East Hampton Town Trustees 2014 water quality study, Draft Final Report

by

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Executive Summary

This study was undertaken from April through December of 2014 for the East Hampton Town Trustees to assess water quality, harmful algal blooms, and pathogenic bacteria in their marine and freshwater bodies including Accabonac Harbor, Napeague Harbor, Hog Creek, Northwest Creek, Fresh Pond, Three-Mile Harbor, Georgica Pond, and Hook Pond. Given issues regarding HABs and low dissolved oxygen in Three Mile Harbor and Georgica Pond in 2013, this study included intensive sampling and focus on these two sites. During 2014, we found East Hampton Town Trustees waters to be generally of a high quality. With the exception of Fresh Pond, fecal coliform bacteria levels across marine sites were low through the spring and summer with only two sites (Hog Creek, Accabonac Harbor) showing single dates of elevated levels in September conincident with elevated rainfall. The 2013 report to the Trustees indicated that Northwest Creek could be opened to shellfishing and that change was actually made by the NYSDEC in 2014. Our 2014 data indicates that regions of Three Mile Harbor and Northwest Creek could be further opened to shellfishing. At nearly all marine locations, dissolved oxygen and chlorophyll *a* were at levels supportive of fisheries and levels of harmful algae were low or undetectable. A significant exception to this trend was Three Mile Harbor. This system had the highest levels of two harmful algae studied, *Alexandrium* and *Cochlodinium*. Densities of *Alexandrium* and *Cochlodinium* in Three Mile Harbor peaked at 400 cells/L and 5,000 cells/mL, respectively, levels that could lead to shellfish toxicity and fish mortality, respectively. Two other marine issues of concern included elevated levels of *Cochlodinium* in Accabonac Harbor (1,000 cells/mL) in August and an extended period of low oxygen in late summer within the Head of the Harbor region of Three Mile Harbor. Among the freshwater sites, Hook Pond displayed good water quality throughout 2014. In contrast, Georgica Pond hosted a series of significant water quality impairments including low oxygen, fish kills, macroalgal blooms, blue green algal blooms, and elevated levels of the cyanotoxins, microcystin and anatoxin-a. These events worsened through the summer (July and August) and were most problematic during September. Consequently, the Pond was closed to shellfishing for much of the summer and fall. The fall letting of the Pond offered the opportunity to closely examine the ecological response of this system to exchange with the Atlantic Ocean. Opening the Pond led to a decrease in water levels and the near elimination of blue green algae while concurrently increasing salinities and dissolved oxygen levels and thus could be considered as an emergency measure to combat algal blooms in the future. Finally, since levels of harmful algae, fecal coliform, and toxic cyanobacteria varied significantly among locations between 2013 and 2014, continued monitoring of locations will be required to establish a firmer base line of conditions across East Hampton Town Trustee waters.

Background

Coastal marine ecosystems are amongst the most ecologically and economically productive areas on the planet, providing an estimated US$14 trillion in annual resources or about 43% of the global ecosystem goods and services (Costanza et al. 1997). Approximately 40% of the World population lives within 100 km of a coastline, making these regions subject to a suite of anthropogenic stressors including intense nutrient loading (Nixon 1995). Excessive nutrient loading into coastal ecosystems promotes algal productivity and the subsequent microbial consumption of this organic matter reduces oxygen levels and can promote hypoxia (Cloern 2001). The rapid acceleration of nutrient loading to coastal zones in recent decades has contributed to a significant expansion of algal blooms, some of which can be harmful to ecosystems or the humans who live around those ecosystems.

Globally, the phytoplankton communities of many coastal ecosystems have become increasingly dominated by harmful algal blooms (HABs) and New York's coastal waters are a prime example of this trend. Prior to 2006, algal blooms in NY were well-known for their ability to disrupt coastal ecosystem and fisheries, but were never considered a human health threat. Since then, blooms of the saxitoxin-producing dinoflagellate *Alexandrium fundyense* (> 1,000,000 cells L^{-1}) have led to paralytic shellfish poisoning (PSP)-induced closures of nearly 10,000 acres of shellfish beds in western Suffolk County during six of the past seven years. In 2008, a second toxic dinoflagellate, *Dinophysis acuminata*, began forming large, annual blooms (> 100,000 cells L^{-1}) that have generated the toxins okadaic acid and DTX-1, both of which are the causative agents of diarrhetic shellfish poisoning (DSP) syndrome. During the past two years, PSP events have spread progressively east to Shinnecock Bay and Sag Harbor. Moreover, moderate levels of *Alexandrium* and *Dinophysis* have recently been detected in East Hampton Town waters. The limited nature of sampling, however, has prohibited definitive conclusions regarding the extent and maximal densities of blooms from being established

Cochlodinium polykrikoides is an ichthyotoxic dinoflagellate which forms blooms around the world (Kudela and Gobler 2012). The highly lethal effects of these blooms on fish, shellfish, shellfish larvae, and zooplankton, and subsequent impacts on fisheries have been well established (Kudela and Gobler 2012). Studies to date suggest short-lived, labile toxins, similar to reactive oxygen species (ROS), play a central role in the toxicity of *C. polykrikoides* to fish and shellfish (adult, juvenile, and larvae) (Tang & Gobler 2009A&B). In Suffolk County, *Cochlodinium* blooms have occurred every year since 2004 in the Peconic Estuary and Shinnecock Bay and bloom water from these regions has been shown to cause rapid morality in fish, shellfish, and shellfish larvae (Gobler et al. 2008, Tang & Gobler 2009a and b). In 2012, these blooms spread through East Hampton Town waters, and large populations of bay scallops that were abundant prior to blooms were dead following these blooms events (Deborah Barnes, NYSDEC, pers. comm.). The precise distribution of *Cochlodinium polykrikoides* blooms in East Hampton Town waters is, however, unknown.

Toxic cyanobacteria blooms represent a serious threat to aquatic ecosystems. Globally, the frequency and intensity of toxic cyanobacteria blooms have increased greatly during the past decade and toxin concentrations during many blooms often surpass the World Health Organization (WHO) safe drinking water and recreational water limit (Chorus and Bartham, 1999). There are multitudes of examples of sicknesses and deaths associated with chronic, or even sporadic, consumption of water contaminated with cyanotoxins (O'Neil et al., 2012). Cyanotoxin exposure has been linked to mild to grave medical conditions in humans including gastrointestinal cancers (i.e. liver, colorectal; Chorus and Bartham 1999) and most recently, neurological disorders such as Alzheimer's disease (Cox *et al.*, 2005). These toxic bloom events have become commonplace in the upper reaches of many US estuaries. Since 2003, the Gobler lab of Stony Brook University has assessed levels of toxic cyanobacteria and microcystin in more than 30 freshwater systems across Suffolk County. All lakes sampled contained potentially toxic cyanobacteria (typically *Microcystis* sp. or *Anabaena* sp.) and detectable levels of the hepatoxin made by cyanobacteria, microcystin. Fifteen of the lakes had levels of microcystin exceeding levels permissible for drinking water according to the World Health Organization (WHO).

In early September 2012, the NYS Department of Health reported the death of a Jack Russell Terrier following the consumption of toxic cyanobacteria in Georgica Pond. According to the NSYDOH, the dog had wandered into the reeds along Georgica Pond and did not come out. It was found unconscious and brought to the Riverhead Emergency Veterinary Hospital where the dog experienced seizures and died. An autopsy of the dog indicated its stomach contained cyanobacteria and an autopsy revealed the cause of death was liver failure. *Microcystis* is a cyanobacteria that synthesizes a liver toxin known as microcystin. Although no bloom was obvious in the pond when it was investigated in late September of 2012, blooms are typically ephemeral and the most toxic events are typically associated with nearshore, wind accumulated scums, rather than lake water. Historically, the temporal and spatial dynamics of toxic cyanobacteria in Georgica Pond as well as densities of other harmful algae in East Hampton waters have not been well-characterized.

A final group of microbes of concern in coastal ecosystems are pathogenic bacteria. Such pathogens can present a hazard to humans recreating in infected waters when an infective dose colonizes a suitable growth site in the body and leads to disease. Sites of infection can include the alimentary canal, ears, eyes, nasal cavity, skin and upper respiratory tract (Thompson et al., 2005).

Some exposure pathways include head or face immersion, swallowing water (including splashed water during boating), entering water up to or beyond waist level and skin abrasions (Thompson et al., 2005). Consumption of contaminated shellfish is one of the most common exposure routes for marine pathogens. Fecal coliform bacteria are the recommended indicator for human pathogens in marine waters and gastrointestinal symptoms are a frequent health outcome associated with exposure (Thompson et al., 2005)

The objectives of this study were to assess the temporal and spatial dynamics of coliform bacteria, the PSP-causing dinoflagellate *Alexandrium*, the DSP-causing dinoflagellate *Dinophysis*, and the ichthyotoxic dinoflagellate, *Cochlodinium* in East Hampton Town Trustee marine waters, as well as assess the dynamics of toxic cyanobacteria and cyanotoxins in East Hampton's major freshwater/brackish bodies. Sampling for other, general water quality parameters was also included and sampling proceeded from April through November of 2014. Results have been placed in the context of prior studies as well as state and federal standards.

Approach:

The 2014 sampling season ran from April through December including both marine and freshwater systems and sampling was biweekly for most sites but was weekly or more frequently during HABs in Three Mile Harbor and Georgica Pond. Sampling included twelve marine sites between Napeague Harbor, Fresh Pond, Accabonac Harbor, Hog Creek, Three-Mile Harbor, and Northwest Creek; and four freshwater sites between Georgica Pond and Hook Pond. Two marine sites from the 2013 study were discontinued in 2014 due to accessibility, and two new sites were added to Georgica Pond to provide better special coverage. Sampling also involved the use of new devices in Georgica Pond and Three Mile Harbor that included continuous measurements in space and time.

Each marine water body was sampled from two to three individual sites, with at least one located near the water body's inlet to the Peconic estuary, and the others further from the inlet. Northwest Creek and Fresh Pond were exceptions, with only one site a piece, and both located near their inlets. General water quality measurements obtained for each site included salinity, temperature, and dissolved oxygen levels measured with a handheld YSI 556 probe. Two Onset HOBO data loggers were also deployed in Three-Mile Harbor to continuously record temperature and dissolved oxygen levels over time. Additionally, water was collected at each of these twelve sites and analyzed for chlorophyll *a* and fecal coliform bacteria. To quantify fecal coliform bacteria levels, water samples were transferred onto nutrient pads, or agar plates permissive for the growth of these bacteria, and incubated at 44.5 degrees celsius for 24 h. After 24 h, the number of colonies grown on the media were quantified and densities of fecal coliform per 100 mL of seawater were determined via standard methods. Notably, our 2014 study switch to measuring fecal coliform bacteria from total coliform bacteria in 2013 since NYSDEC opens and closes shellfish beds using fecal coliform bacteria measurements. The pigment chlorophyll *a* serves as an analog for algal biomass. It was measured by filtering whole water through glass fiber filters, extracting the collected pigment from the filter with acetone, and measuring the fluorescence (Parsons et al., 1984).

To assess the abundance of harmful algae, eight of these marine sites were sampled more comprehensively with each harbor having at least one such site. These sites were located away from their respective inlets in areas that are more prone to elevated nutrient levels and the proliferation of algae. All three of Three-Mile Harbor's and Georgica Pond sites for this study were treated as such.

The toxic dinoflegellate *Dinophysis acuminata*, which is responsible for diarrhetic shellfish poisoning (DSP), was sampled for from April into early June. The harmful "rust tide" dinoflagellate *Cochlodinium*, known for causing fish kills, was monitored from July to the middle of September. In both cases, whole water was collected and preserved with Lugol's iodine and cells were counted on a Sedgewick-Rafter slide under a microscope. *Alexandruim fundyense*, another toxic marine dinoflagellate, one responsible for paralytic shellfish poisoning, was sampled from April into early June. Samples were filtered through a 20µm sieve, backwashed into a 15mL centrifuge tube, and preserved in formalin and methanol. Cell densities were determined by marking the cells with an oligonucleotide probe, and counting with an epifluorescent microscope, as detailed in Hattenrath et al. (2010).

At the four freshwater sites (three in Georgica and one in Hook Pond) samples were collected for the quantification of chlorophyll *a*, temperature, salinity, and dissolved oxygen as described above. HOBO and YSI data logging water quality probes were deployed into Georgica Pond as well to continuously measure dissolved oxygen, chlorophyll, salinity, temperature, water depth, and blue green algae. Additionally, each site was sampled for bluegreen algae (cyanobacteria), including *Microcystis* and *Anabaena*. Bluegreen fluorescence, an analog for cyanobacteria biomass, was measured using a Fluoroprobe with live samples. Colonies of these algae were preserved in whole water samples with Lugol's iodine solution, and counted using a microscope as described above.

Due to the outbreak of blue green algae and macroalgae blooms in Georgica Pond a series of cruises were during the summer, fall, and early winter. Summer cruises were performed by kayak and involved making measurements for cyanobacteria and macroalgae at 20 sites across the Pond. During the fall and early winter, cruises were performed with a mechanized vessel, GPS, and continuously measuring water quality devices to map levels of dissolved oxygen, chlorophyll, salinity, temperature, and blue green algae across the Pond and to specifically understand how the opening of the ocean inlet in Georgica Pond changed these parameters. The installation of continuously measuring water quality devices at specific locations in the north and south of the Pond as well as in Georgica Cove facilitated an understanding of the temporal dynamics of these parameters.

Results:

Marine Systems

Fecal Coliform Bacteria

Fecal coliform values were significantly lower than the total coliform levels measured in 2013. Then mean values of fecal coliform bacteria ranged from 0 colony forming units (CFU)/100mL to 145 CFU/100mL (Fig 1). The NYSDEC shellfishing standard for fecal coliform bacteria is a mean value below 14 CFU/100mL, and 90% of individual values below 49 CFU/100mL. A majority of the sites sampled appeared below these standard and had very low fecal coliform bacteria levels. Fresh Pond in Amagansett held the highest fecal coliform values with an average value of 145 CFU/mL, a peak value of 980 CFU/100mL from July 2nd, and values that surpassed 49 CFU/100mL from June, through July, and into August (Fig 2). Fresh Pond experienced low levels from April into the middle of May, and again from late August into October. Other sites whose mean values surpassed the standard included Sites 5 and 6 in Accabonac Harbor, and Site 9 in Hog Creek. Sites 6 and 9 are situated further from their inlets. These sites maintained low levels for much of the year, at or below 10 CFU/100mL, but experienced extremely high levels during late September and early October that drove their averages over the standard (Fig 2). Accabonac Harbor has maximum levels of 410 and 220 CFU/100mL for Sites 5 and 6 respectively, and Hog Creek reached 160 CFU/100mL.

The 2013 study showed that total coliform levels were lower near inlets where the water flushes regularly and higher in the back of these harbors where water resides for a greater duration and accumulates land-derived bacteria and also determined that coliform bacterial levels generally paralleled temperatures and thus were highest during summer. This seasonal trend was quite clean again in 2014. However, the spatial trend with regard to inlets was less clear in 2014 with Hog Creek and Three-Mile Harbor following this trend, but Napeague and Accabonac Harborshaving higher nearer to inlets (Fig 1).

NYSCEC Comparison of Fecal Coliform Data

The values of fecal coliform bacteria that this study measured were compared with the NYSDEC shellfish bed statuses, and with the recommendations of the 2013 report. Eight of the twelve sites measured were supportive the DEC's closures, with none of the sites being worse than the DEC statuses (Fig 3). That is compared to the total coliform method used in the 2013 study, which resulted in very high values, and as a result, several sites appearing worse than DEC standards. Consistent with our 2013 recommendation, approximately 88 acres of Northwest Creek's northern extent were seasonally opened for 2014 between December 15th and March 31st (Fig 5). Measurements from 2014 suggest that Northwest Creek could be opened longer, as it was one of the cleanest systems in regards to fecal coliforms (Fig 1). The quantification of fecal coliform bacteria below NYSDEC standards during much of the year at Sites 11 and 12 in Three

Mile Harbor, and Site 8 in Hog Creek also suggest that they could be opened further. These sites represent small closed areas that are surrounded by open area (Fig 4,5). The "Seasonal and Confirmed" Sites 5, 6, and 9, which were mentioned above, only had a single measured day where the values peaked above 49 cells/mL, but the values were so high that they forced the mean value over 14 cells/100mL (Fig 2). For most of the year, those three sites were within satisfactory limits, and further observation may narrow down the closure window.

Harmful Algae: *Dinophysis, Cochlodinium, & Alexandrium*

All algae contain the pigment chlorophyll *a*, and it is therefore measured as a proxy for total phytoplankton biomass. Moderate levels of algae support productive fisheries and ecosystems, but algae in excess can lead to a series of negative ecological impacts including hypoxia and acidification. The average chlorophyll *a* values for marine sites during the 2014 sampling season ranged between 3µg/L and 8µg/L, which are below or close to the normal level of 5µg/L for the eastern Peconic estuary (Fig 6). UPEPA considers 20µg/L a eutrophic level (too high) of chlorophyll and the only marine site to surpass this level was Head of the Harbor, Three Mile Harbor, which reached a peak value of 49µg/L on August 25th, which coincided with an algal (*Cochlodinium*) bloom (Fig 7). Aside from the peak in late August, and a second smaller one August 5th, the chlorophyll *a* values at Head of the Harbor were fairly low.

Dinoflagellates of the genus *Dinophysis* can cause Diarrhetic Shellfish Poisoning (DSP), a globally significant human health syndrome (Reguera et al., 2012). *Dinophysis* spp. synthesize okadaic acid (OA) and dinophysistoxins (DTXs), the causative toxins of DSP. While DSP is common in regions of Europe, South American and Asia (Reguera et al., 2012), prior to 2008 the US had not experienced a DSP event. However, there have been a series of such outbreaks recently, including in NY (Hattenrath-Lehmann et al., 2013). *Dinophysis* was detected in all six of the sampled harbors and creeks but the densities were relatively low, with mean levels ranging from 7 cells/L to 37 cells/L (Fig 8). Maximal densities were detected in Northwest Creek with a peak value of 126 cells/L measured in April, followed by a quick decline before gradually increasing into June (Fig 9). Between 2013 and 2014, average *Dinophysis* levels have remained similar, or have increased across most sites. The maximum values in 2014 vdid not reach the peak of 300 cells/L that was measured in 2013. The largest change was within Northwest Creek, which in 2013 had no detected cells, and in 2014 had the highest measured value of all sites (Fig 10). For comparative purposes, *Dinophysis* blooms exceeding 10,000 cells/L have the potential to contaminate shellfish. As such, East Hampton waters are far from reaching dangerous levels of this toxic algae.

Cochlodinium is an ichthyotoxic dinoflagellate that has caused fish kills across the globe including some sites on eastern LI (Kudela and Gobler, 2012). *Cochlodinium* was detected in five of the six measured marine systems and displayed a seasonal pattern that differed from 2013. Napeague Harbor, Fresh Pond, Hog Creek, and Northwest Creek had low concentrations of *Cochlodinium* in 2014 with fewer than a dozen cells, matching observations from 2013. In contrast, Accabonac Harbor and Three Mile Harbor both experienced *Cochlodinium* blooms in 2014, with mean densities in the 100s of cells/mL and peak densities exceeding 5,000 cells/mL (Fig 11). In Accabonac Harbor at Landing Ln. the bloom reached peak of nearly 1,000 cells/mL in mid-August (Fig 12). Densities remained high the next two weeks, but declined at the end of the month and was no longer present thereafter. The largest *Cochlodinium* bloom occurred in Three Mile Harbor at Head of the Harbor. Cell concentrations began to climb in early August, remained above several hundred cells/mL for the rest of the month, and reached a maximum recorded value of 5,220 cells/mL in late August which coincided with peak chlorophyll *a* for the site (Fig 12). For comparative purposes, *Cochlodinium* blooms of 500 cells/mL or greater can cause mortality in larval fish, which use these estuarine systems as nurseries (Tang and Gobler 2009). Compared to 2013, the *Cochlodinium* blooms in East Hampton were longer in duration, more intense, more widespread, and occurred earlier in the year. In 2013, there was a single observation of a dense *Cochlodinium* blooms in Three Mile Harbor in early October with some visual observations of dense populations in September. In 2014, the blooms persisted through much of August were in two locations (Accabonac Harbor and Three Mile Harbor) experienced blooms and they occurred lower average densities in 2014, but remained significantly high. It is notable that unlike 2013 and prior years when *Cochlodinium* blooms initiated in the far western Peconic Estuary and spread east, in 2014 the first observations of *Cochlodinium* blooms on Long Island were in East Hampton Town waters. The reason for this early emergence in this region are currently unknown, but may be related to the ability of this organism to for cysts (Tang and Gobler 2012). The strong differences in *Cochlodinium* in East Hampton Town Trustee waters between 2013 and 2014 illustrates the importance of long term monitoring of water quality trends.

Alexandrium is a toxic dinoflagellate that synthesizes saxitoxin that leads to the syndrome, Paralytical Shellfish Poisoning that can causes illness or death in individuals consuming shellfish with these toxins (Anderson 1997). PSP has been occurring annually in New York waters since 2006 when it first appeared, with Sag Harbor being the closest region to East Hampton experiencing these events. In 2013, densities of *Alexandrium* exceeding 1,000 cells/L, levels known to cause toxicity in shellfish (Anderson 1997), were detected in Three Mile Harbor. For the 2014 study, *Alexandrium* was sampled for between April and June. It was not detected in Napeague Harbor or Fresh Pond while most other sites had low levels of cells ranging of 2 to 20 cells/L. The highest mean and maximum values were measured in Three Mile Harbor at Head of the Harbor (Fig 14). *Alexandrium* densities peaked in the middle of May, reaching 452 cells/L, but remained much lower for the rest of the samplings (Fig 15, 16). Concentrations of *Alexandrium* were lower in 2014 compared to 2013, emphasizing the importance of long term monitoring of water quality trends.

General Water Quality: Salinity & Dissolved Oxygen

Salinity across East Hampton's marine sites was relatively static, mostly staying within 28 or 29 PSU, and were generally higher at the sites closest to their respective inlets (Fig 17). Fresh Pond is a brackish system with heavy freshwater influence, and averaged a salinity of 17 PSU. Fresh Pond also had the greatest variation in salinity, dependent on tide, whether the inlet had closed off to the bay, and rainfall.

The mean levels of dissolved oxygen from discreet measurements ranged from 6 to 8 mg/L for marine sites, levels supportive of fisheries, shellfisheries, and wildlife (Fig 18). Additional, continuous dissolved oxygen data was recorded for Three Mile Harbor. Two dissolved oxygen probes, one at Head of the Harbor, and one at the Gann Rd. dock, were installed to measure dissolved oxygen at depth from July through October. Data was recorded every 15 minutes to provide better resolution and show diurnal cycles. Dissolved oxygen levels at Gann Rd. were high, and remained above 5.7 mg/L for the entire study period (Fig 19). Head of the Harbor, furthest from the inlet and with greatest harmful algal blooms problems, experienced periods of low dissolved oxygen. The site's mean dissolved oxygen levels were lower than Gann Rd., and it displayed a wider variation between its high and low values between day and night. For much of August and into September, dissolved oxygen dropped at night below 3 mg/L and even as far as 0 mg/L, indicating hypoxic and anoxic conditions unsuitable for benthic life (Fig 19). For comparative purposes, NYSDEC's standard for dissolved oxygen for more water bodies is above 3 mg/L.

Freshwater Systems

Hook Pond

Hook Pond was one of two freshwater bodies studied in 2014, and saw no outstanding water quality issues. Chlorophyll *a* values for the pond were low, with a mean value of 6 µg/L, and maximum level of 10 µg/L (Fig 6). Blue green fluorescence, which serves as an analog for cyanobacterial biomass, had a mean value of 2 µg/L (Fig 20). Unlike Georgica Pond, it sees little to no marine influence, with a mean salinity of 0.2 PSU (Fig 17). The mean dissolved oxygen level was 4.7 mg/L, lower than marine systems but still within healthy levels (Fig 18). All conditions were moderately better than 2014. Hook Pond appears healthy from the site sampled, but with only one site, has poor special coverage. Our expansion to sampling multiple sites across Georgica Pond revealed the great spatial heterogeneity in water quality in that water body. A similar pattern may exist in Georgica Pond

Georgica Pond

Harmful Algae

Georgica Pond was substantially impaired by algae for much of the 2014 season. This was significantly different than 2013 which may be due to the addition of two new sampling sites which provided data more representative of the greater Pond than the more isolated sites sampled in 2013. The greatest chlorophyll *a* values were measured in East Hampton Town Trustee waters were measured in Georgica Pond in 2014. The highest mean chlorophyll *a* was measured in southern Georgica Pond, near the ocean, at 43 µg/L (Fig 6). Georgica Cove saw similar concentrations, and the lowest values were measured in the north of the Pond near Route 27. Notably, this site is mostly freshwater and experiences significant inflows of groundwater in this region, preventing the accumulation of algal biomass. Given this was one of two major sites sampled in 2013, this partly explains the low characterization of low algal biomass levels in Georgica Pond during that year. Southern Georgica and Georgica Cove had values above 20µg/L for most dates sampled from July and into November. Southern Georgica Pond reached 113 µg/L, its maximal value, in mid-September. Georgica Cove reached its highest value on the same date, with a peak of 109 µg/L (Fig 7). Northern Georgica, at Rt. 27, had significantly lower concentrations, but was still within high levels. Freshwater bodes with over 8µg/L of chlorophyll *a* are considered eutrophic, or over enriched in phytoplankton and nutrients, by the US EPA (2000). All three Georgica sites had mean values above this level.

Georgica Pond and Georgica Cove experienced a dense bloom of the filamentous macroalgae *Cladophora* for much of the early summer. The bright green macroalgae was uncommon in the central body of the pond, instead collecting in the protected areas of coves and creeks (Fig 21). The floating mats were several inches thick in places which shaded the water column beneath, and caused a general nuisance for recreational use of the pond. Georgica Cove was especially congested, being almost entirely covered with the algae. By late August, the coverage of *Cladophora* was greatly diminished, though it was still present in low quantities along the shoreline (Fig 21). As the *Cladophora* bloom subsided, it gave way to the subsequent cyanobacterial blooms.

Toxic Cyanobacteria: *Microcystis* & *Anabaena*

Toxic cyanobacteria blooms represent a serious threat to aquatic ecosystems and human health. Globally, the frequency and intensity of toxic cyanobacteria blooms have increased greatly during the past decade and toxin concentrations during many blooms often surpass the World Health Organization (WHO) safe drinking water and recreational water limit (Chorus and Bartham, 1999). In early September 2012, the NYS Department of Health reported the death of a Jack Russell Terrier following the consumption of toxic cyanobacteria in Georgica Pond.

Whereas chlorophyll *a* is an analog for algal biomass, blue green algal fluorescence serves as an analog specifically for cyanobacterial biomass. Georgica Pond saw extremely high levels of blue green algae during 2014, with the highest values in southern Georgica Pond. Mean fluorescence was 70 µg/L in southern Georgica, and 37 µg/L in Georgica Cove, both values exceeding the 20 µg/L standard that the NYSDEC uses to close a lake to recreational use (Fig 20). A cruise performed in July saw levels exceeding 20 µg/L for the southern half of the pond (Fig 22). A shift occurred in August, following the decline of the *Cladophora* bloom, cyanobacteria bloomed in Georgica Cove and bluegreen levels exceeded the NYSDEC standard with levels were higher in southern Georgica than the other two sampling sites (Fig 22). The major bloom initiated in Georgica Cove in mid-August, picked up in southern Georgica late August, and both sites saw the height of their blooms September 4th (Fig 24). The highest blue green fluorescence measured was in southern Georgica, with a value of 373 µg/L in September. The Georgica Pond site at Rt. 27 saw its levels rise in mid-September, though not nearly to the same extent, following the southern bloom. In October, following the height of the bloom, cyanobacteria concentrations were highest in southern Georgica and Georgica Cove, with lower levels present within the tributaries that feed the pond (Fig 23). High levels persisted at both sites until the opening of the cut and draining of the pond.

Quantification of cyanobacterial cells present during the period from June to November showed two major genera of cyanobacteria present: *Microcystis* and *Anabaena*. *Anabaena* was the first to appear in July, reaching a small peak in early August. Levels decreased as *Microcystis* appeared and bloomed briefly. *Anabaena* then resurged, becoming the dominant cyanobacteria for the duration of dense September into October bloom reaching cell desnities exceeding 150,000 cells/mL. Following the opening of the inlet to the ocean, *Anabaena* declined to lower levels, and *Microcystis* then bloomed again from late October into November (Fig 25).

Toxin samples were taken and analyzed from the peak of the cyanobacteria bloom, associated primarily with *Anabaena*. Microcystin values were found in excess of the WHO standard for drinking water of 1 μg/L from August 27th through October 7th (Fig 25). At the peak of the bloom, microcystin values reached as high as 10.6 μg/L. Initial anatoxin measurements showed high levels, in the range of 5.6 μg/L to 35.8 μg/L, during the bloom (Fig 25). These values are pending verification.

General Water Quality: Salinity & Dissolved Oxygen

Salinity varied between sites across Georgica Pond. Southern Georgica, nearest the ocean had an average salinity of 9.6 PSU, but stayed close to 6 PSU with little variation prior to breaching the pond (Fig 17, 26). The average salinity of Georgica Cove was 6.0 PSU (Fig 17). For the beginning of the summer, Georgica Cove had a salinity near 2 PSU. At the very end of July, salinity climbed up around 7 PSU until the opening of the cut (Fig 26). Average salinity for Georgica at Rt. 27 was 0.7 PSU (Fig 17). For July through August, levels were close to 0 PSU.

For September into October, the salinity slowly climbed up towards 2 PSU (Fig 26), perhaps due to evaporation as there were no known ocean intrusions at this time. Bluegreen fluorescence also rose for this site, perhaps due to a decreased influx of freshwater, and increased mixing with the central body of the pond (Fig 24).

The average level of discrete dissolved oxygen measurements were above 3 mg/L across all three sites (Fig 18). The sampling station at Rt. 27 had a mean value of 4.0 mg/L, which is below the NYSDEC minimum daily average of 5.0 mg/L to support fish, shellfish, and wildlife propagation and survival (class C waters; http://www.dec.ny.gov/regs/4592.html). The NYSDEC also states that oxygen levels should, at no point, fall below 3mg/L to support survival of fish, shellfish, and wildlife. All sites fell below this limit during this study. Site 15, at Rt. 27, fell below 3 mg/L nightly and experienced anoxic conditions for most of September (Fig 27). Southern Georgica Pond experienced the highest daily oxygen levels. However, from late July onward, it also experienced levels below 3 mg/L on most nights, and did not go above that level between September 1st and 7th during the intense algal bloom period. Consequently, some residents reported the occurrence of fish kills the summer. Georgica Cove had continuous dissolved oxygen monitoring for the shortest duration but its levels stayed mostly above, but on occasion fell below 3 mg/L.

Effects of Opening the Ocean Inlet on Water Quality in Georgica Pond

Georgica Pond was opened to the Atlantic Ocean via the creation of an inlet on October 15th, closed naturally due to storm activity three days later, was reopened on October 20th, and remained open until it closed on November 13th. An array of probes was set up and cruises were performed to monitor conditions resulting from the induction of ocean exchange. Immediately following the opening of the pond, salinity levels increased in Georgica Pond evidencing the influx of ocean water which generally has a salinity of 32 PSU. The most dramatic change was in the south nearest the cut, where salinity rose from ~ 5 PSU into the 20s and even above 30 during incoming tides. The salinity in Georgica Cove also increased, but the response there was slower and not of the same magnitude (Fig 26). When the inlet closed, water level slowly increased, and salinity gradually decreased (Fig 28). By mid-December, ~one month after the inlet had closed, water levels had risen to the levels prior to the opening of the cut (Fig 28). The influx of ocean water had left the salinity levels significantly higher than before the opening at about 10 PSU (Fig 28).

Cruise data following the opening of the ocean inlet illustrated the effect of the exchange of seawater across the Pond. The water readily exchanges between the southern and northern regions of Georgica Pond. Georgica Cove however, does not exchange as readily, and seems to have more freshwater influence. This was especially apparent during October, when the salinity in the Cove dropped after the opening of the inlet, before rising again in November (Fig 29). Dissolved oxygen levels generally rose while the Pond was opened and stabilized once it was closed in November (Fig 29). Blue green concentrations fell by half after the first opening of the cut and by the end of October were at negligible levels following the second opening (Fig 23). Chlorophyll *a* concentrations also dropped immediately following the opening of the cut as water drained from the pond and salinity rose (Fig 30). At the end of October and into early November following the second opening, chlorophyll *a* concentrations increased slightly as diatoms bloomed in the brackish system (Fig 7). Importantly, diatoms are generally considered a good food source for aquatic food webs.

Use of the ocean inlet for managing water quality in Georgica Pond

The observations made during the October – November 2014 openings of the Georgica Pond via the ocean inlet provided important insight regarding its effects on water quality and water levels in this system. First, following the opening of the inlet, the blue green algae blooms in the Pond ended. There were likely three factors contributing toward this rapid occurrence. First, the induction of tidal exchange with the ocean facilitated the export of the blue green algae to the ocean. Next, the higher salinities brought to the Pond via the ocean water created salt conditions which were not conducive to blue green algae which thrive under freshwater and low salinity conditions, with *Anabaena* only tolerant of salinities below 15 (Moisander et al 2002) and *Microcystis* only tolerant of salinities below 10 (Orr et al 2004). Finally, blue green algae abundances generally parallel temperatures (Paerl and Huisman 2008) and thus these populations were likely to have diminished in November even if the inlet had not opened. Regardless, the first two mechanisms (enhanced tidal exchange and higher salinity) will both occur during any opening of the ocean inlet and thus will discourage blue green algal blooms. Beyond the mitigation of the blue green algae, opening of the ocean inlet also likely to improve other Pond attributes such as increased dissolved oxygen.

In a manner that differs from other similar temporarily-open estuaries in the region such as Mecox Bay, Georgica Pond's water levels are highly responsive and dynamic, with the Pond reverting to pre-cut water levels ~25 days after opening (Fig 28). Despite reverting to prior water levels, salinities remaining higher than before the opening the Pond which, as discussed above, will discourage the growth of blue green algae. The extent to which the Pond water levels recover is likely to be a function of recent rainfall and seasonality. The occurrence of above average rainfall in the late summer and fall of 2014 likely contributed to slightly above average refilling of the Pond as did the cooler temperatures which yields a larger fraction of freshwater entering the Pond instead of evaporating. Summer, drought conditions might lead to Pond water levels taking a longer amount of time to refill.

When opening the ocean inlet during summer months, one consideration may be the balance of water quality with recreational use of the Pond, specifically for boating. Prior to opening the ocean inlet, the water depth in the south of the Pond was 1.4 meters (Fig 28). After the first opening of the cut, this depth dropped to 0.5 m (Fig 28). Upon closing for three days in October, the depth quickly rose to 0.7 m, but then dropped again to a minimum of 0.2 m in the days after the second opening (Fig 28). While the inlet was open until November 13th, its effective size seemed to greatly diminish in the two weeks before this as water depths rose to an average of 0.7 m in early November (Fig 28). As described above, the Pond reached pre-cut depth by early December (Fig 28). In the future, the Trustees may need to consider the value of improving water quality against water depth / access and other more general ecological considerations such as optimal salinities for desired aquatic life.

A final consideration regarding the opening of the ocean inlet to Georgica Pond is the fate of macroalgae in the Pond following the opening of the inlet. During the summer months of July and August, macroalgae of the genus *Cladophora* became dense and abundant within Georgica Cove and other cove and inlets across the Pond. Given the decreases in water depths in these regions when the cut is open and the fact that these algae generally secure themselves the Pond bottom, there remains the possibility that significant amount of *Cladophora* and other macroalgae could be left on mud flats to die, degrade, and rot in some parts of the Pond. The amount of *Cladophora* that would become exposed following an inlet opening and the extent to which this concern would manifest is not fully clear. Regardless, the opening of the cut does have clear benefits for reducing microalgal blooms and increasing levels of dissolved oxygen. A more frequent schedule of opening the Pond in the spring should keep salinity levels high and thus may discourage the formation of blue green algal blooms. Moreover, opening the Pond during the summer may discourage the intensification of these events. The impact of summer Pond lettings on macroalgae requires further investigation.

Citations:

Anderson, D. M. (1997). Bloom dynamics of toxic Alexandrium species in the northeastern US. Limnology and Oceanography, 42(5), 1009-1022.

Chorus, I., & Bartram, J. (1999). Toxic cyanobacteria in water: A guide to their public health consequences, monitoring and management. Spon Press.

loern, J. E. (2001). Our evolving conceptual model of the coastal eutrophication problem. Marine ecology progress series, 210(2001), 223-253.

Costanza, Robert, et al (1997) Valuing ecosystem services with efficiency, fairness and sustainability as goals." Nature's services: societal dependence on natural ecosystems. Island Press, Washington, DC: 49-70.

Gobler, C. J., Berry, D. L., Anderson, O. R., Burson, A., Koch, F., Rodgers, B. S., ... & Nuzzi, R. (2008). Characterization, dynamics, and ecological impacts of harmful< i> Cochlodinium polykrikoides</i> blooms on eastern Long Island, NY, USA. Harmful Algae, 7(3), 293-307.

Hattenrath-Lehmann TK, Marcoval MA, Berry DL, Fire S, Wang Z, Morton SL, Gobler CJ. 2013. The emergence of Dinophysis acuminata blooms and DSP toxins in shellfish in New York waters. Harmful Algae 26: 33–44

Hattenrath TK, Anderson DA, Gobler CJ. 2010. The influence of nutrients and climate on the dynamics and toxicity of Alexandrium fundyense blooms in a New York (USA) estuary. Harmful Algae 9: 402–412

Kudela RM, Gobler CJ. 2012. Harmful dinoflagellate blooms caused by Cochlodinium sp.: Global expansion and ecological strategies facilitating bloom formation. Harmful Algae. 14: 71–86

Moisander, P. H., McClinton, E., & Paerl, H. W. (2002). Salinity effects on growth, photosynthetic parameters, and nitrogenase activity in estuarine planktonic cyanobacteria. Microbial Ecology, 43(4), 432-442.

Nixon, S. W. (1995). Coastal marine eutrophication: a definition, social causes, and future concerns. Ophelia, 41(1), 199-219.

O'Neil JM, Davis TW,* Burford MA, Gobler CJ. 2012. The Rise of Harmful Cyanobacteria Blooms: The Potential Roles of Eutrophication and Climate Change. Harmful Algae. 14 : 313–334

Orr, P. T., Jones, G. J., & Douglas, G. B. (2004). Response of cultured Microcystis aeruginosa from the Swan River, Australia, to elevated salt concentration and consequences for bloom and toxin management in estuaries. Marine and Freshwater Research, 55(3), 277-283.

Paerl, H. W., & Huisman, J. (2008). Blooms like it hot. Science 320(5872), 57.

Parsons, T. R., Maita, Y., & Lalli, C. M. (1984). A manual of chemical and biological methods for seawater analysis. Pergamon press

Reguera, B., Velo-Suarez, L., Raine, R., Park, M.G., 2012. Harmful Dinophysis species: A review. Harmful Algae 14, 87-106.

Tang YZ, and Gobler CJ. 2009. Cochlodinium polykrikoides blooms and clonal isolates from the northwest Atlantic coast cause rapid mortality in larvae of multiple shellfish species. Marine Biology 156: 2601-2611

Tang YZ, Gobler CJ. 2009. Characterization of the toxicity of Cochlodinium polykrikoides isolates from Northeast US estuaries to finfish and shellfish. Harmful Algae 8:454-462

Gobler et al. 2008,

Thompson, J. R., Marcelino, L. A., & Polz, M. F. (2005). Diversity, sources, and detection of human bacterial pathogens in the marine environment. In Oceans and Health: Pathogens in the Marine Environment (pp. 29-68). Springer US.

Tonk, L., Bosch, K., Visser, P. M., & Huisman, J. (2007). Salt tolerance of the harmful cyanobacterium Microcystis aeruginosa.

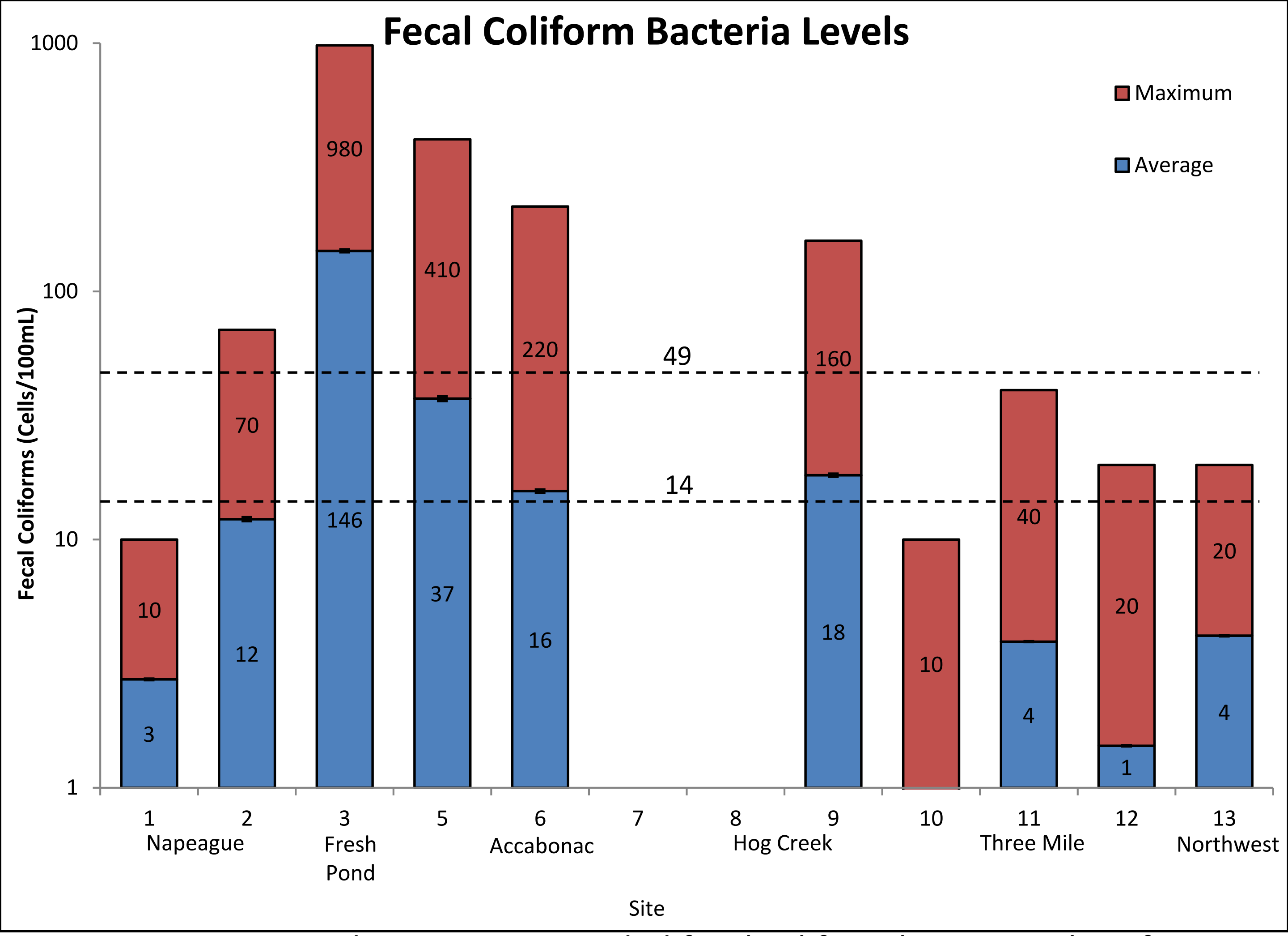

Figure 1: Average and maximum recorded fecal coliform bacteria values from April through November of 2014, shown on a logarithmic scale. Dashed lines represent level standards: 14 cells/100mL for averages, and 49 cells/100mL for individual values.

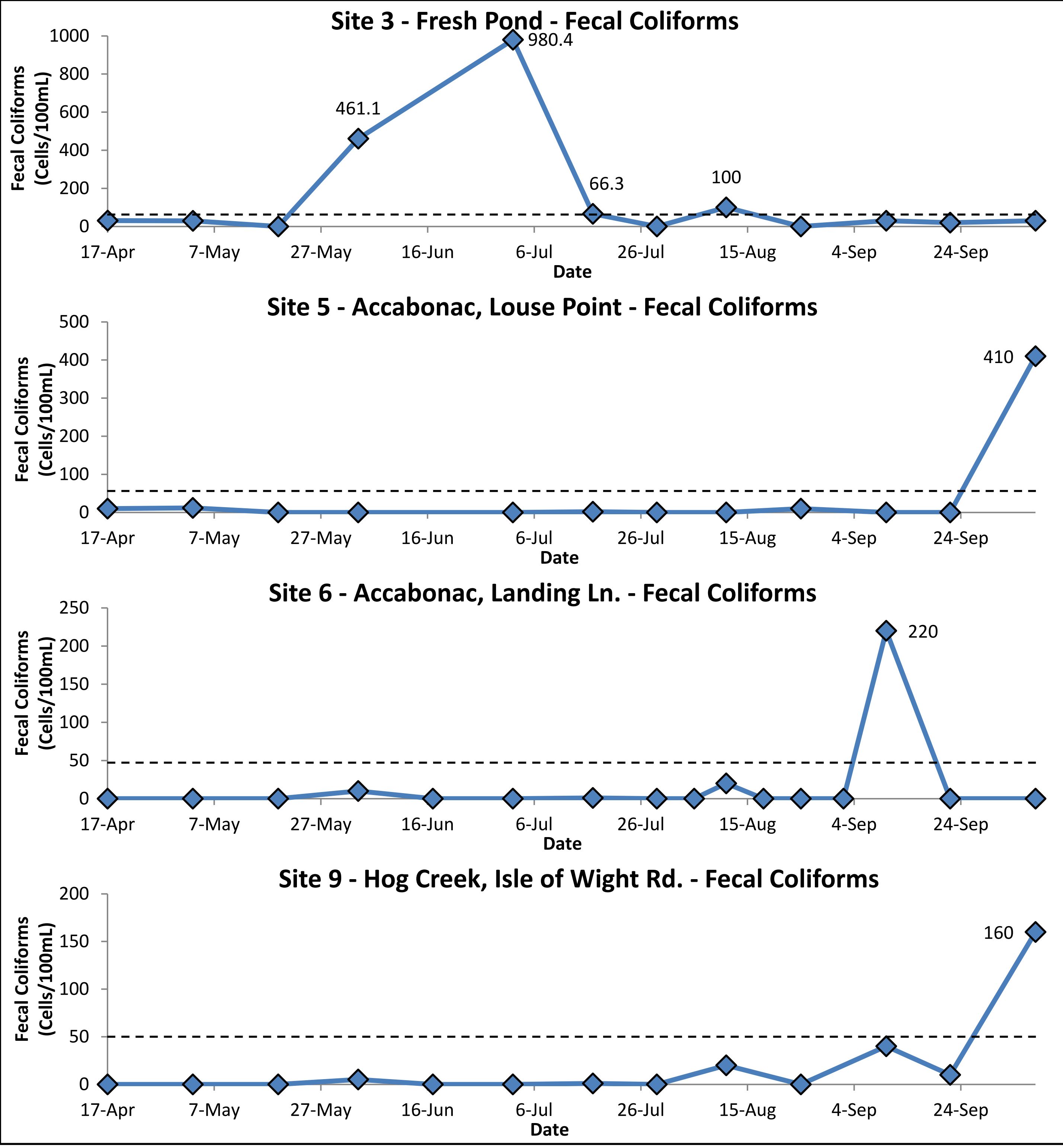

Figure 2: Fecal coliform bacteria levels over time from four sites that passed the 14 cells/100mL standard. Dashed lines show the high standard for individual dates of 49 cells/100mL.

Site #	Site Name	2014 Measured Values	2014 DEC Status	2013 Recommendation	2014 Recommendation
1	Napeague	Under	Open	Should be Seasonal	Open and Confirmed
2	Napeague - Lazy Point	Under	Open	Should be Seasonal	Open and Confirmed
3	Fresh Pond - Outlet	Over	Uncertified	Closed and Confirmed	Closed and Confirmed
5	Accabonac - Louse Point	Over	Seasonally Uncertified	Seasonal and Confirmed	Seasonal and Confirmed
6	Accabonac - Landing Lane	Over	Seasonally Uncertified	Seasonal and Confirmed	Seasonal and Confirmed
7	Accabonac - Gerard Drive	Under	Open	Should be Seasonal	Open and Confirmed
8	Hog Creek - Clearwater	Under	Seasonally Uncertified	Seasonal and Confirmed	Could be Opened
9	Hog Creek - Isle of Wight	Over	Seasonally Uncertified	Seasonal and Confirmed	Seasonal and Confirmed
10	Three Mile Harbor - Gann Road	Under	Open	Seasonal and Confirmed	Open and Confirmed
11	Three Mile Harbor - Head of the Harbor	Under	Uncertified	Could be Seasonal	Could be Opened
12	Three Mile Harbor - Hand's Creek	Under	Seasonally Uncertified	Seasonal and Confirmed	Could be Opened
13	Northwest Creek	Under	Seasonally Uncertified	Could be Seasonal	Could be Opened

Figure 3: Comparison of measured values against NYSDEC shellfish bed status, and the 2013 report's recommendations. Green text represents recommendations that agree with the 2013 recommendation. Black text confirms the DEC status. Blue text is a new recommendation.

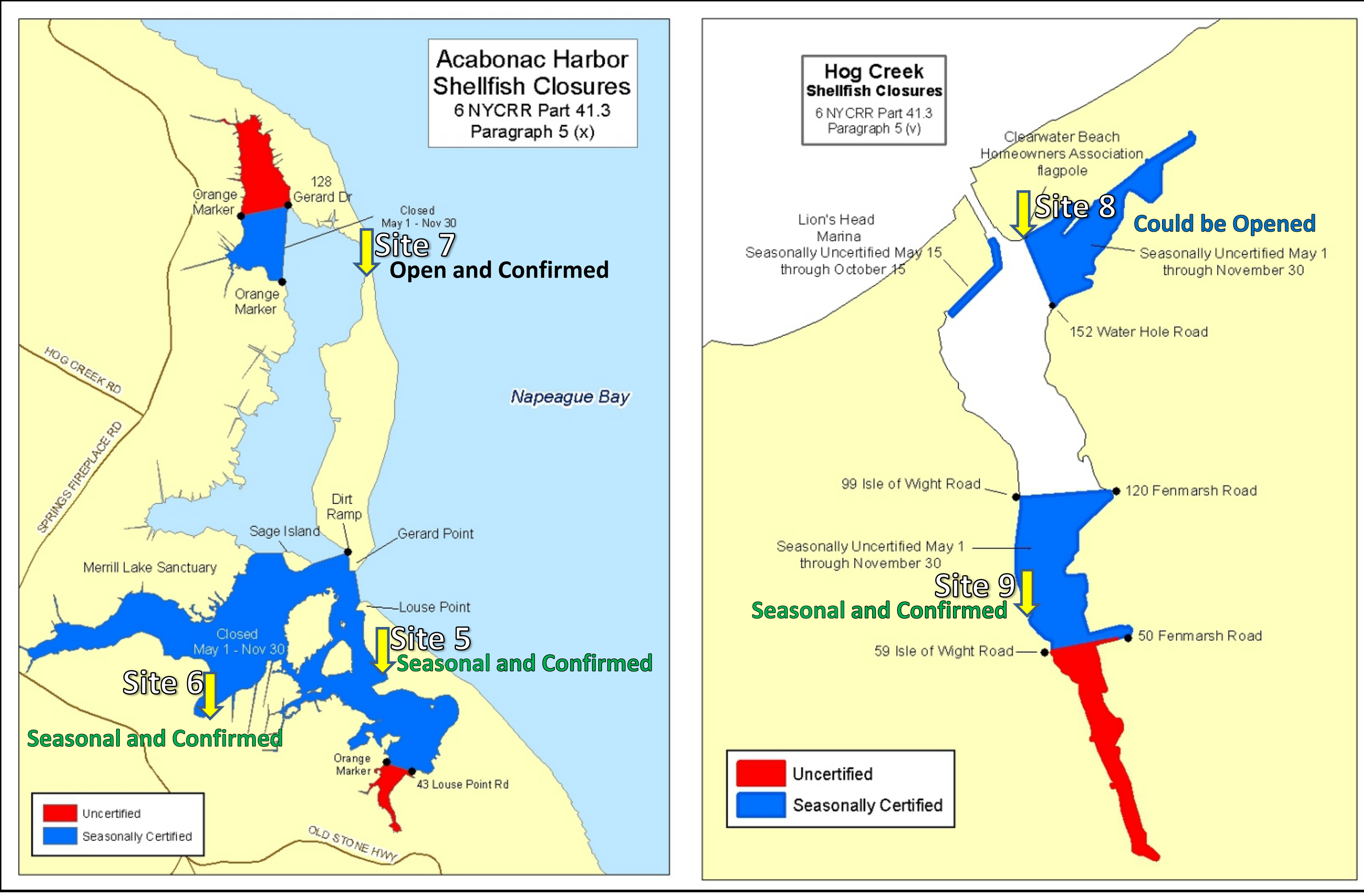

Figure 4: Maps showing 2014 NYSDEC shellfish bed statuses for Accabonac Harbor, and Hog Creek, as well as showing sampling sites.

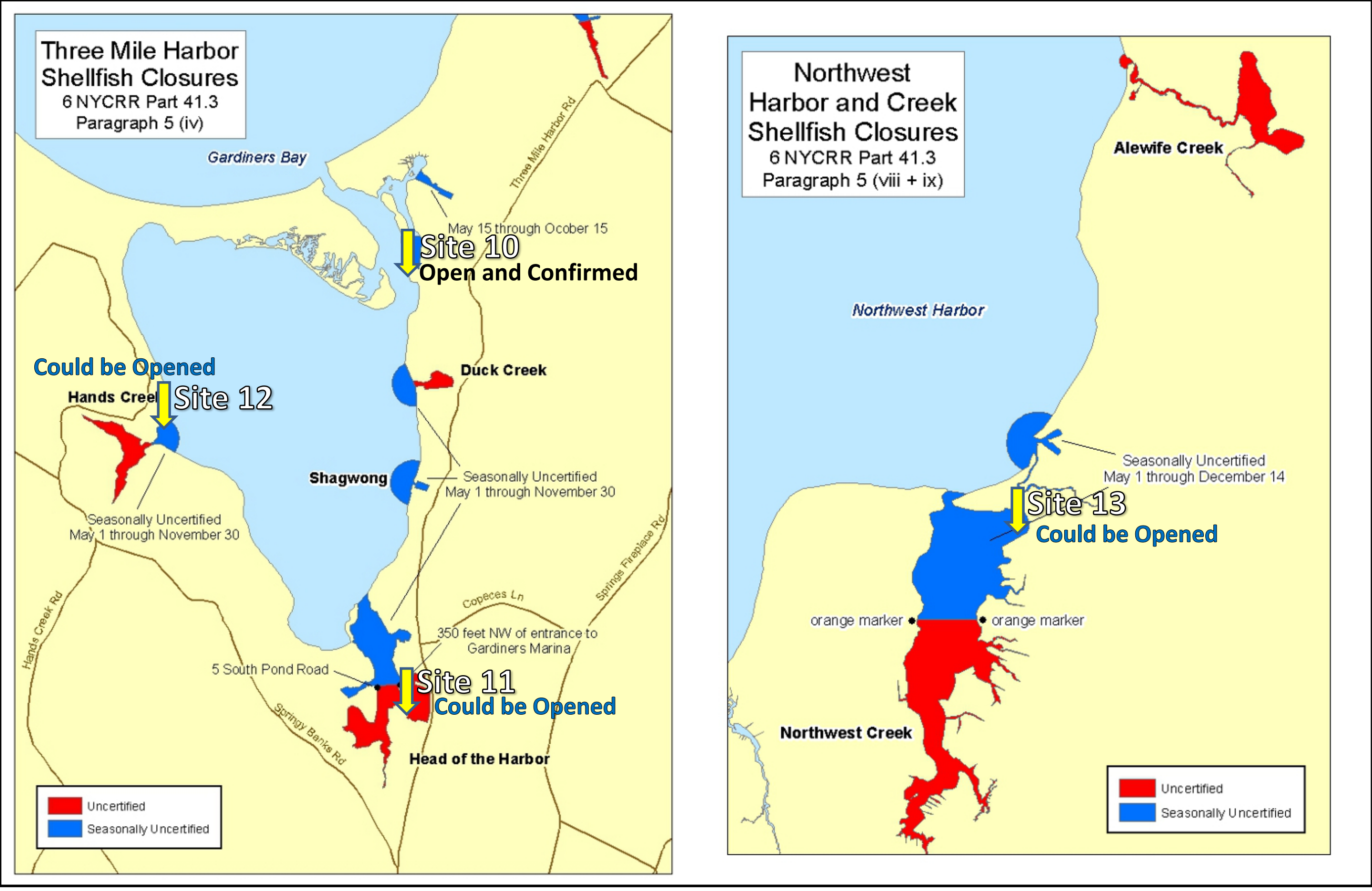

Figure 5: Maps showing 2014 NYSDEC shellfish bed statuses for Three Mile Harbor, and Northwest Creek, as well as showing sampling sites.

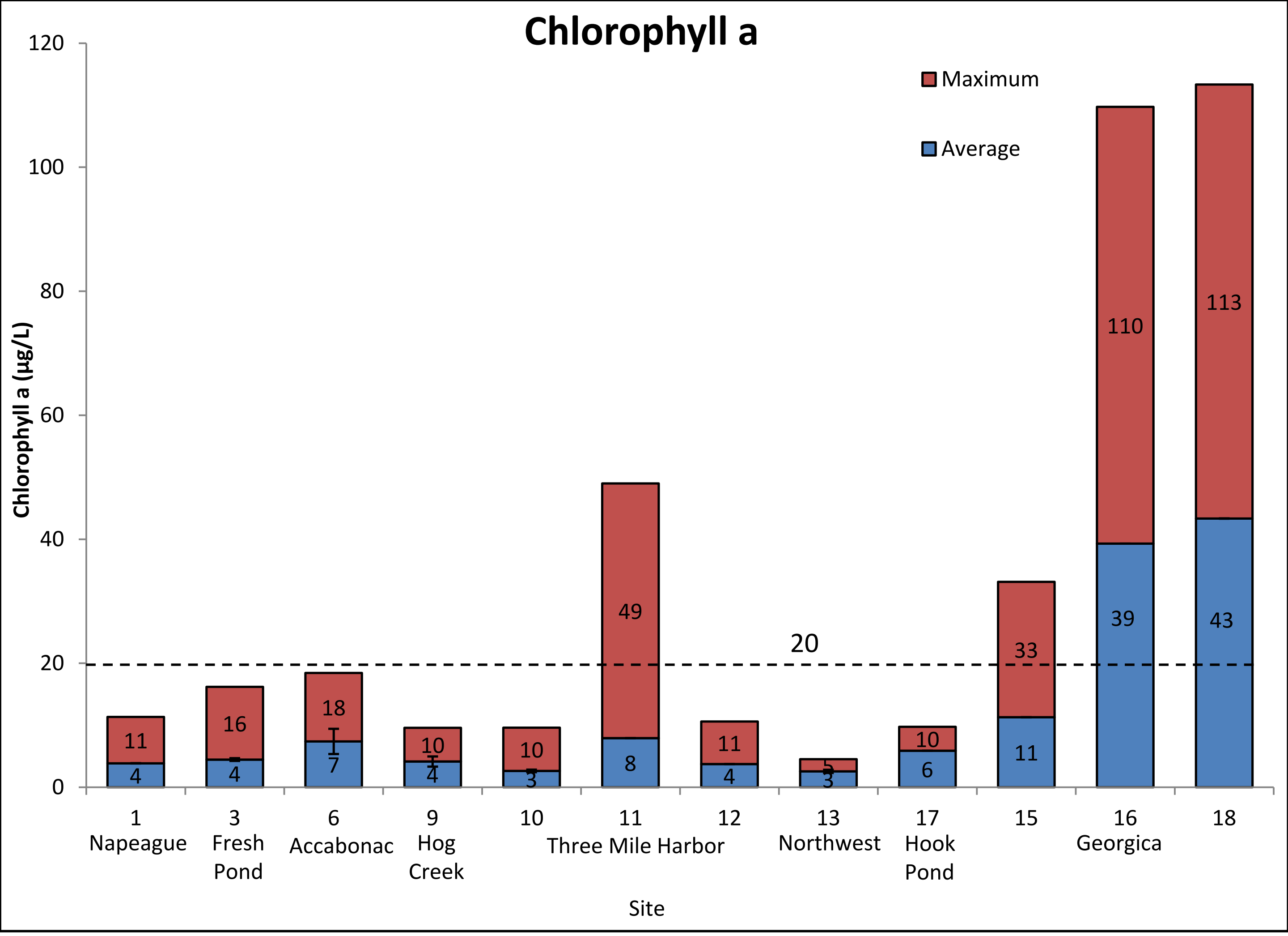

Figure 6: Average and maximum measured values of chlorophyll a across all marine and freshwater sites, from April through November of 2014. The dashed line represent a high standard of 20µg/L.

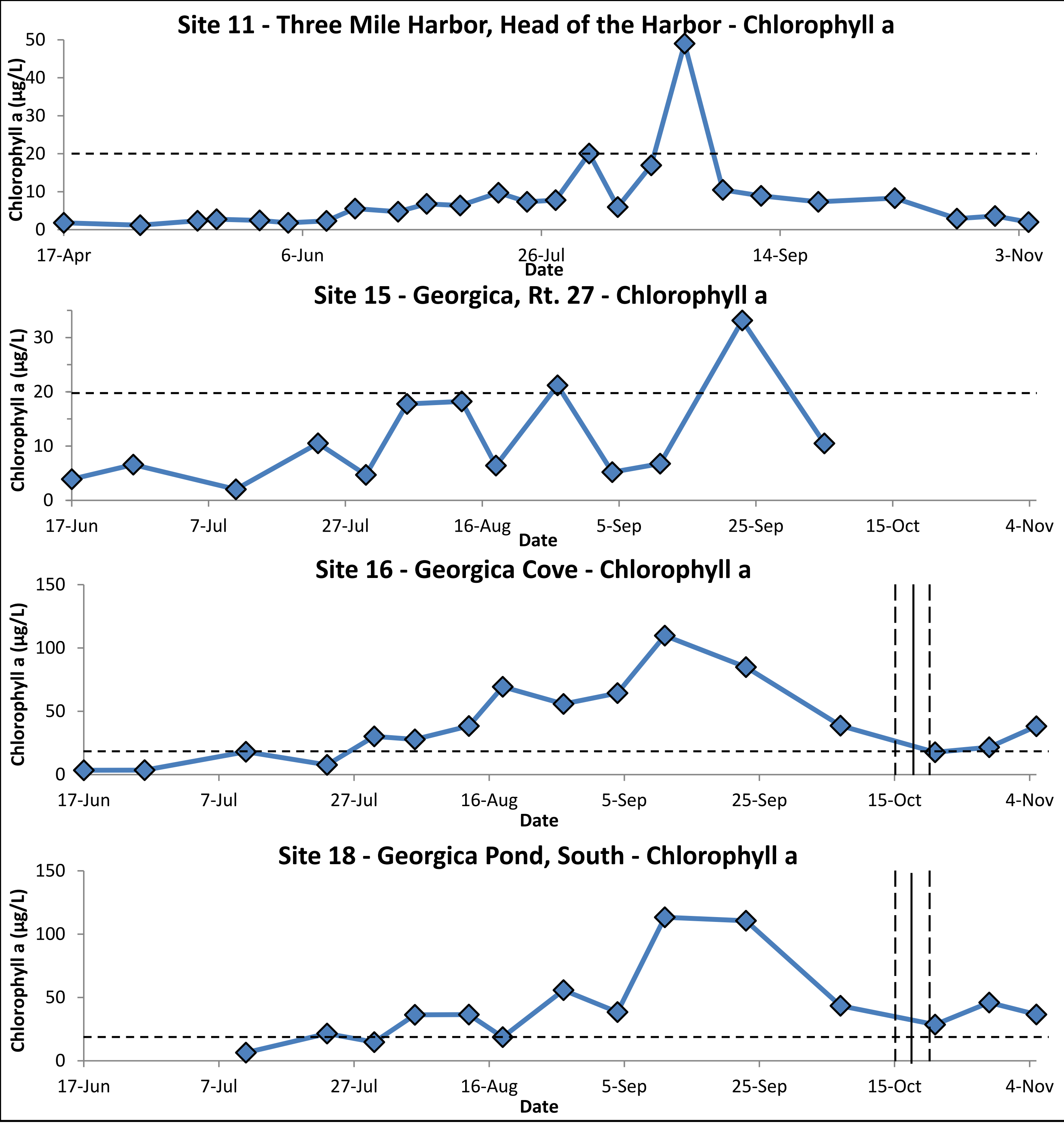

Figure 7: Measured *chlorophyll a* values over time for four sites which passed the standard of 20µg/L, as represented by the dashed line. Dashed vertical line shows when the cut at Georgica Pond was opened. Solid vertical shows closure of the cut.

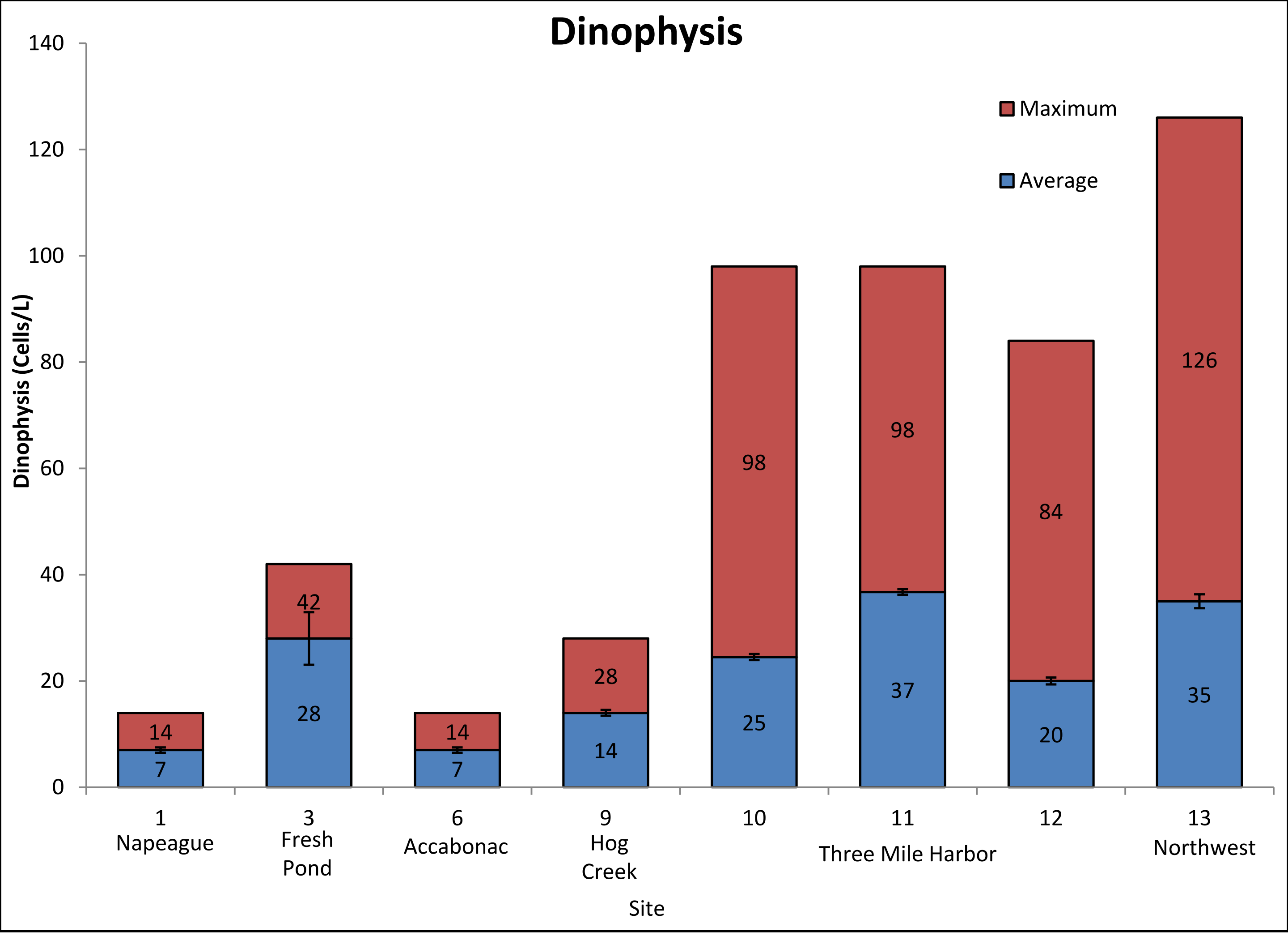

Figure 8: Average and maximum counts of the harmful dinoflagellate *Dinophysis*. Samples were collected April through June 2014.

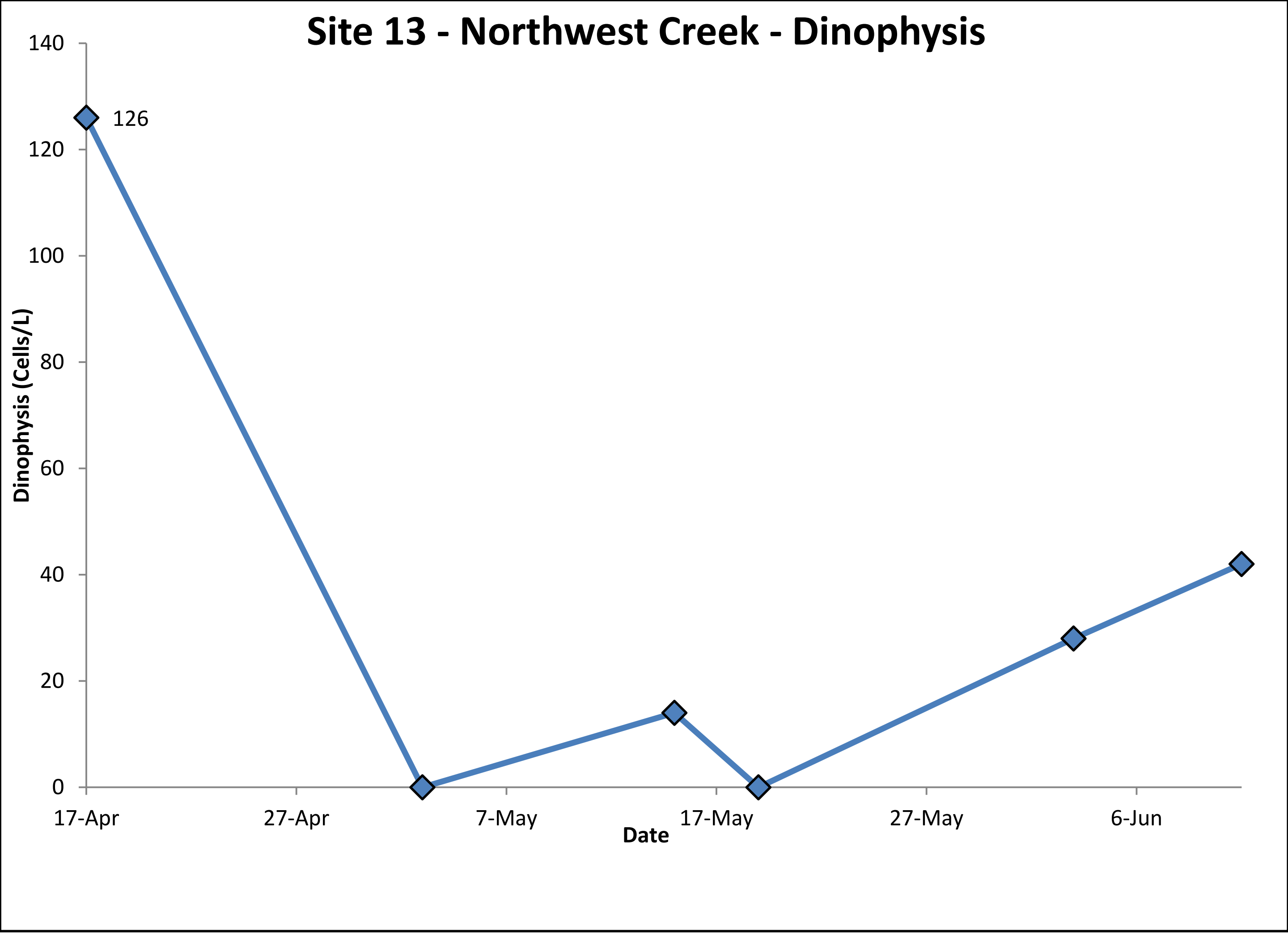

Figure 9: Individual *Dinophysis* counts from Northwest Creek over time from April through June 2014.

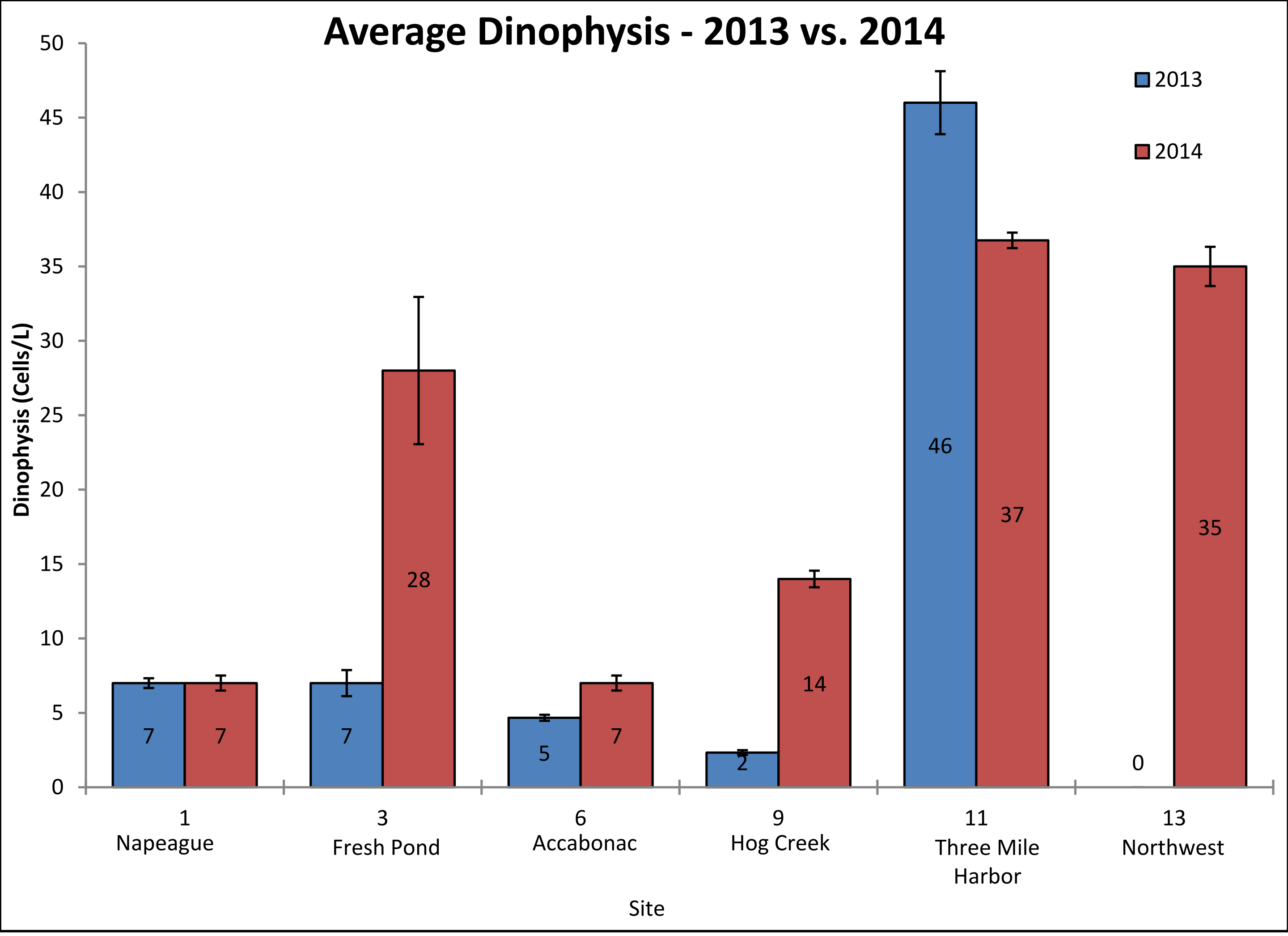

Figure 10: Comparison of average *Dinophysis* values between the 2013 and 2014 sampling seasons.

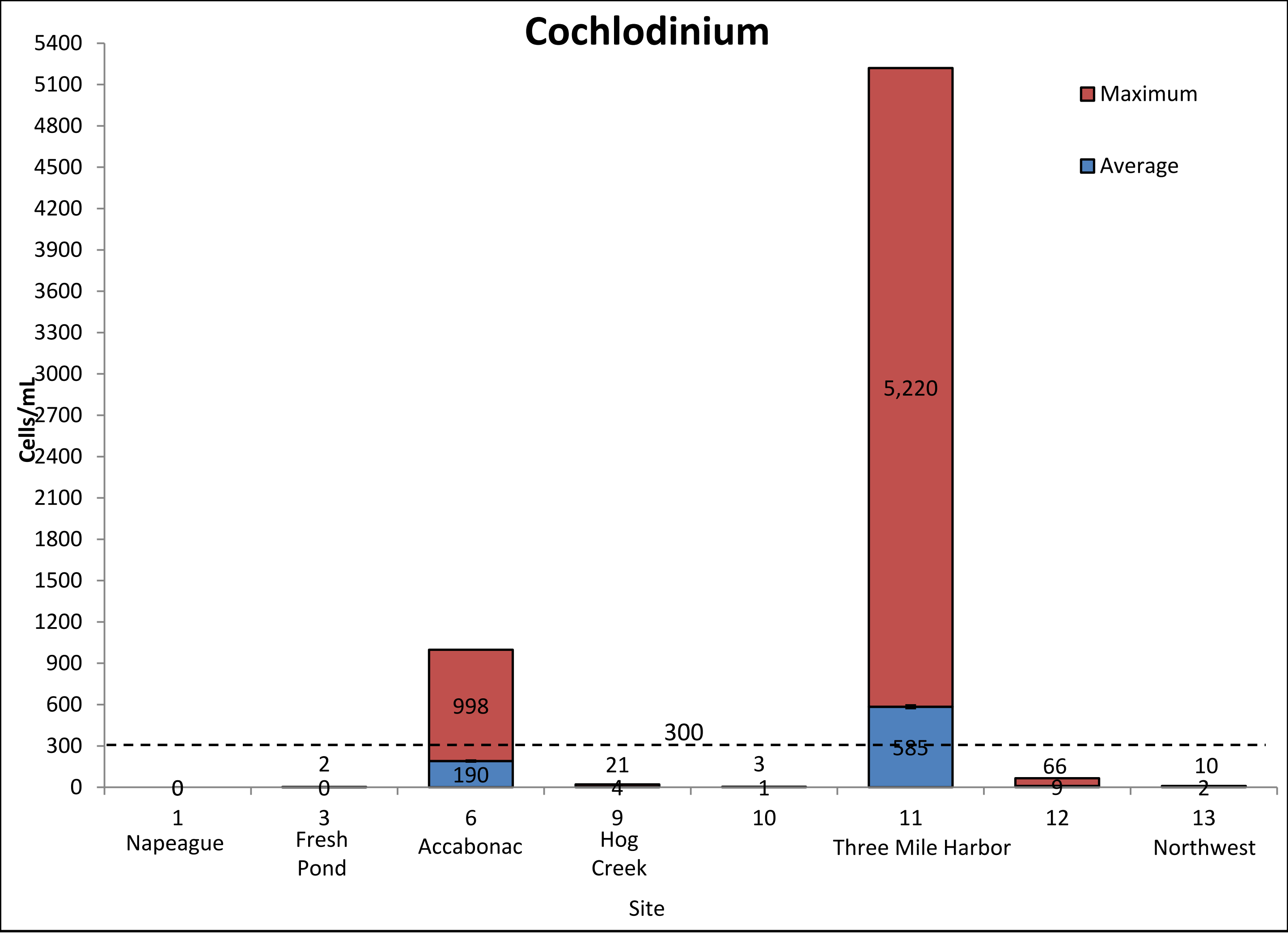

Figure 11: Average and maximum values of Cochlodinium across marine sites from June into September 2014. Dashed line shows level standard of 300 cells/mL.

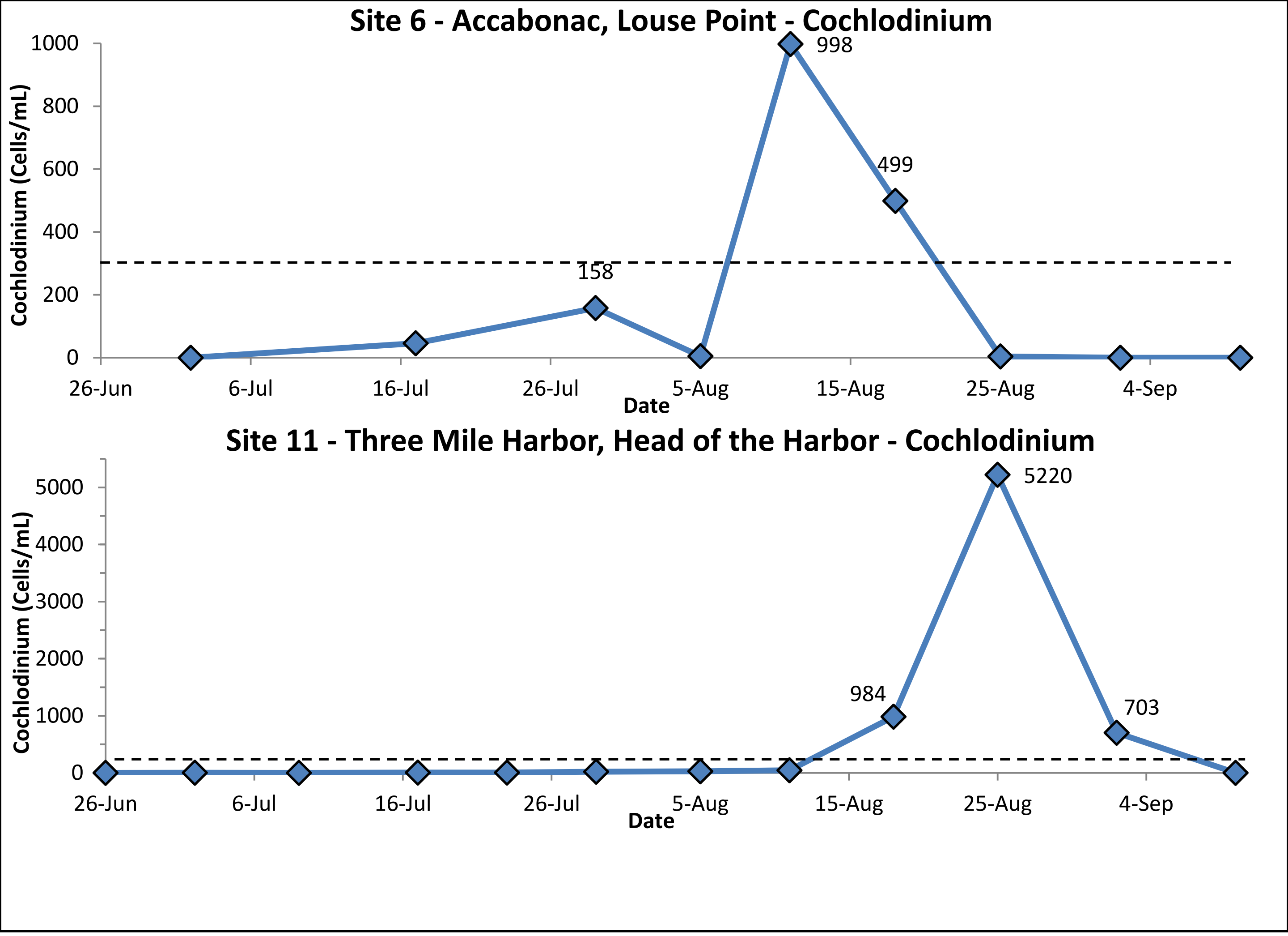

Figure 12: Cochlodinium values over time for two individual sites with highest densities. Dashed line shows 300 cells/mL

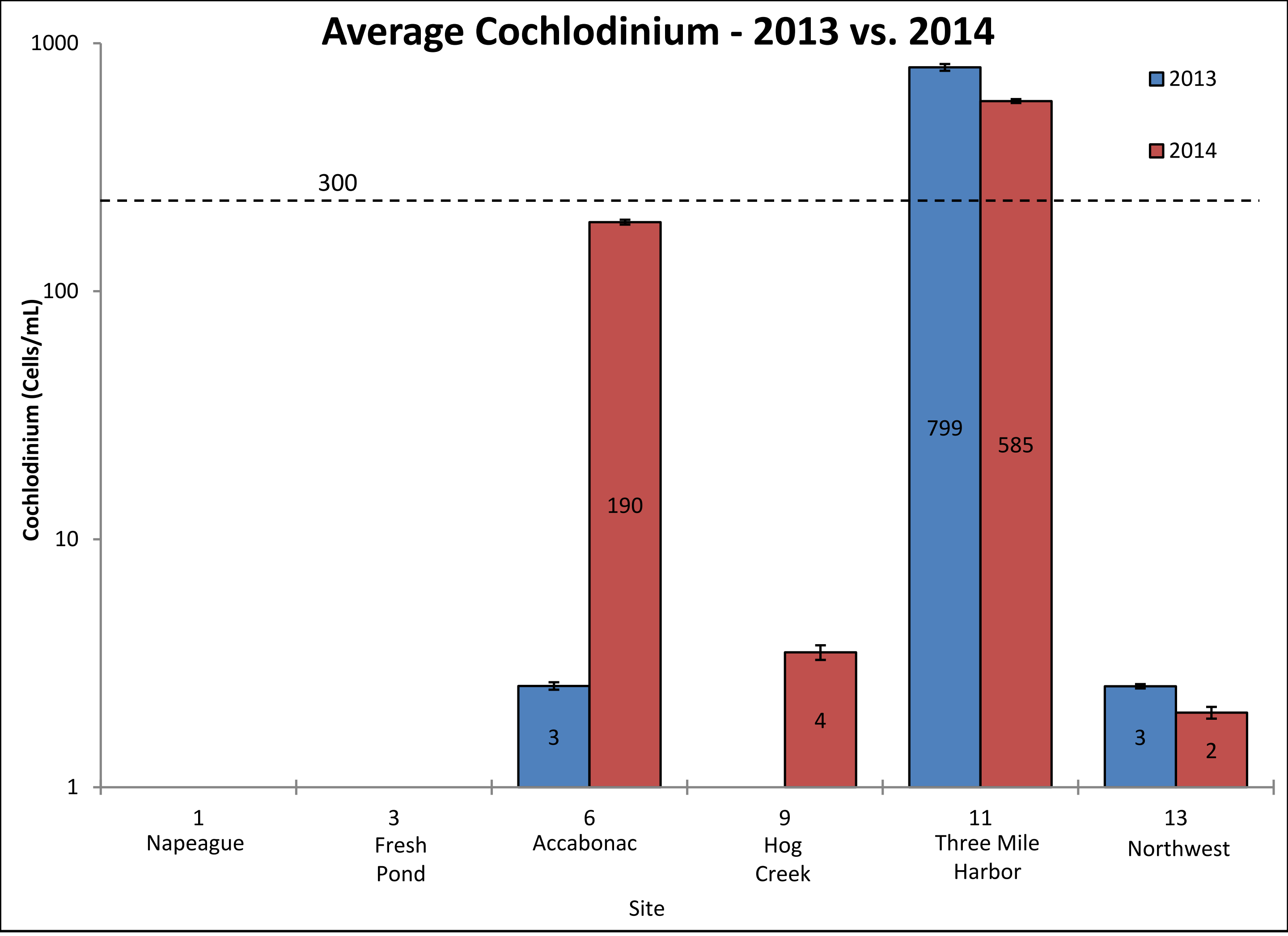

Figure 13: Comparison of average Cochlodinium counts between the 2013 and 2014 sampling seasons. Dashed line represents 300 cells/mL.

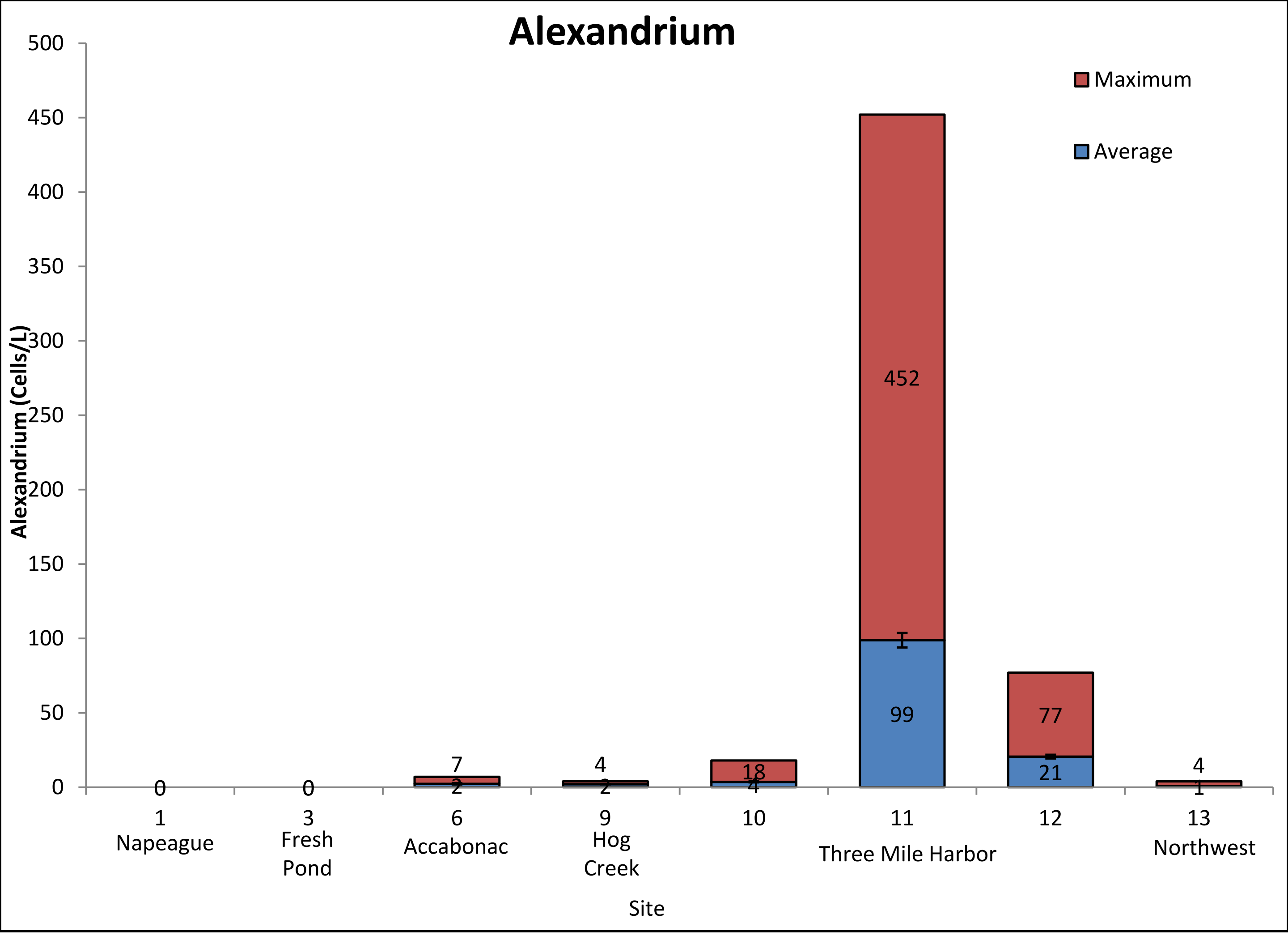

Figure 14: Average and maximum values for *Alexandrium,* from April into June 2014.

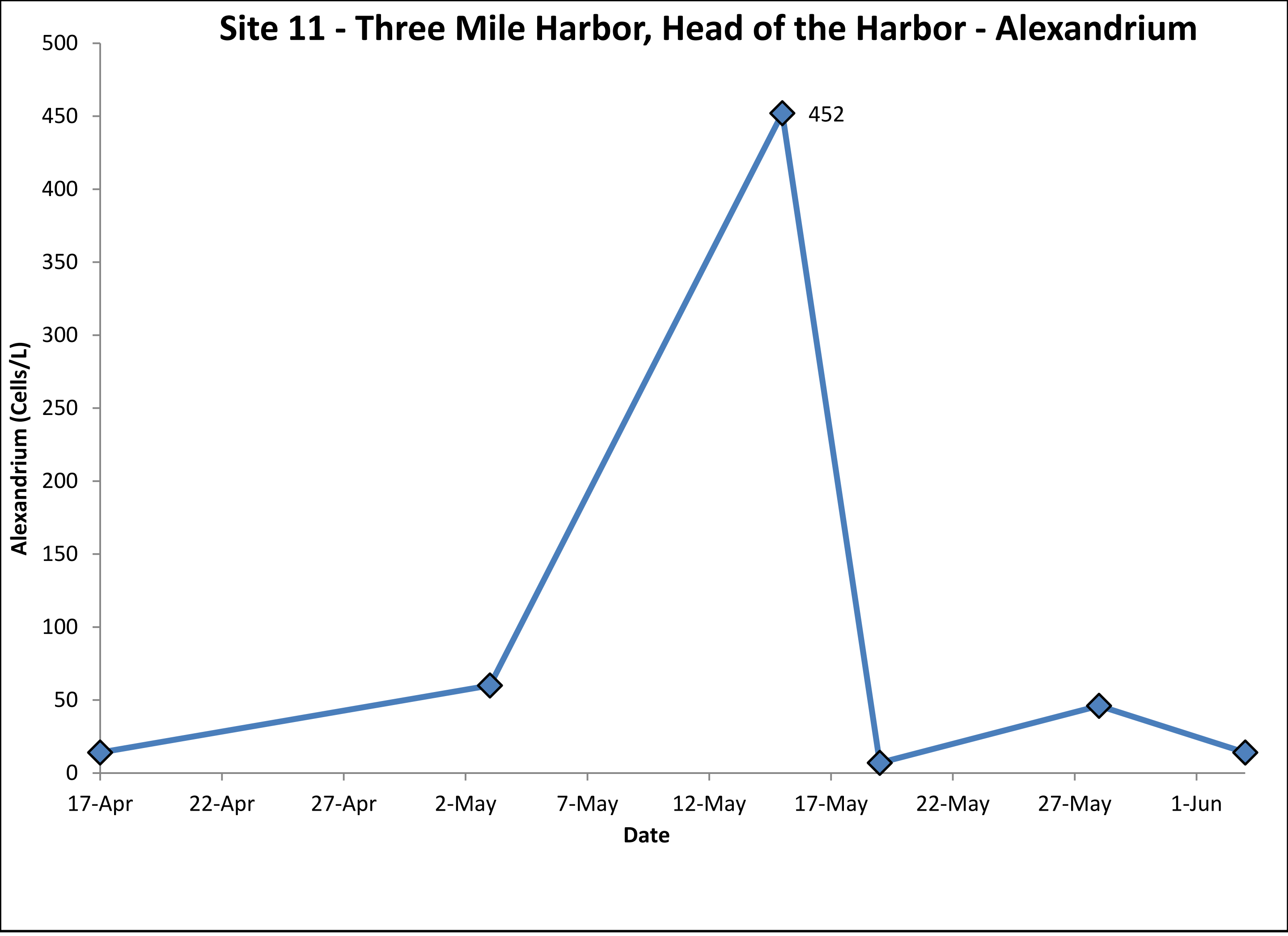

Figure 15: Alexandrium concentrations over time for Three Mile Harbor at Head of the Harbor for the 2014 sampling season.

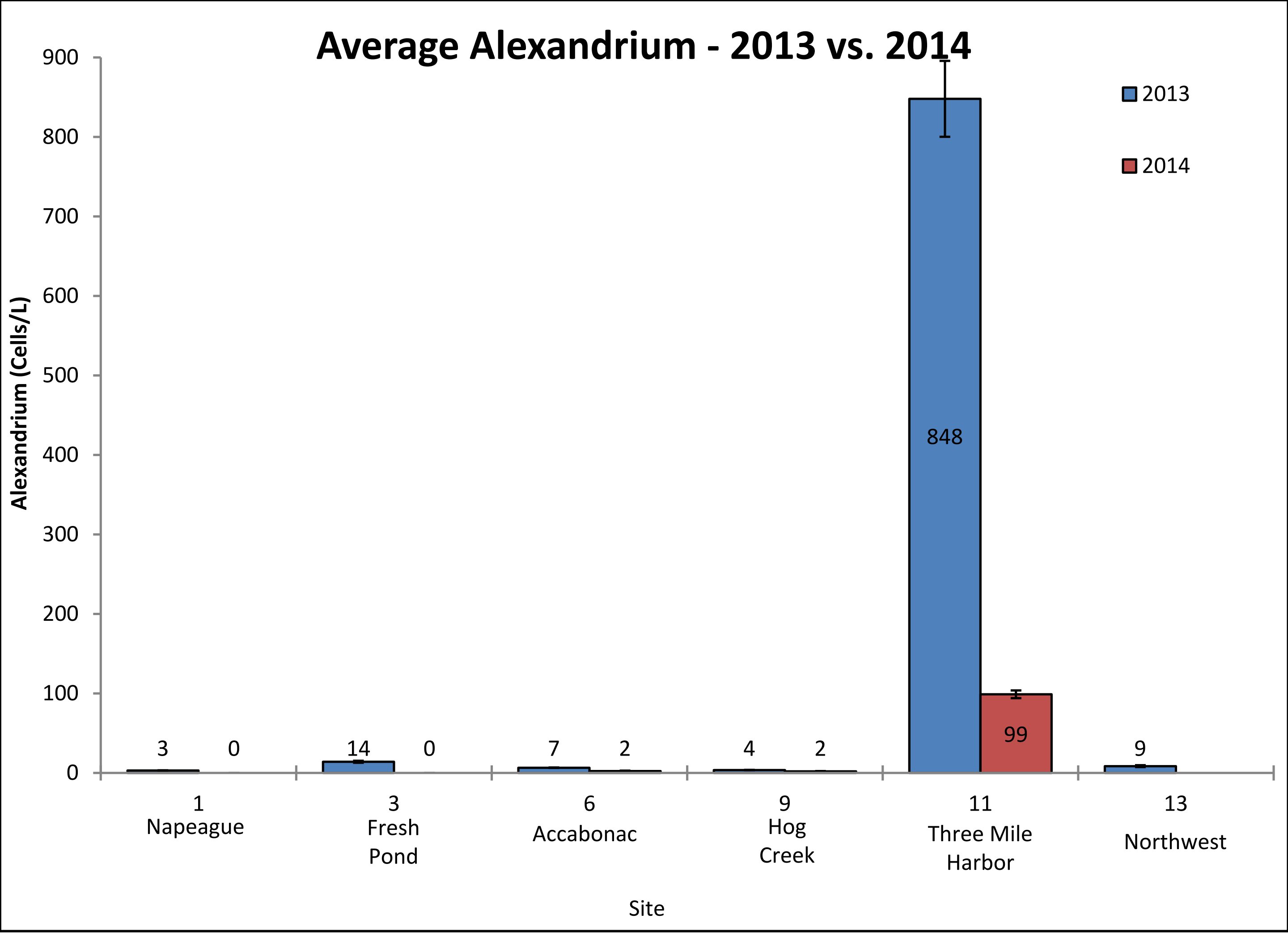

Figure 16: Comparison of average Alexandrium values between 2013 and 2014 for East Hampton Waters.

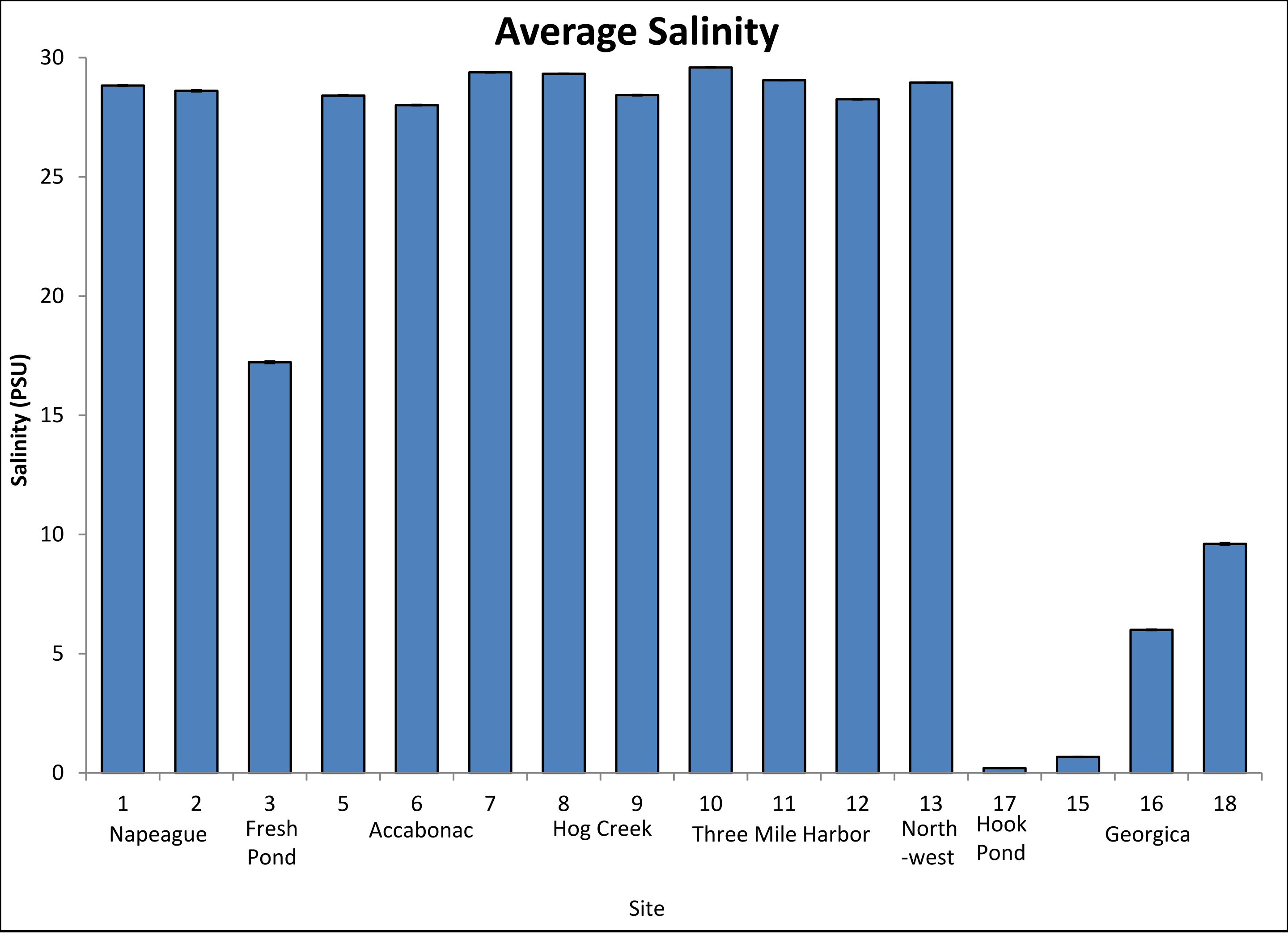

Figure 17: Average salinities across all marine and freshwater sites, from April through Novemeber 2014.

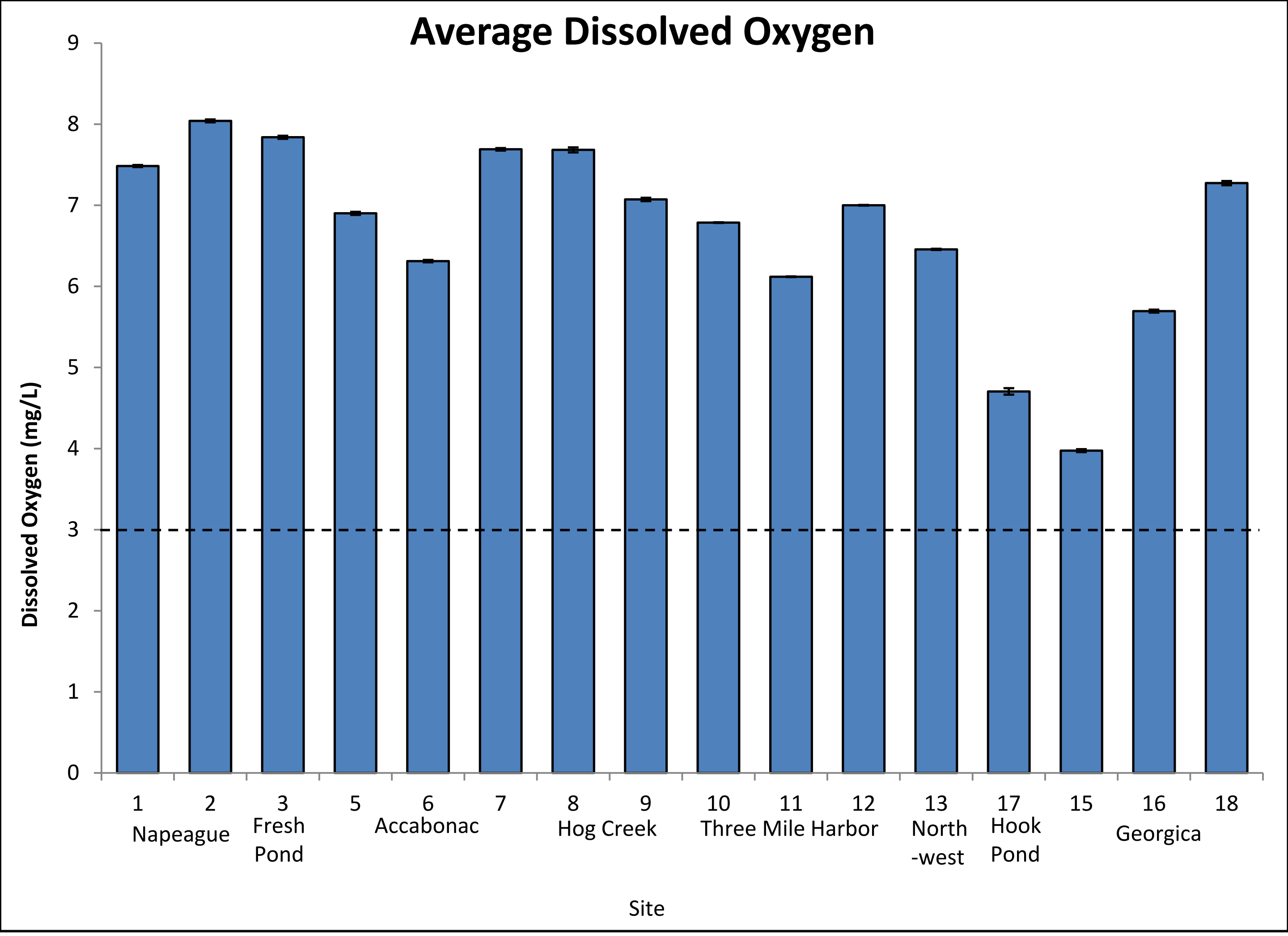

Figure 18: Mean dissolved oxygen values across all marine and freshwater sites for 2014. Dashed line at 3mg/L shows limit for hypoxic waters.

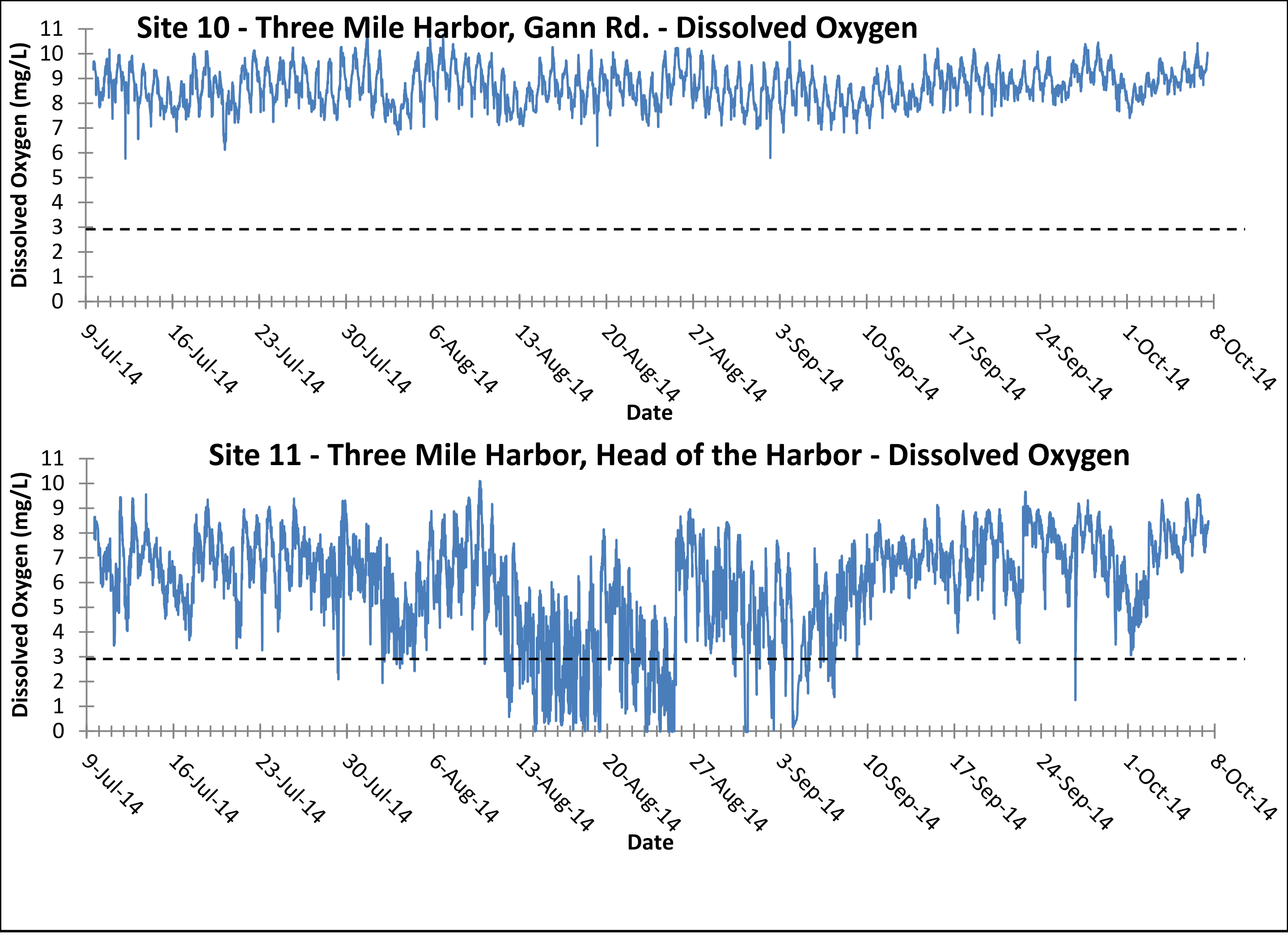

Figure 19: Time series of dissolved oxygen levels at depth from Gann Rd., and Head of the Harbor. HOBO data loggers were deployed between July 9th and October 7th, and recorded values every 15 minutes. Dashed line at 3 mg/L shows hypoxic level.

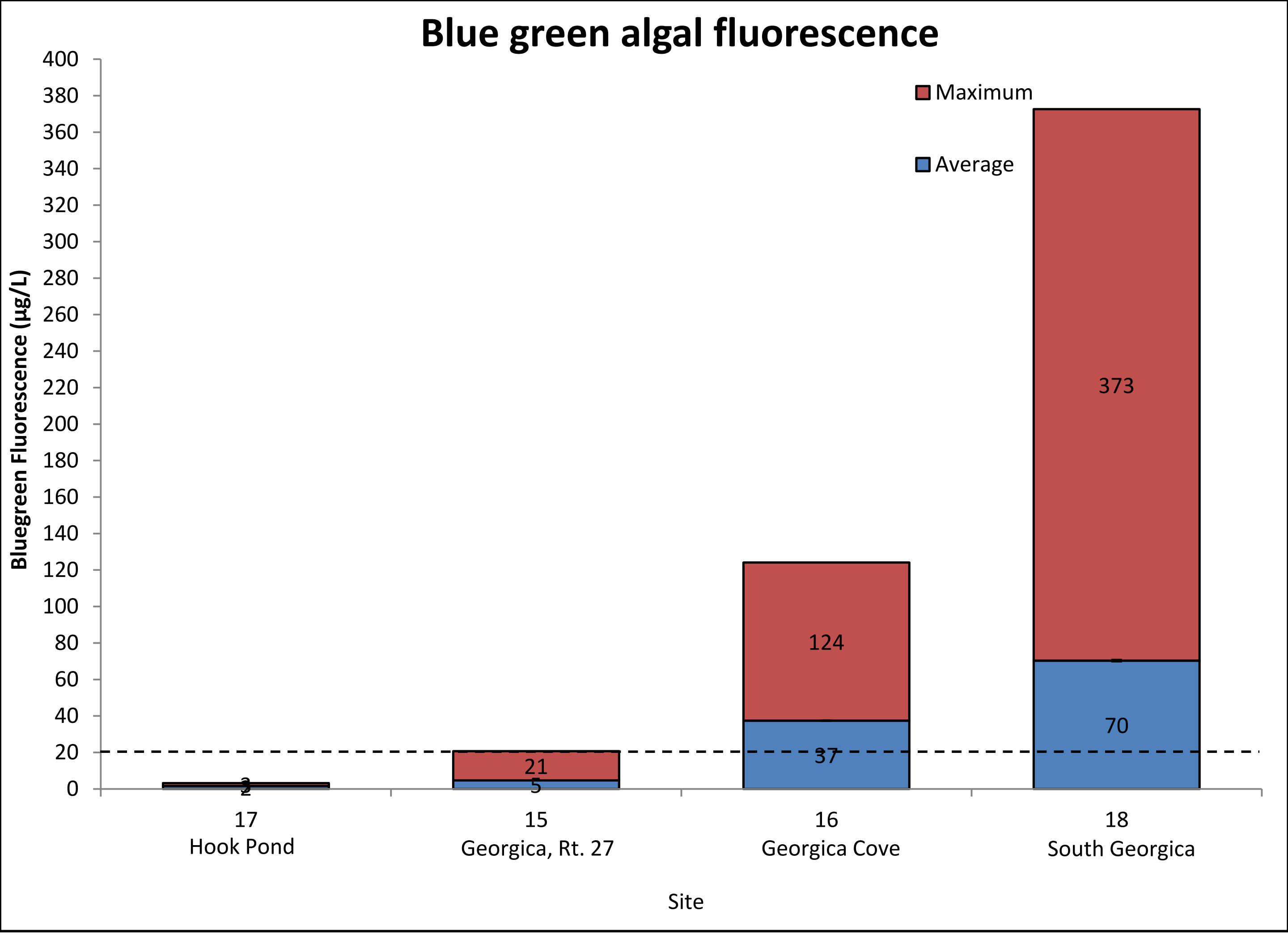

Figure 20: Average and maximum levels of bluegreen fluorescence, measured across the freshwater sites of Hook Pond and Georgica Pond from June through November 2014. Dashed line shows 20 µg/L.

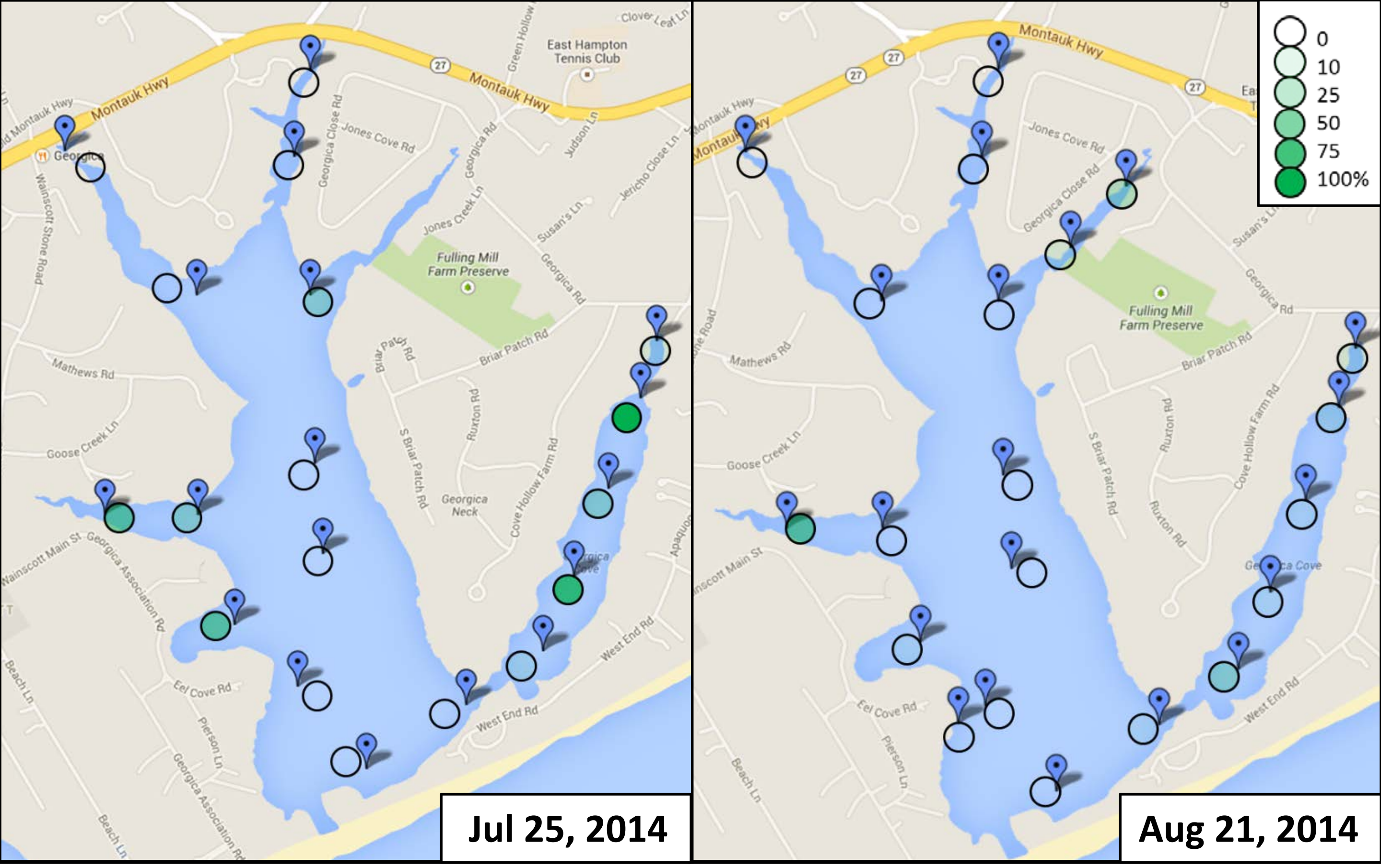

Figure 21: Percent macroalgal coverage of *Cladophora* from two cruises.

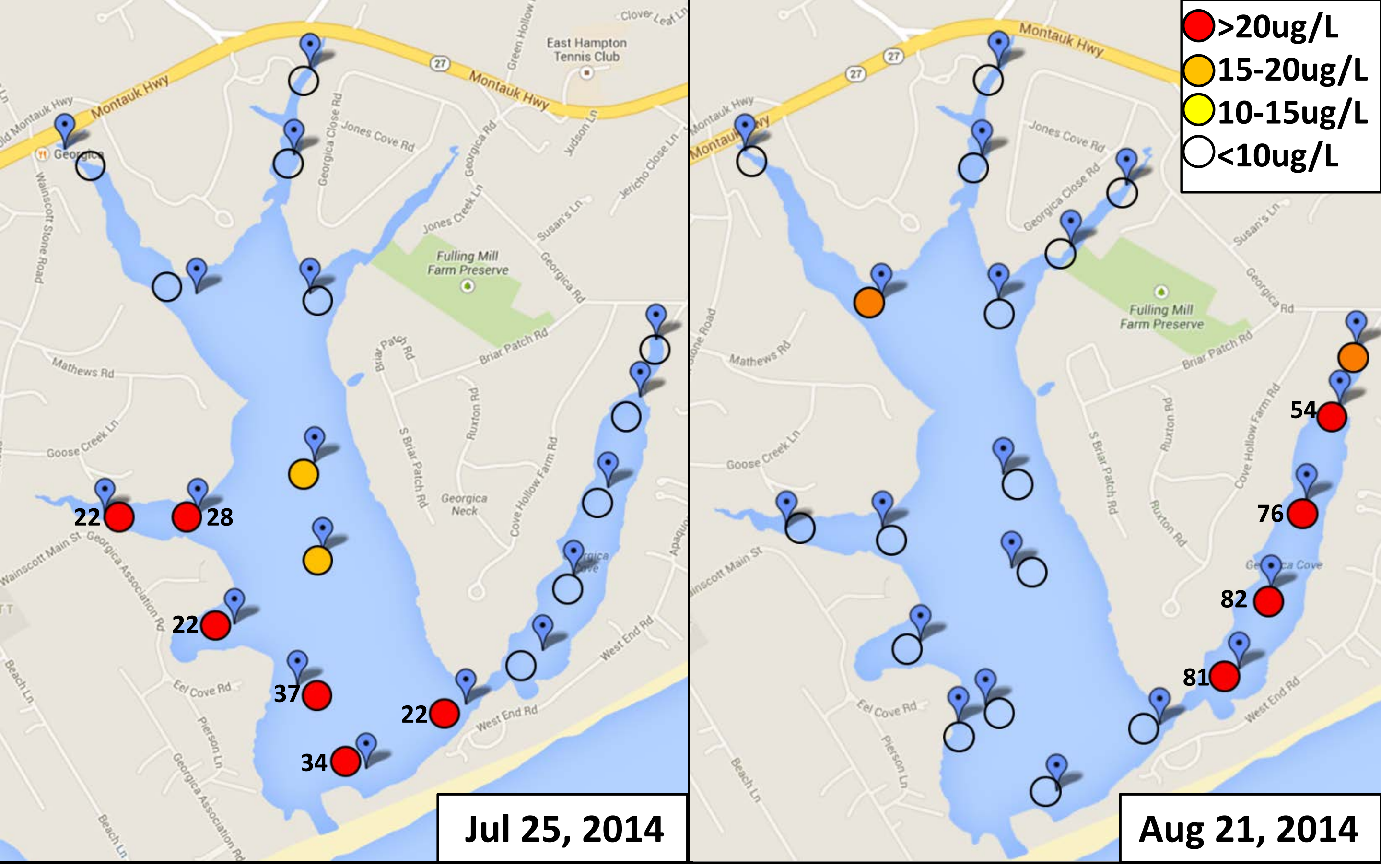

Figure 22: Discrete blue green algal fluorescence measurements from two cruises. Red circles show values that exceeded 20µg/L. Labeled fluorescence values in µg/L.

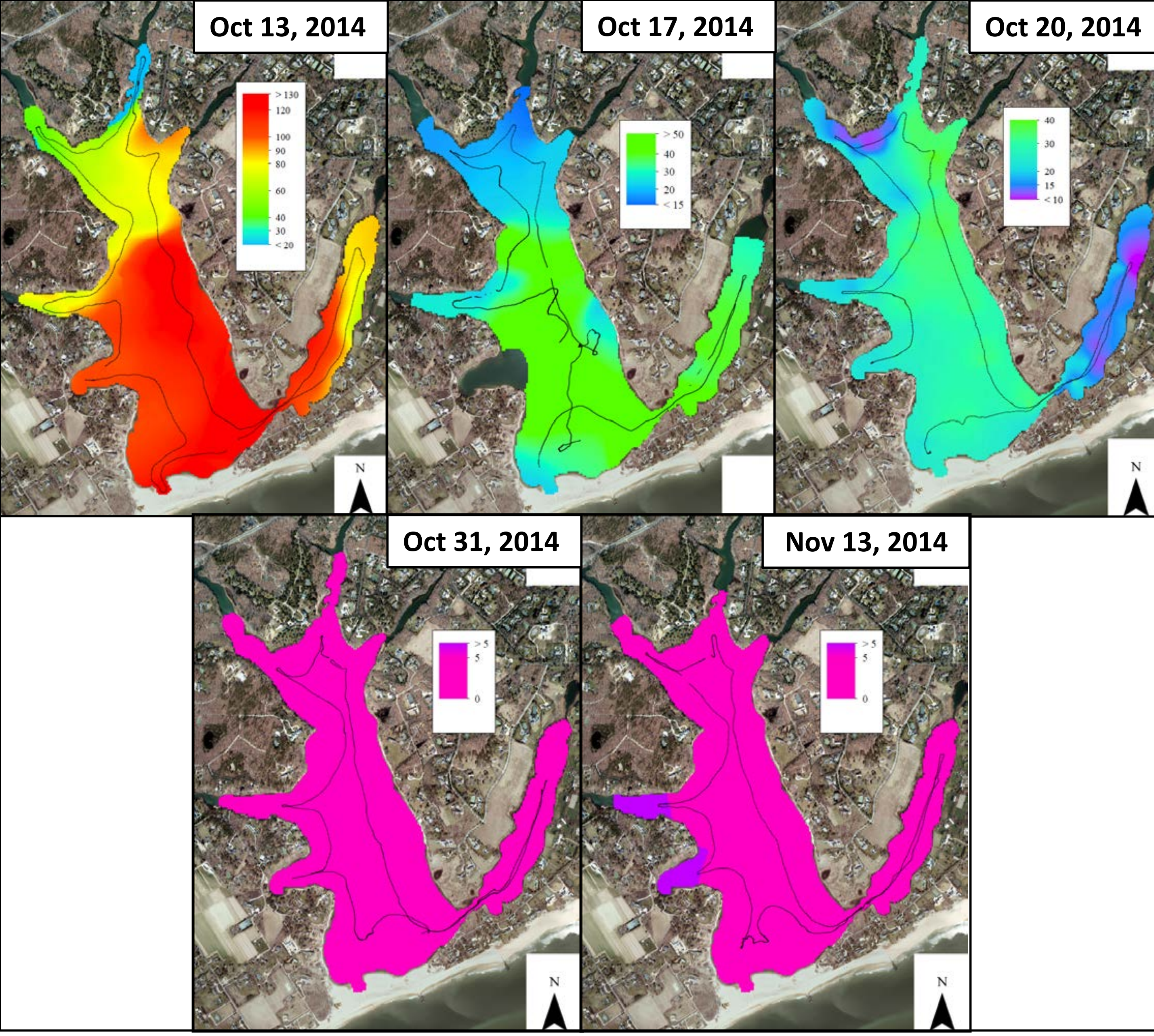

Figure 23: Blue green algal fluorescence data from five fall cruises with continuous readings. Georgica Pond was first opened October 15th, change shown between first two maps.

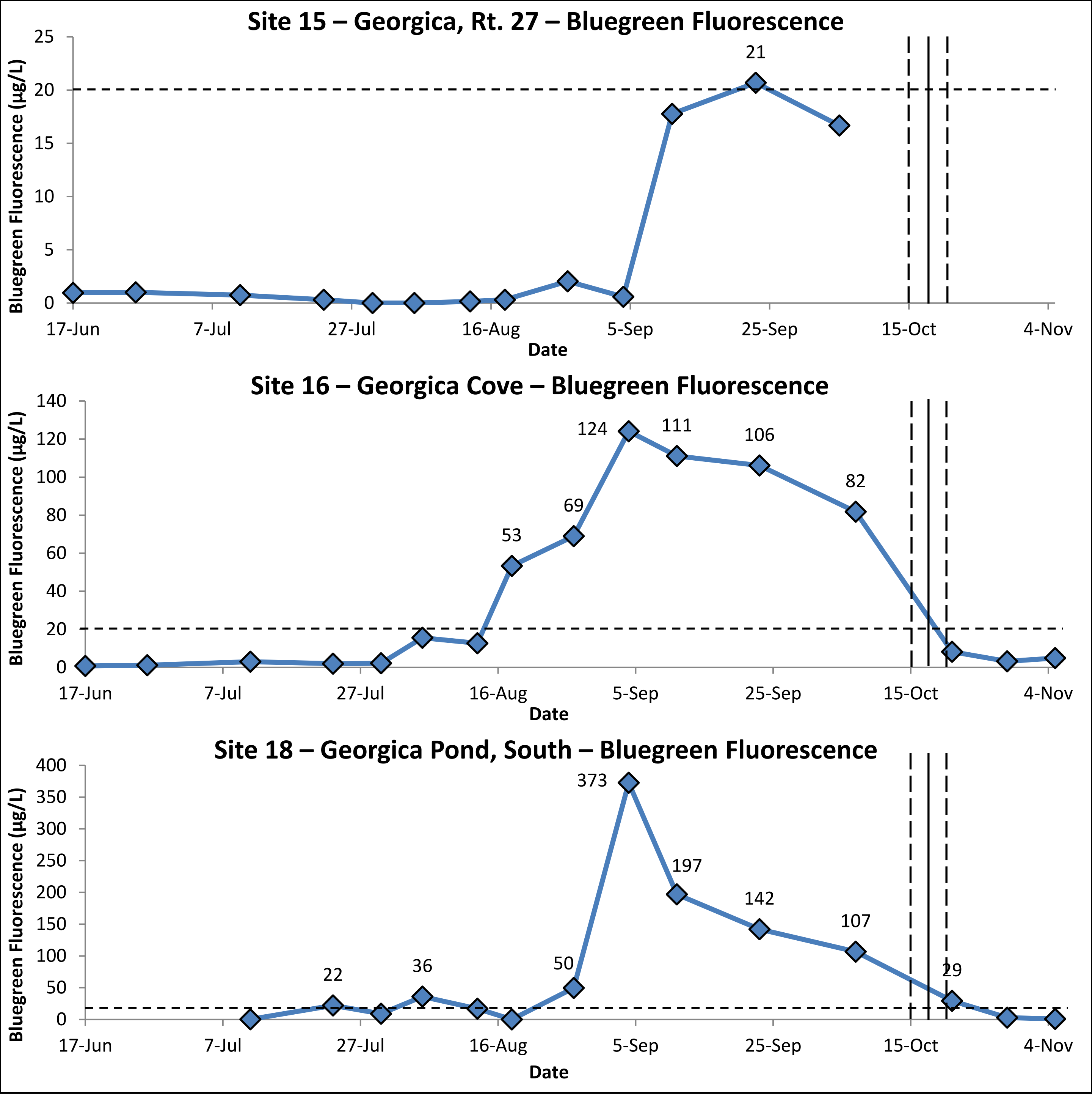

Figure 24: Individual bluegreen fluorescence values over time for the three Georgica Pond sites. These sites exceeded 20 µg/L, which is represented by the horizontal dashed line. Dashed vertical line shows when the cut at Georgica Pond was opened. Solid vertical shows closure of the cut.

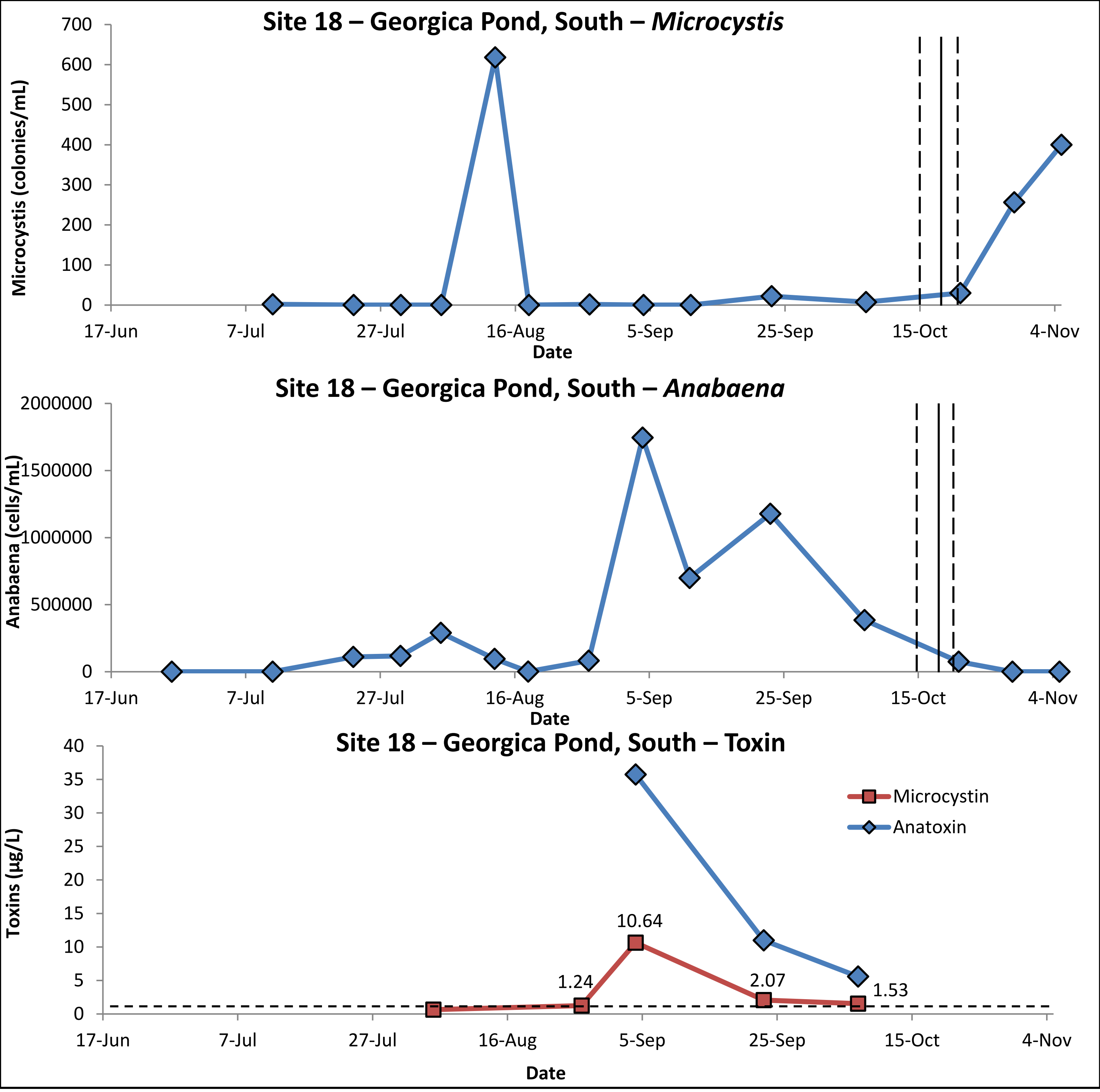

Figure 25: Individual counts of cyanobacteria in Georgica Pond, and associated toxin levels. Horizontal dashed line on the toxin plot shows WHO microcysin standard for drinking water of 1 µg/L. Dashed vertical line shows when the cut at Georgica Pond was opened. Solid vertical shows closure of the cut.

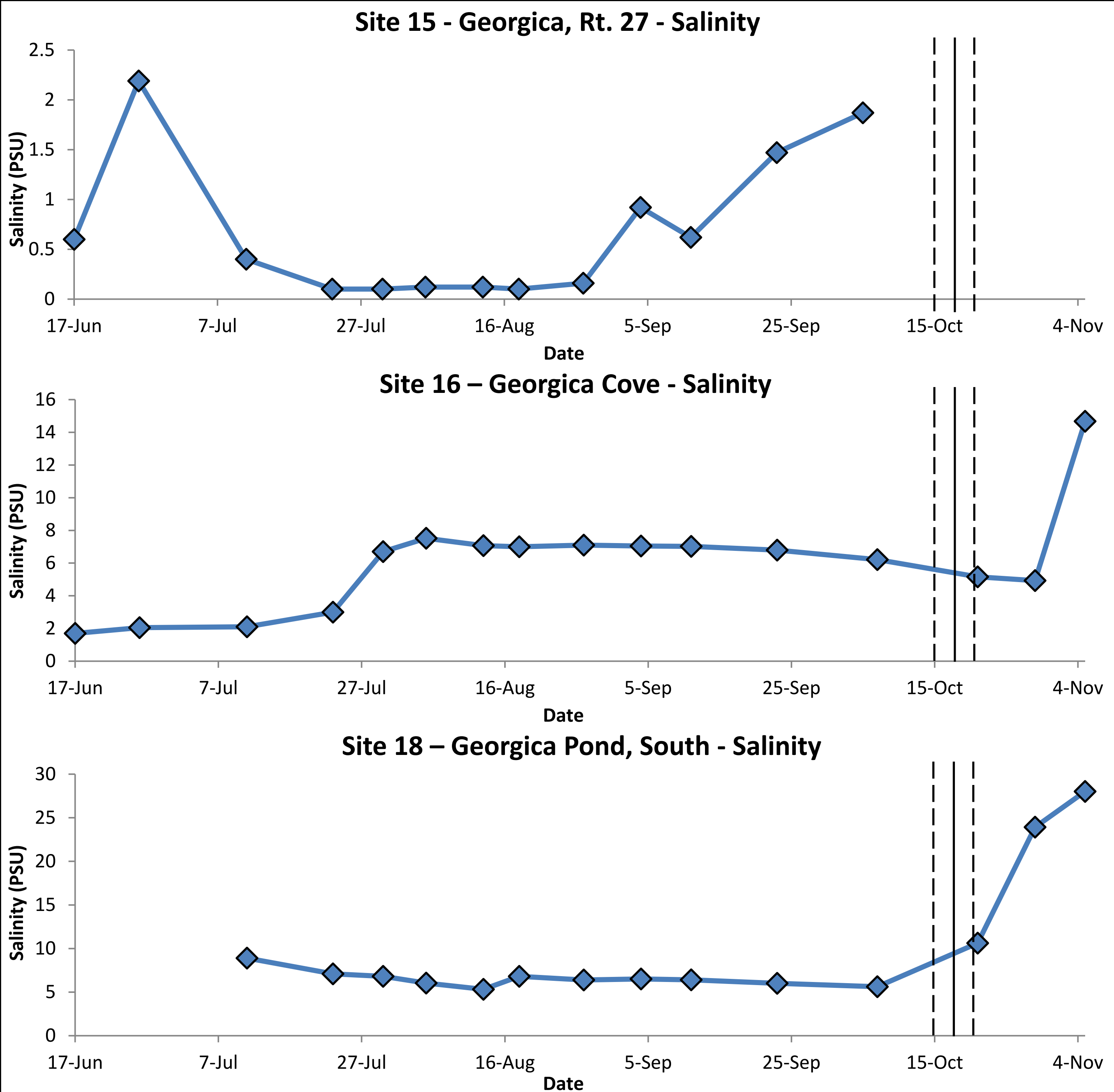

Figure 26: Time series of salinity data for Georgica Pond's three sites. Dashed vertical lines show when the pond was opened to the ocean, and vertical line shows when it closed.

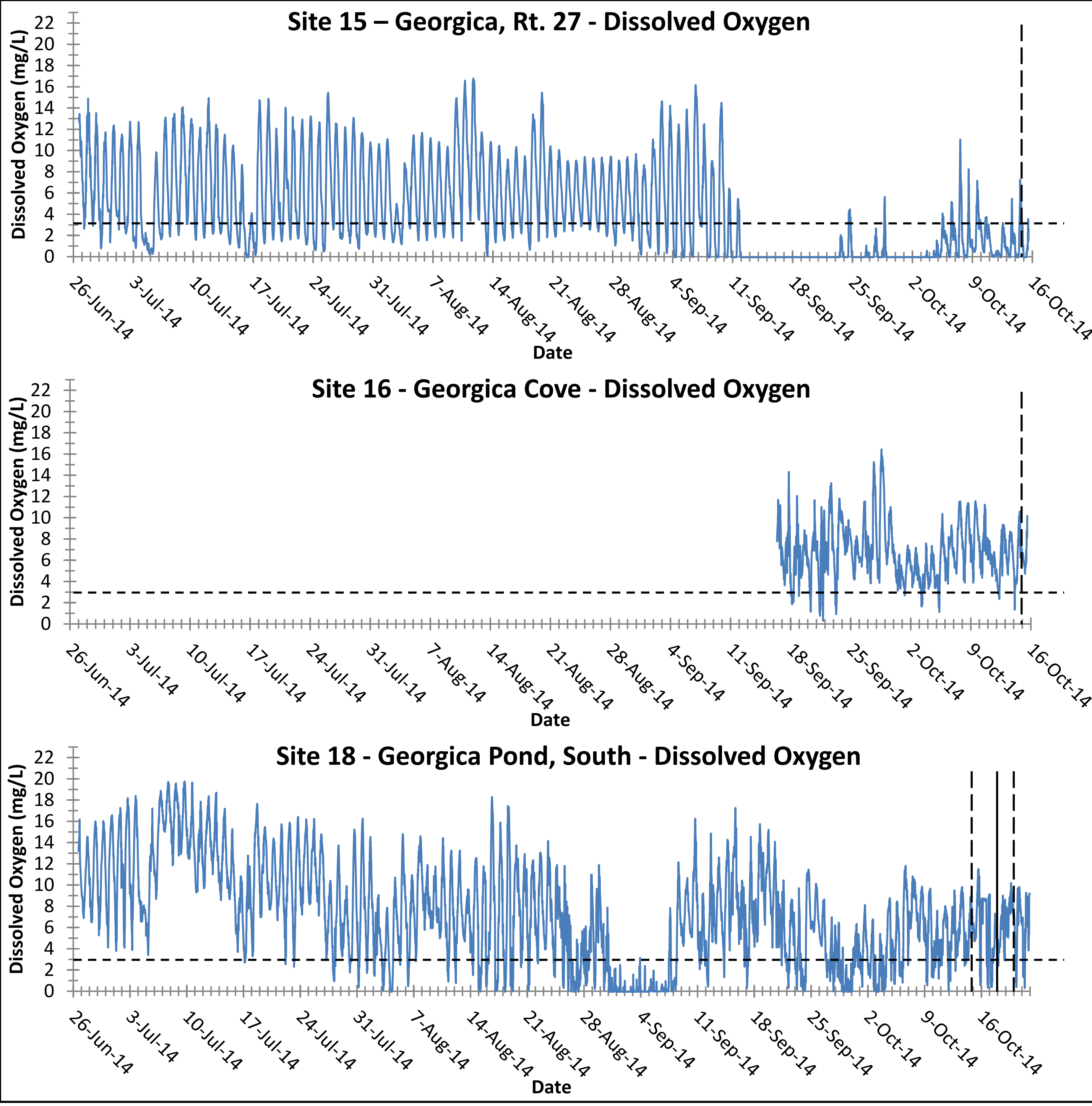

Figure 27: Dissolved oxygen data over time from deployed probes in Georgica pond. Horizontal dashed line is at 3 mg/L, showing hypoxic level. Dashed vertical line shows when the cut at Georgica Pond was opened. Solid vertical shows closure of the cut.

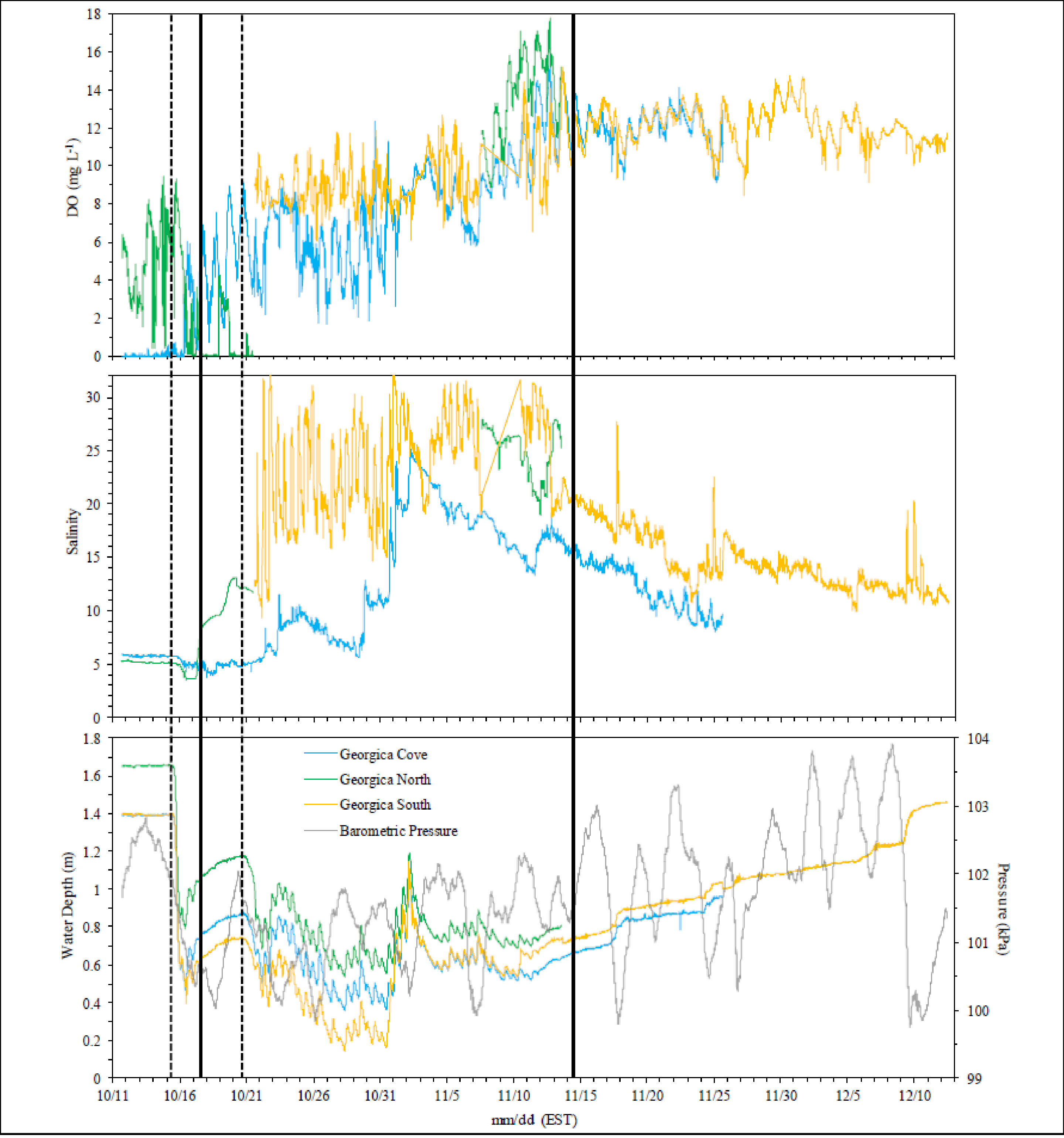

Figure 28: Dissolved oxygen, salinity, and water depth data from the Georgica Pond sonde array. Vertical dashed lines show opening of cut to ocean, solid vertical lines show when the cut closed.

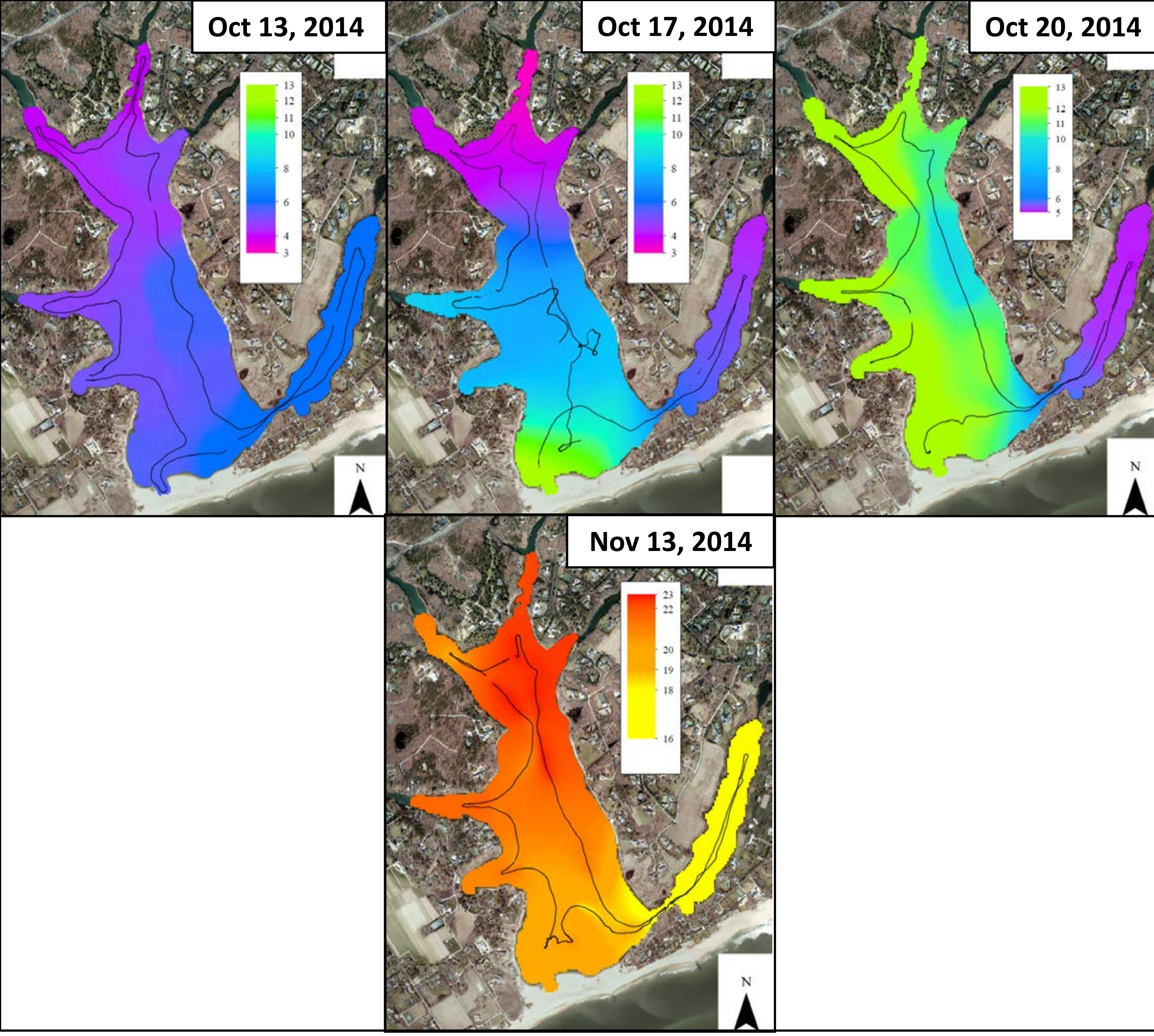

Figure 29: Salinity data from four fall cruises. Georgica Pond was first opened to the Atlantic Ocean on October 15th. After closing October 18th, it was opened again October 20th.

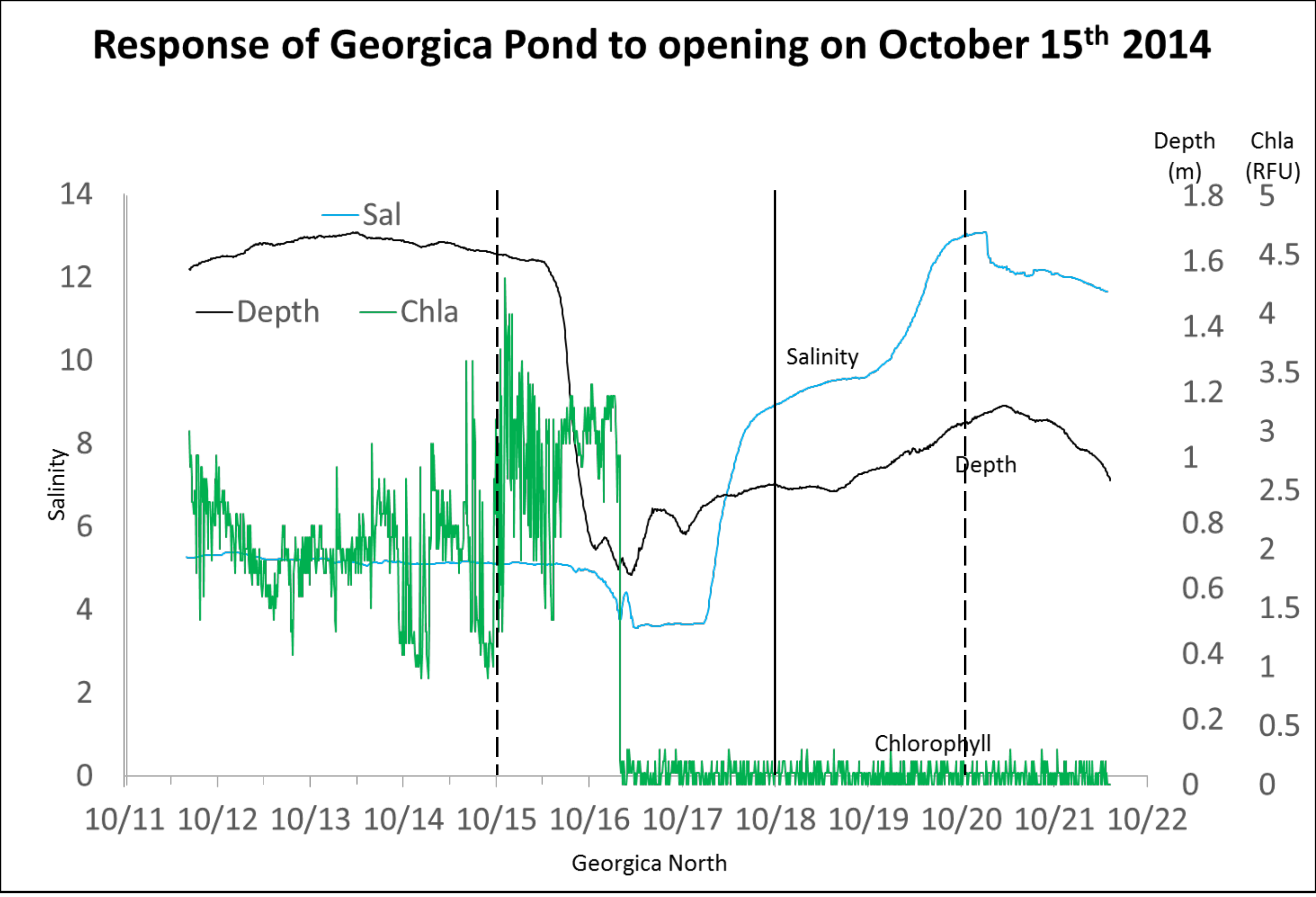

Figure 30: Water depth, salinity, and chlorophyll *a* measurements from southern Georgica Pond relative to the opening and closure of the pond to the Atlantic Ocean. Dashed vertical lines show opening of the cut, and solid lines show closure.