure 1). In addition, in 2014 and 2015, as the blue-green algae blooms intensified, other type of phytoplankton in Georgica Pond vanished including green algae and diatoms whereas in 2016, total algal biomass levels were lower and blue-green algae were one of several types of algae that co-existed in Georgica Pond over the summer (Figure 2). Finally, the levels of blue-green algae in 2016 in Georgica Pond were among the lowest present in lakes and ponds across Suffolk County, whereas in 2014 and 2015 it had the highest (Figure 3).

Dissolved oxygen is another environmental parameter in Georgica Pond that showed marked improvement in 2016 (Figure 4). During 2013, 2014, and 2015, Georgica Pond experienced extended periods of anoxia or dissolved oxygen levels of zero at night during the summer (Figure 4). For example, in 2015, anoxia first occurred in August and continued to occur sporadically through September and into October (Figure 4). In contrast, in 2016, levels rarely fell below 5 mg/L and were never below 4mg/L (Figure 4).

Implications and perspective

The prime objective of implementing macroalgae / macrophyte harvesting in Georgica Pond in 2016 was to remove nitrogen and phosphorus and minimize the intensity of blue-green algae blooms and anoxia associated with those blooms. From late June through early September, nearly 56,000 lbs of macrophytes were removed from the Pond along with 10 and 20% of the summer nitrogen and phosphorus loads to the Pond. Concurrently, blue-green algal bloom intensity was an order of magnitude lower than past years and levels of dissolved oxygen remained high throughout the year. While many inter-annual differences regarding Georgica Pond could have contributed to the improved environmental conditions in 2016, the significant reduction in nitrogen and phosphorus loading via the harvest of macrophytes during the months when blue-green algae bloom was likely to have played a role in these improved conditions.

Georgica Pond is a unique ecosystem being one of three estuaries on Long Island that are mechanically opened to the ocean annually but also receiving high rates of freshwater inflow. Traditionally, Georgica Pond had been opened once in the fall in mid-October and once in the spring in mid-April. More recently, the East Hampton Town Trustees have elected to open the cut more frequently between these two dates in the event the cut closes. For example, in 2015, the cut was opened in January and it remained open through June. In 2016, the cut closed in early April and remained closed until it was opened in October. These differences in opening and closing the cut can strongly influence the ecology of Georgica Pond. When the cut is open, Georgica Pond is well-flushed with ocean water, keeping phytoplankton biomass low. When closed, nutrients in the freshwater entering Georgica Pond are retained and algal biomass accumulates, leading to algal blooms. In 2016, the spring closure of the cut allowed the dinoflagellate, *Prorocentrum minimum*, to form a dense and extended “mahogany tide” during May and early June. The high levels of phytoplankton biomass in the water column reduced the amount of light reaching the bottom of Georgica Pond during this time, a change that may have minimized the ability of macroalgae to grow maximally. This hypothesis is consistent with the observations that the levels of total macroalgae in Georgica Pond were lower in 2016 than recent years and that the levels of the macroalga, *Cladophora*, were far lower than prior years. Notably, these lower levels of macroalgae made the harvesting less effective than it would have been with denser stands and thus reduced the potential effectiveness of this process.

Beyond the effect of the opening/closing of the cut on nutrients and algal blooms, it also has a strong effect on salinity in the Pond. In 2015, the salinity of Georgica Pond was nearly 30 through June. In 2016, it was below 15 for much of the year. While most of the aquatic life in Georgica Pond including *Cladophora*, in halo-tolerant, it is possible that the lower salinity in 2016 discouraged the maximal growth of macroalgae thus reducing the potential effectiveness of macroalgae harvest. In addition, the rates of freshwater discharge on Long Island were about 10% lower in 2016 compared to 2015 (USGS records), a difference that may have lowered the intensity of both macroalgae and blue-green algae blooms. It is notable, however, that in the case of blue-green algae, biomass levels were 90% lower in 2016, suggesting this difference could not be accounted for simply by difference in freshwater discharge. Moreover, this slightly reduced rate of freshwater input did not minimize blue-green algae blooms in other waterbodies across Suffolk County.

One concern regarding the use of a mechanical harvester was the potential for by-catch of aquatic life by the mechanical harvester. A benefit of the particular harvester used in Georgica Pond was the ability to stop the harvester when aquatic animals large enough to be seen were captured, allowing for the animals to be returned to the Pond. In addition, a bar on the bottom of the cutter prevented it from dredging the pond bottom. Through the summer of 2016, the silversides, *Menidia menidia* and *Menidia beryllina,* and juvenile eels (*Anguilla rostrata*) were by-catch of the macroalgae harvest. Larger marine animals, however, were removed from the harvester and saved. These animals included snapping turtles (*Chelydra serpentine)*, larger eels, fluke, and blue crabs (*Callinectes sapidus)*, none of which were by-catch during this project.

A second concern regarding the harvest of macroalgae is the potential for the presence of excessive levels of trace metals or algal toxins in the harvested macroalgae. In 2016, eight samples collected weekly during July and August were tested for the cyanotoxins, microcystin and anatoxin a and both toxins were undetectable in the harvested algal biomass. In addition, trace metal analyses were performed and showed levels of zinc (0.08 µg/g), mercury (0.0001 µg/g) and cadmium (0.003 µg/g) very far below standard set by the US EPA for biosolids (7500, 85, and 57 µg/g, respectively) or by the German government for composted materials (500, 3, and 3 µg/g, respectively) for these elements.

In 2015, the total nitrogen and phosphorus loads to Georgica Pond were precisely quantified using multiple methods. In addition, the levels of nitrogen and phosphorus in Georgica

Pond and the freshwater (creeks, groundwater) entering Georgica Pond were precisely quantified. Based on recommendations and standards set by the US EPA and several other environmental agencies, it was found that the levels of nitrogen and phosphorus in Georgica Pond should be reduced by 80% and 50% respectively. Part of the 2015 study by the Gobler Lab also included a comprehensive list of approaches for achieving these reductions that included the harvesting of macroalgae. In 2016, the removal of nitrogen and phosphorus associated with macroalgae was a small fraction of annual loads (1-2%) but was a larger fraction for the months of July and August (10-20%). Blue-green algae blooms were one of the primary environmental threats that nutrient reductions were designed to mitigate as these events are known to be a consequence of excessively high levels of nitrogen and phosphorus and are specifically known to be fueled by 'recycled' nutrients that emanate from decaying algae or sediments (Paerl et al., 2001; Gobler et al., 2016). Hence, it is possible that the removal of macroalgae represented an ideal approach for mitigating blue-green algal blooms by removing the ideal form of nitrogen and phosphorus (recycled forms) at the ideal time (summer). The lowered levels of these nutrients seem to more supportive of a mixed algal community where blue-green algae were present at modest levels along with green algae, diatoms, and other algae capable of supporting a healthy aquatic ecosystem.

The harvesting of macroalgae from Georgica Pond represents one of many environmental remediation approaches underway within this system with others including the exploration of dredging of the pond, the use of permeable reactive barriers to remove nitrogen from groundwater, upgrading regional septic systems, and mitigating storm water run-off. In future, some or most of these approaches will be advanced to the point of the actively reducing nutrient loads from Georgica Pond and contributing toward achieving the goals of 80% and 50% reductions in nitrogen and phosphorus loads, respectively. In the meanwhile, the harvest of macroalgae can be refined and made more efficient. Given the lower levels of macroalgae present in Georgica Pond in 2016, it seems likely that future years of harvesting will yield even larger amounts of nitrogen and phosphorus. Additional years of harvest and observation will be needed to better understand the precise relationship between the harvest of macroalgae, blue-green algae, and anoxia. Based on the results of 2016, the significant reduction in nitrogen and phosphorus loading via the harvest of macroalgae was likely to have contributed toward the lower blue-green algae and high dissolved oxygen levels through the summer.

Acknowledgement:

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Table 1. Pounds of macroalgae removed from Georgica Pond in 2016 by day and in sum.

Date	lbs harvested
23-Jun	1,900
30-Jun	2,960
5-Jul	740
8-Jul	3,180
11-Jul	3,340
19-Jul	3,400
21-Jul	7,480
23-Jul	1,020
28-Jul	3,160
4-Aug	7,080
9-Aug	1,980
11-Aug	5,360
12-Aug	2,380
20-Aug	4,000
26-Aug	1,660
2-Sep	7,360
8-Sep	640
Total	55,740

Table 2. Input, harvest, and removal of nitrogen and phosphorus from Georgica Pond in 2016.

INPUTS	Nitrogen		INPUTS	Phosphorus	
Annual load	52,800	lbs/yr	Annual load	1,958	lbs/yr
Annual load	24,000	kgN/yr	Annual load	890	kg P/yr
Monthly load	2,000	kgN/month	Monthly load	74	kg P/month
Monthly load	4,400	lbs/mo	Monthly load	163	lbs/mo
Summer month load	2,200	Dry season lbs/mo	Summer month load	82	Dry season lbs/mo
HARVEST			**HARVEST**		
Total harvest	55,740	lbs	Total harvest	55,740	lbs
Dry weight harvest	16,722	dry lbs	Dry weight harvest	16,722	dry lbs
Nitrogen harvest	585	lbs N	Phosphorus harvest	38	lbs P
Percent of N removed, year	1%	Fraction, yr	Percent of P removed, year	1.9%	Fraction, yr
Percent of N removed, July & August	7%	Fraction, summer	Percent of P removed, July & August	12%	Fraction, summer
Percent of N removed, reduced flow	13%	Fraction, summer	Percent of P removed, reduced flow	23%	Fraction, summer

Figure 1. A comparison of blue-green algal biomass levels present in 2015 and 2016. In 2014, blue-green algae levels were observed similar to those found in 2015. Note measurements made via the telemetry buoy. Units are ~1/10 of those on the Fluoroprobe. The horizontal dash line represents an extremely intense, toxic cyanobacterial bloom threshold. The vertical dashed lines represent the opening of the cut in 2015 whereas the solid vertical line represents the re-closing of the cut in 2015.

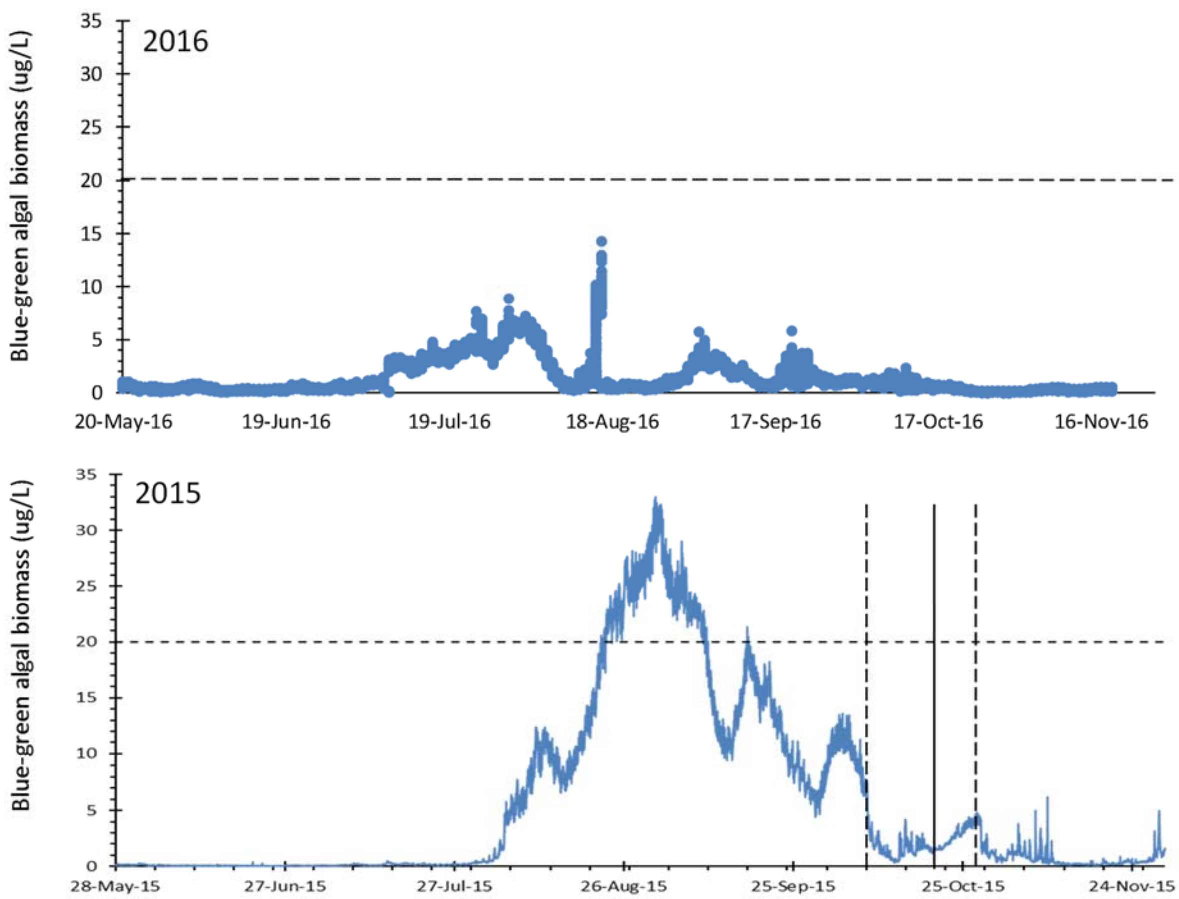

Figure 2. A comparison of algal biomass levels present in 2015 and 2016. Note measurements made via the Fluoroprobe. Units are ~10x those on the telemetry buoy.

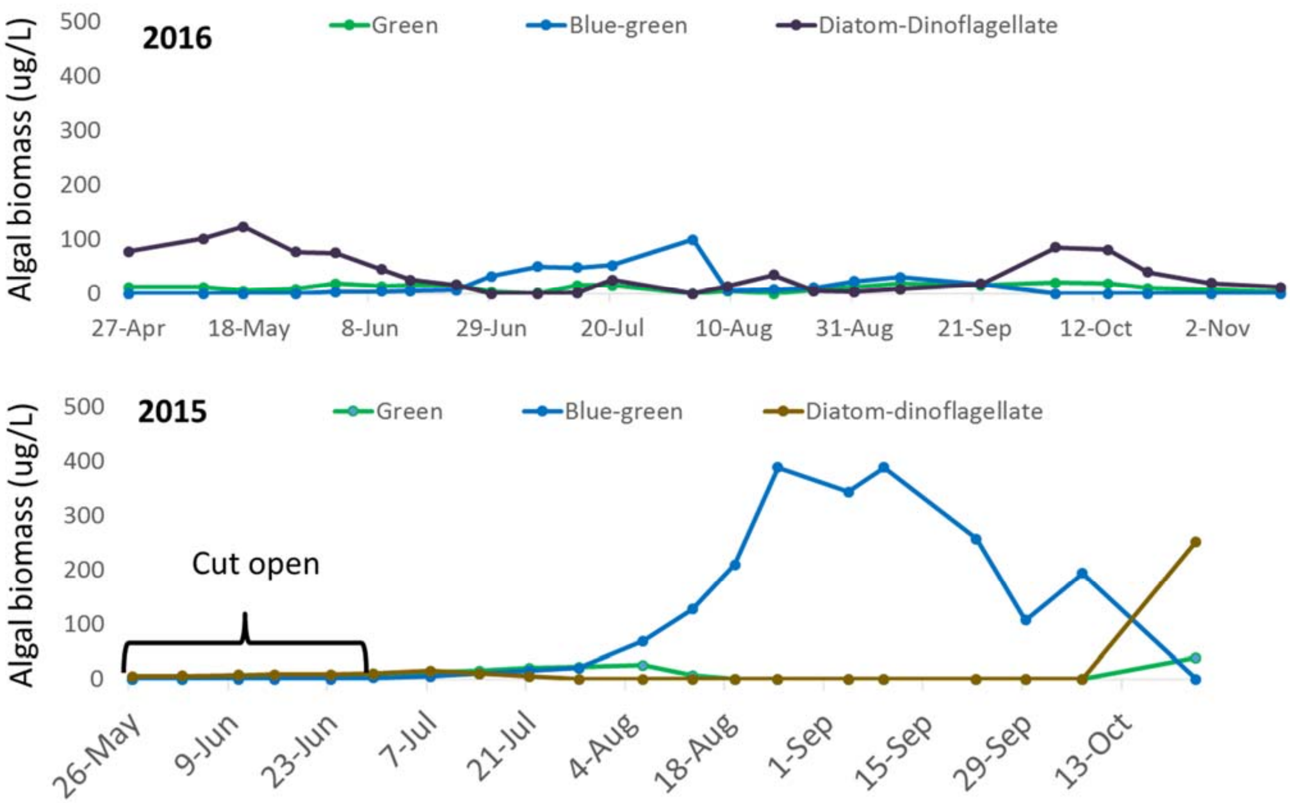

Figure 3. A comparison of blue-algal biomass levels present across Long Island during August of 2014, 2015 and 2016. Note measurements made via the Fluoroprobe. Units are ~10x those on the telemetry buoy.

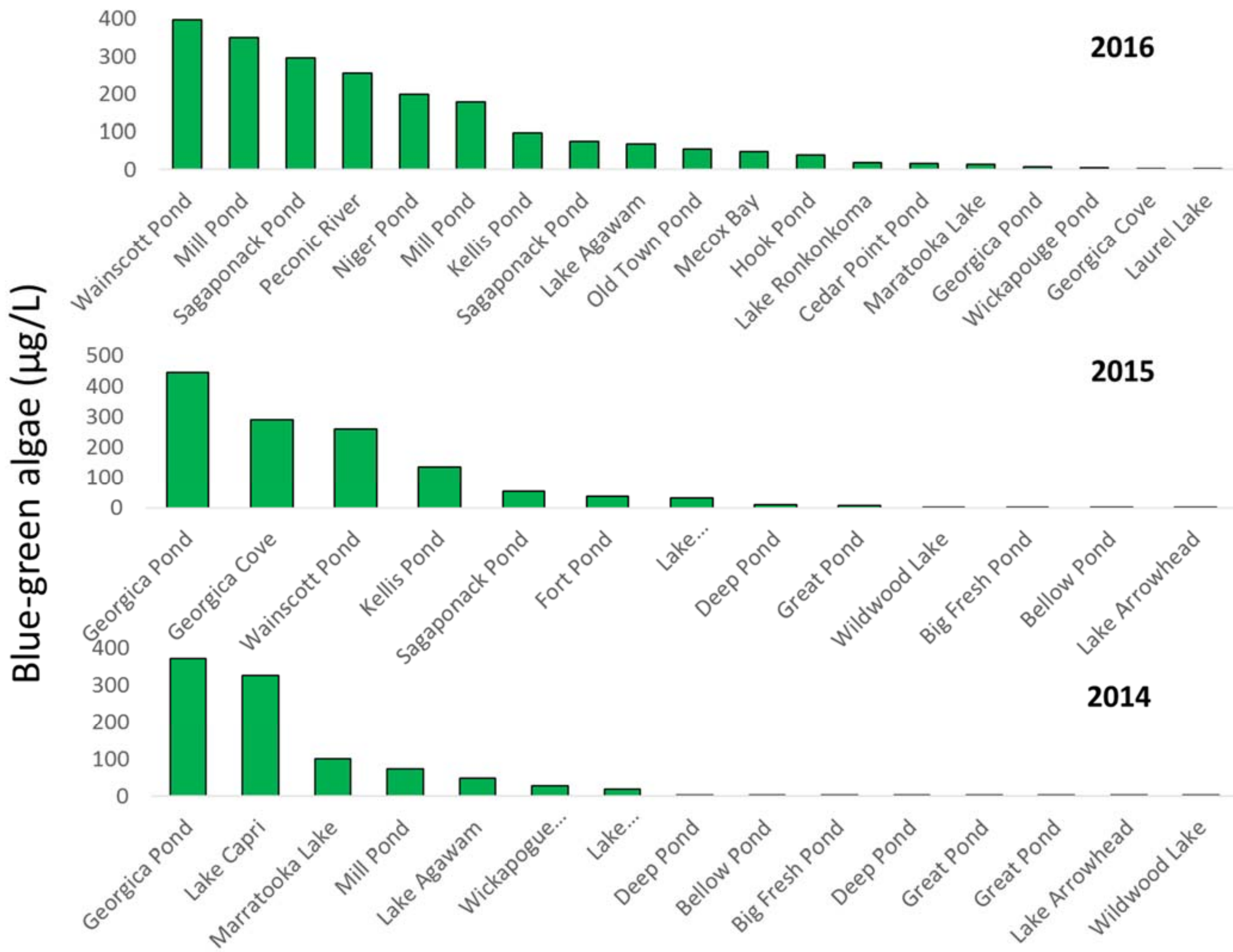

Figure 4. A comparison of dissolved oxygen levels present in 2015 and 2016. In 2013 and 2014, anoxic periods were observed similar to those found in 2015.