East Hampton Town Trustees 2013 water quality study, Draft Final Report

by

Christopher J. Gobler, PhD

Stony Brook University
School of Marine and Atmospheric Sciences

Submitted March 2014

Executive Summary

This study was undertaken from March through November of 2013 for the East Hampton Town Trustees to assess water quality, harmful algae, and pathogenic bacteria in their marine and freshwater bodies. Total coliform bacteria were quantified as indicators of pathogenic bacteria and to assess current shellfish bed closures in Trustee waters. Total coliform bacteria levels were highest during the warmest months of the study, were higher closer to shore compared to deeper waters, and were higher in poorly flushed regions compared to more open waters. The levels of total coliform were generally consistent with and supportive of NYSDEC shellfish bed closures with some minor exceptions that require further investigation. *E. coli* levels were low in all regions and were undetectable in some regions during spring and fall. For nearly all marine sites sampled, general water quality was excellent: Dissolved oxygen and chlorophyll *a* were at levels supportive of fisheries and levels of harmful algae were low and, in some cases, undetectable. The significant exception to this trend was Three Mile Harbor. This system had the highest levels of all harmful algae studied, *Alexandrium*, *Cochlodinium*, and *Dinophysis*. Densities of *Alexandrium* and *Cochlodinium* in Three Mile Harbor peaked at 2,000 cells/L and 8,000 cells/mL, respectively, levels that have previously been shown to cause shellfish toxicity and fish mortality, respectively. Georgica, Hook, and Fresh Pond were sampled to assess blue green algae and potentially toxic cyanobacteria and levels were found to be low throughout the 2013 sampling season. These sites did, however, attain levels of algal biomass that were in the range deemed eutrophic by USEPA during late summer. Furthermore, Georgica Pond was found to have low levels of dissolved oxygen during late summer and fall and on occasion reached levels not supportive of fish survival and propagation according to NYSDEC standards. Opening the cut to Georgica Pond could help alleviate low oxygen conditions, high algal biomass, and other potential water quality impairments conditions during late summer.

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 3020 freshwater systems across Suffolk County. All lakes sampled contained potentially toxic cyanobacteria (typically *Microcystis* 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 revealed its stomach contained the toxic cyanobacteria, *Microcystis*, and an autopsy revealed the cause of death was liver failure. *Microcystis* synthesizes a liver toxin known as microcystin. Although no bloom was obvious in the pond when it was investigated in late September, blooms are typically ephemeral and the most toxic events are typically associated with nearshore, wind accumulated scums, rather than lake water. The temporal and spatial dynamics of toxic cyanobacteria in Georgica Pond are unknown as well as densities of other harmful algae in East Hampton waters are unknown.

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 March through November of 2013. Results have been placed in the context of prior studies as well as state and federal standards.

Approach:

The sampling season for 2013 ran from April through November and included a total of 14 marine sites between Napeague Harbor, Fresh Pond, Accabonac Harbor, Hog Creek, Three-Mile Harbor, and Northwest Creek; and 3 freshwater sites between Georgica Pond and Hook Pond.

For the marine sampling: most of the water bodies had multiple sites, with one of the sites located near the inlet to the Peconic Estuary and another further from the inlet. Through the eight month season, water samples were gathered to measure levels of total coliforms and *E. coli* for 12 of the sites (excluding sites 3 and 4). A most probable number (MPN) analysis was performed using the Colilert®-18 / Quanti-Tray® testing kit, which is a U.S. EPA approved method (Colilert

2013). In addition to land sampling, three boat cruises were also performed for coliform testing: one in Accabonac Harbor, and two in Three-Mile Harbor. Therse cruises were designed to contrast nearshore sampling with open water sampling for marine indicator bacteria.

Aside from the coliform sampling which occurred at every marine site, there was more comprehensive sampling at six sites; one for each harbor. These samplings specifically sampled for harmful algae. The sites themselves were those furthest from the inlet (for those harbors with multiple sites), and thus were potentially susceptible to elevated nutrient levels and proliferation of algae. Chlorophyll *a*, an analog for algal biomass, was measured by filtering collected water onto glass fiber filters, extracting the pigment with acetone, and measuring the fluorescence (Parsons et al., 1984).

Sites were monitored for *Dinophysis acuminata*, a toxic marine dinoflagellate responsible for diarrhetic shellfish poisoning (DSP), from April to mid-July. Concentrated samples were collected by sieving 1L of water through a 20μm mesh, backwashing the sample into a 15mL centrifuge tube, and preserving with Lugol's iodine. Cells were counted on a Sedgewick-Rafter slide under a microscope. The harmful "rust tide" dinoflagellate *Cochlodinium*, known for causing fish kills, was monitored from July to early November by preserving whole water samples with Lugol's iodine and counting as with *Dinophysis*. *Alexandruim fundyense*, another toxic marine dinoflagellate, one responsible for paralytic shellfish poisoning, was sampled from April through May. 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). Water quality measurements also included temperature, salinity, and dissolved oxygen for every site, which were measured with a handheld YSI 85 probe.

The three freshwater sites were also sampled for chlorophyll *a*, salinity, and dissolved oxygen as with the marine sites. There were two sites in Georgica Pond, and one site for Hook Pond which were sampled from July through September. In addition, each site was sampled for cyanobacteria, blue-green algae, and the toxic algae *Microcystis*. Blue-green fluorescence was measured in a Fluoroprobe with live samples, and like chlorophyll a is an analog for biomass, but is more specific to cyanobacteria. *Microcystis* colonies were preserved in whole samples with Lugol's iodine, and counted under a microscope.

Results:

Total Coliforms & E. Coli – Land Sampling

The mean levels of total coliform bacteria ranged from 78.45 cells/100mL to 19,429.1 cells/100mL over the course of this study (Fig 1). Of all the sites samples, the Fresh Pond in Amagansett maintained the highest levels of coliform bacteria with a mean value of nearly 19,500 cells/100mL; well over the shellfishing limit of ~100 cells/100mL. Figure 2 again shows total coliform bacteria, but with focus on the lower range for a better view of the other locations. For most systems, samples were obtained from multiple locations with one near the inlet to the Peconic Estuary and others further within each creek or harbor. For example, sites further from inlets included: site 1 in Napeague, site 6 in Accabonac, site 9 in Hog Creek, and site 11 in Three-Mile Harbor. In any given system, the total coliforms levels near inlets to the Peconic Estuary were always lower than the sites further within the system. Near inlets to the Peconic Estuary, water from the creeks or harbors mixes with Peconic water and dilutes constituents originating from within them. In contrast, further from the inlet, the water resides longer and has a greater chance of accumulating and retaining land-derived bacteria from sources such as animal or human waste.

Fresh Pond and Northwest Creek only had a single sampling location each. These sites were located near their inlets to the bay, which further emphasizes their high values. The back end of Hog Creek also had very elevated bacterial levels, second to Fresh Pond. Napeague was the cleanest site, having the only mean values below 100 cells/100mL.

As discussed, Fresh Pond in Amagansett had, by far, the highest total coliforms values. Figure 3 shows the temporal dynamics of total coliform bacteria through the year and shows that levels were lower during spring and fall but from mid-July to October exceeded the measurable limit of test kits, 24,196 cells/100mL. Hog Creek, site 8, near the inlet to the creek, displayed a similar temporal trend with regard to coliform bacteria (Fig 4). The site's location at the inlet had lower the total coliforms values although from mid-May through most of October the values were still above the safe limit. One of the sampling days in particular, July 17th, had an unusually high measurement that passed 1,000 cells/100mL. Three-Mile Harbor had fairly high concentrations across its three sites with particularly high values at site 11, at the Head of the Harbor (Fig 5). For most of the year, the values were above the safe limit, in the hundreds of cells/100mL. From mid-July into early September, the total coliform values rose to the highest values being thousands of cells/100mL, peaking as high as 6,131 cells/100mL.

The mean levels of *E. coli* measured for each site are shown in Figure 6. Levels of *E. coli* were generally low at all sites and were often undetectable during spring and fall. The averages ranged from 16 cells/100mL at Napeague to 3,171 cells/100mL at Fresh Pond. These levels followed trends are similar to the total coliforms values, in that: 1. Fresh Pond had the highest concentrations, 2. Levels were lowest near inlets, 3. Levels tracked water temperatures.

Total Coliforms & E. Coli – Cruise Sampling

The Accabonac Harbor cruise took place September 5th. The land and open water sampling sites, and the total coliform values for those sites are displayed in Figure 7. The highest values were measured in the Southeast end of the harbor near Landing Lane. The total coliform bacteria levels were generally higher at the land-based sampling sites than the cruise samples obtained from open water (Fig 8). Across the entire system, coliform levels were highest around Landing Lane. *E. coli* values were lower than total coliform bacterial levels by more than an order of magnitude and displayed a spatial distribution similar to total coliform bacteria with land stations having higher values and the area around Landing Lane having the highest overall values (Fig 9).

The first of the two Three-Mile Harbor cruises for indicator bacteria occurred on August 15th (Fig 10). The coliform values from the cruise increased from the Peconic Estuary towards the Head of the Harbor. The site in the Peconic Estuary had levels of total coliform bacteria that were below the detection limit of our methods. Low values were measured at both the inlet and in the middle of the Harbor (~30 cells / 100 mL). As in Accabonac, the near-shore land sites displayed significantly higher levels ranging from 300 – 2,000 cells / 100 mL (Fig 11). Comparing the total coliform values for the land sites to their nearest cruise site, again, the values are shown to be higher nearer to shore, with the highest values for both being measured at the Head of the Harbor (Fig 11). *E. coli* levels were very low at most sites at ~10 cells / 100 mL, with the land-based Hand Creek site being slightly higher at 40 cells / 100 mL (Fig 12).

The second Three-Mile Harbor cruise was on October 3rd (Fig 13). Compared to the cruise in August, the bacterial levels were significantly lower, emphasizing the strong seasonal trend for these populations. Levels within open waters were all $\leq$ 20 cells / 100 ml whereas near shore site had levels between 100 and 300 cells / 100 mL maintaining the trend of higher values near shore for total coliforms (Fig 14). The highest total coliform values were again within the Head of the

Harbor (Fig 14). *E. coli* levels were again very low being 10 cells / 100 mL for open water sites and 10 – 40 cells / 100 mL for near shore sites (Fig 15).

NYSDEC Comparison of bacterial data

The measured levels of the total coliform bacteria were compared with the NYSDEC shellfish bed statuses for each sampled water body (Fig 16). For a majority of the sites, the measured values supported the DEC's closures. Both Napeague sites, as well as the Gerard Drive site in Accabonac Harbor are listed by the DEC as "Open". For all three of these sites, the measured coliform values exceeded 100 cells/100mL for several months of the year. The southeastern shore of Napeague was over the safe limit from May through October, and Lazy Point near the inlet was over for a shorter period between July and September. The Accabonac site was over during May through September. If confirmed, this data would suggest that these three sites might require seasonal closures. In contrast, Three-Mile Harbor at Head of the Harbor and the inlet of Northwest Creek were under the NYSDEC limit for some periods of sampling where the DEC lists them as "Uncertified" for the entire year. Head of the Harbor was below the threshold in April and November, the beginning and the end of the sampling period. Northwest Creek was below from April through May. If this data were confirm, it would suggest that these sites could be opened seasonally like other East Hampton Town Trustee waters. The maps in Figures 17-22, show the DEC shellfish closure areas, and the coliform sampling sites relative to them for Northwest Creek, Three-Mile Harbor, Hog Creek, Fresh Pond, Accabonac, and Georgica Pond respectively.

In making these comparisons, several important caveats should be considered. Firstly, NYSDEC has relied on fecal rather than total coliform bacteria levels to open and close shellfish for the past decade. While standards for total coliform bacteria are still in existence, future studies measuring fecal coliform bacterial levels would be required to better compare to the shellfish bed declarations made by the NYSDEC. Further, while the system used during this study has been certified by USEPA for measuring fecal coliform bacteria in wastewater, it had to be modified for the detection of total coliform bacteria in marine systems. Follow-up studies could utilize multiple approaches to confirm the absolute levels of fecal and/or coliform bacteria in East Hampton waters. In conclusion, while the trends in total coliform bacteria detected here are sound and certain, the absolute values require confirmation with other methods and the measurement of fecal coliform bacteria would be ideal for future comparisons to NYSDEC shellfishing declarations.

Harmful Algae: *Dinophysis, Cochlodinium, & Alexandrium*

All algae contain chlorophyll a and this pigment is typically measured, therefore, as proxy for total phytoplankton biomass. While moderate levels of algae are required to maintain productive fisheries on any ecosystem, excessive levels can initiate a cascade of negative impacts on coastal systems. Average values for chlorophyll *a* during the entire study ranged from 2.5 µg/L in Napeague to 15.6 µg/L in Fresh Pond (Fig 23). As a benchmark, 5 µg/L is a normal level for Long Island waters and most sites were near or slightly below this levels. According to US EPA, (2000) freshwater bodes with > 8 µg/L of chlorophyll *a* are eutrophic or overenriched in phytoplankton and presumably nutrients. Two of the freshwater sites, one at each pond, had an average value (7 µg/L; Fig 23) were close to this value, on average, and were, on occasion, above this value. Fresh Pond was double this value but was, ironically, a brackish water site.

Three-Mile Harbor had, on average, moderate levels of chlorophyll *a* through much of the year, although values at the Head of the Harbor displayed with two large peaks, one in early July, and the second, the largest one, in early October (Fig 24), both associated with algal blooms. Fresh Pond on the other hand has one main peak in its chlorophyll values in the fall but had high values on other dates as well (Fig 25). Chlorophyll levels increase through the year from 5 µg/L in early summer to 10 µg/L in late summer and a maximum peak over 60 µg/L in early October (Fig 25).

Among the specific harmful algae monitored, *Dinophysis*, was present at the lowest levels. 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 one in NY (Hattenrath-Lehmann et al., 2013).

Dinophysis densities were generally low, remaining mostly below 10 cells/L, with none being detected in Northwest Creek (Fig 26). The exception is Three-Mile Harbor which had an average of 46 cells/L. During the spring in Three-Mile Harbor, *Dinophysis* was undetected before late May when levels began to ramps up to a peak of ~300 cells/L on July 3rd before dropping to undetectable levels by mid-July (Fig 27). This peak in *Dinophysis* occurred together with the first peak in chlorophyll *a* for this site (Fig 24).

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 found in 3 of 6 systems monitored during this study with no populations found in Napeague, Fresh Pond, and Hog Creek (Fig 28). *Cochlodinium* was present in low concentrations in Accabonac Harbor and Northwest Creek (Fig 28). As with *Dinophysis*, Three-Mile Harbor had much higher concentrations of *Cochlodinium* than the other sites, with an average of nearly 800 cells/mL although there are two caveats to this value. Firstly, due to the tendency of this species to form dense aggregates after being collected, during several dates in late summer, in thick red streaks of *Cochlodinium* were found in Three Mile Harbor and samples were collected but aggregated and formed flocs during transport, leading to only low cell densities in the final count. This methodological limitation was overcome in October when samples were preserved on site. In early October, *Cochlodinium* bloomed at the Head of the Harbor the nearly 8,000 cells/mL were quantified. As a reference point, 1,000 cells/mL of *Cochlodinium* are generally high enough to cause mortality in larval fish (Tang and Gobler 2009). The peak in *Cochlodidium* in Three Mile Harbor was coincident with the second large peak of chlorophyll *a* that was observed in this system.

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 had never occurred in NY before 2006 but has occurred annually since then with Sag Harbor being the region closest to East Hampton waters experiencing such event. During this study, *Alexandrium* was detected at all sites but in mostly low concentrations of 5 – 30 cells/L, on average (Fig 30). In a manner consistent with the other harmful algae, *Alexandrium* was present at high levels at the Head of the Harbor site in Three-Mile Harbor, with an average value of 848 cells/L (Fig 30). At this site, *Alexandrium* was present for the whole sampling period with concentrations peaking at 2,819 cells/L on the 14th of May, before declining steadily over the next two weeks (Fig 31). As a reference point, cell densities exceeding 1,000 cells/L are known to cause toxicity in shellfish (Anderson 1997). In a single sampling of mussels in this system by the NYSDEC in May, PSP levels were below the shellfish closure limit set by the USFDA.

Salinity & Oxygen

Most of the marine sites had a mean salinity in the range of 27 to 30 (Fig 32). Fresh Pond's salinity was much lower, around 10. Though sampled near the bay, fresher water mostly flows out of the pond. Occasionally the flow out was lowered to the point that it became cut off from the bay as sand built up. The freshwater sites had low salinities as expected. Hook Pond had a salinity close to 0. Georgica, which is occasionally open to the ocean, was slightly higher in the salinity range of 1 to 2.5. The higher values were from Georgica Cove, closer to the ocean.

The mean dissolved oxygen values were similar among site being near 8 mg/L (Fig 33). These are high levels and thus are supportive of all types of fisheries, shellfisheries, and wildlife. The freshwater sites were the most variable. Hook Pond had the highest dissolved oxygen average of all sites with 9.8 mg/L. The lowest average was from the Georgica Pond access point on Rt. 27, with a mean value of 4.14 mg/L, which is approaching hypoxic conditions (see discussion below).

Freshwater ponds- Toxic Cyanobacteria

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. Compared to other ponds and lakes across Suffolk County, the three freshwater sites sampled for this report had fairly low concentrations of blue-green algae (Fig 34). The value of the blue-green algae fluorescence for all three of the sampled ponds was below 4 µg/L, which is dwarfed by the other values and below the 20µg/L that the NYSDEC uses to close a lake. The average counts from the three sites for *Microcystis* colonies were modest (Fig 35). Georgica's sites were below 10 colonies/mL while Hook Pond had a higher value of ~60 colonies/mL. The higher Microcystis levels in Hook Pond were consistent with the higher chlorophyll levels during 2013 that twice exceeded the USEPA threshold for a eutrophic water body (8 µg/L; Fig 36).

General water quality in Georgica Pond through the summer

The data generated in 2013 for Georgica Pond indicated it was generally free of high levels of blue green algae. There were, however, several indications that this system experienced degraded water quality during late summer and early fall, the period of time of a putative deadly algal bloom in 2012. Specifically, the salinity in Georgica Pond decreased through the study from brackish levels in the spring to almost freshwater by late summer (Fig 37), suggesting that the inlet to Georgica Pond was open in the spring but was closed through the summer and early fall. During this same period, chlorophyll a levels in this system rose through the summer, and were twice above the USEPA threshold for a eutrophic water body and once exceeded 20µg/L which is more than double the threshold (Fig 38). Of more significant concern were the oxygen levels present during late summer in Georgia Pond (Fig 39). The NYSDEC indicates that the minimum daily average dissolved oxygen levels shall not be less than 5.0 mg/L, and at no time shall the DO concentration be less than 4.0 mg/L to support for fish, shellfish, and wildlife propagation and survival (class C waters; http://www.dec.ny.gov/regs/4592.html). The NYSDEC further indicates dissolved oxygen levels should not be less than 3.0 mg/L at any time to support for fish, shellfish, and wildlife survival (http://www.dec.ny.gov/regs/4592.html). Following these state standards, Georgica Pond had oxygen levels during late summer that were not supportive of fish, shellfish, and wildlife propagation (< 4mg/L) and at times reached levels not supportive of fish, shellfish, and wildlife propagation and survival (< 3 mg/L; Fig 39). Given that oxygen levels are known to be minimal at night and maximal during the day and that the measurements of oxygen in Georgica Pond were during that day, it is likely that the levels in the Pond were significantly lower at night that shown in Fig 39. It is probable that opening the cut to Georgica Pond during late summer would help alleviate low oxygen conditions.

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.

Colilert-18 water testing product information.
<http://www.idexx.com/view/xhtml/en_us/water/products/colilert-18.jsf>

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

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

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.

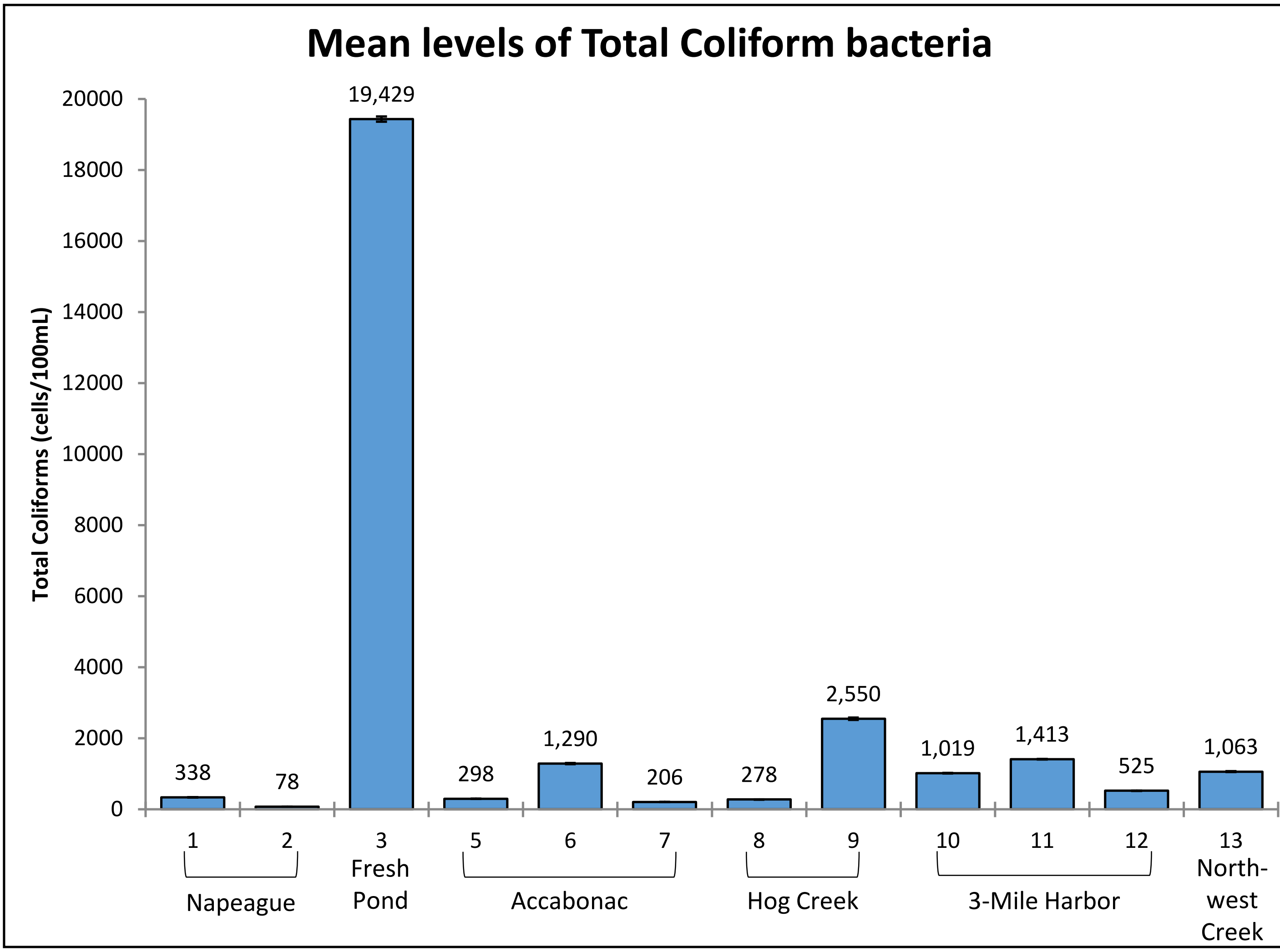


Figure 1: Average total coliform values for April – November 2013.

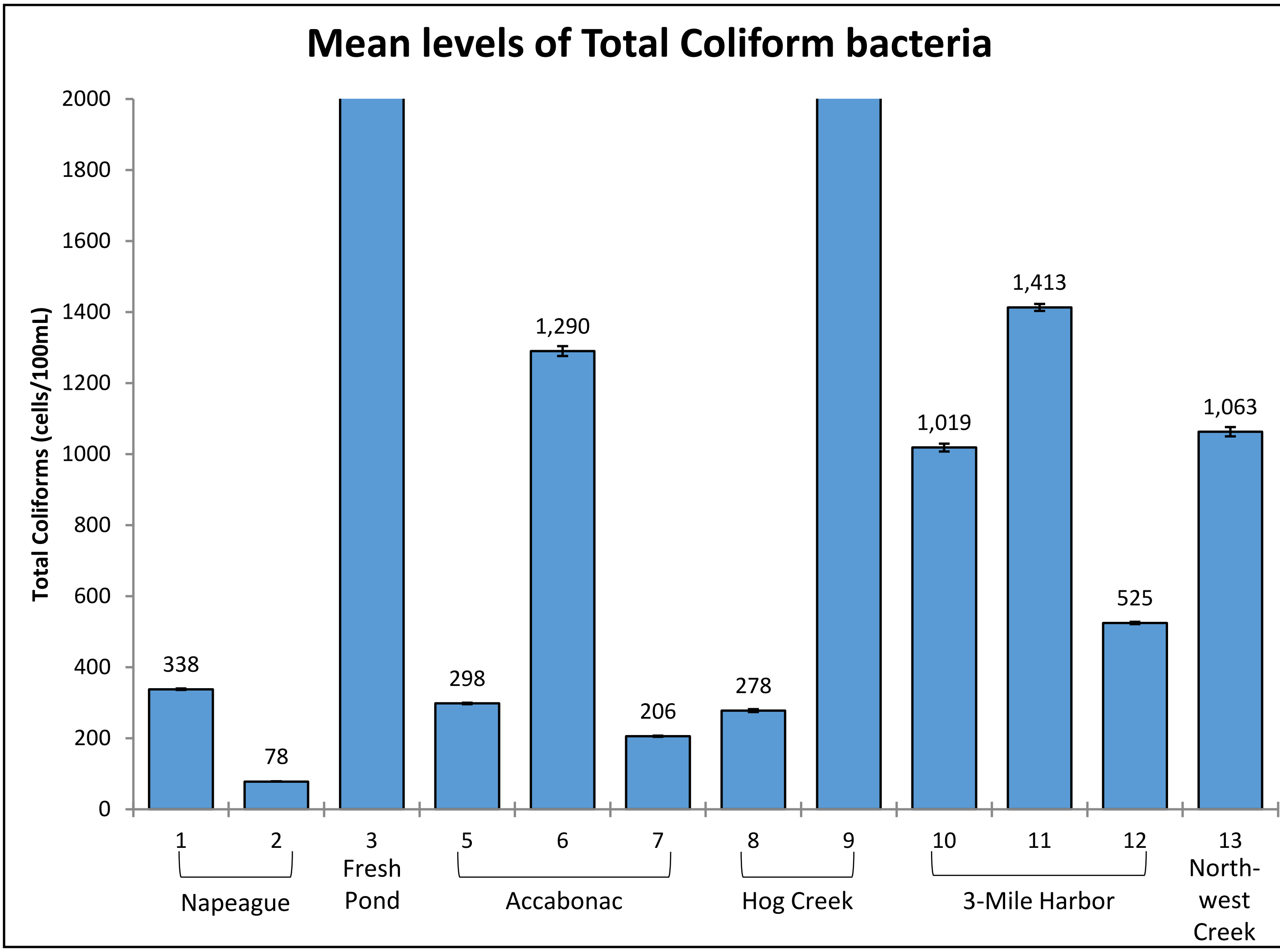


Figure 2: Average total coliform values for April – November 2013, showing lower range of values.

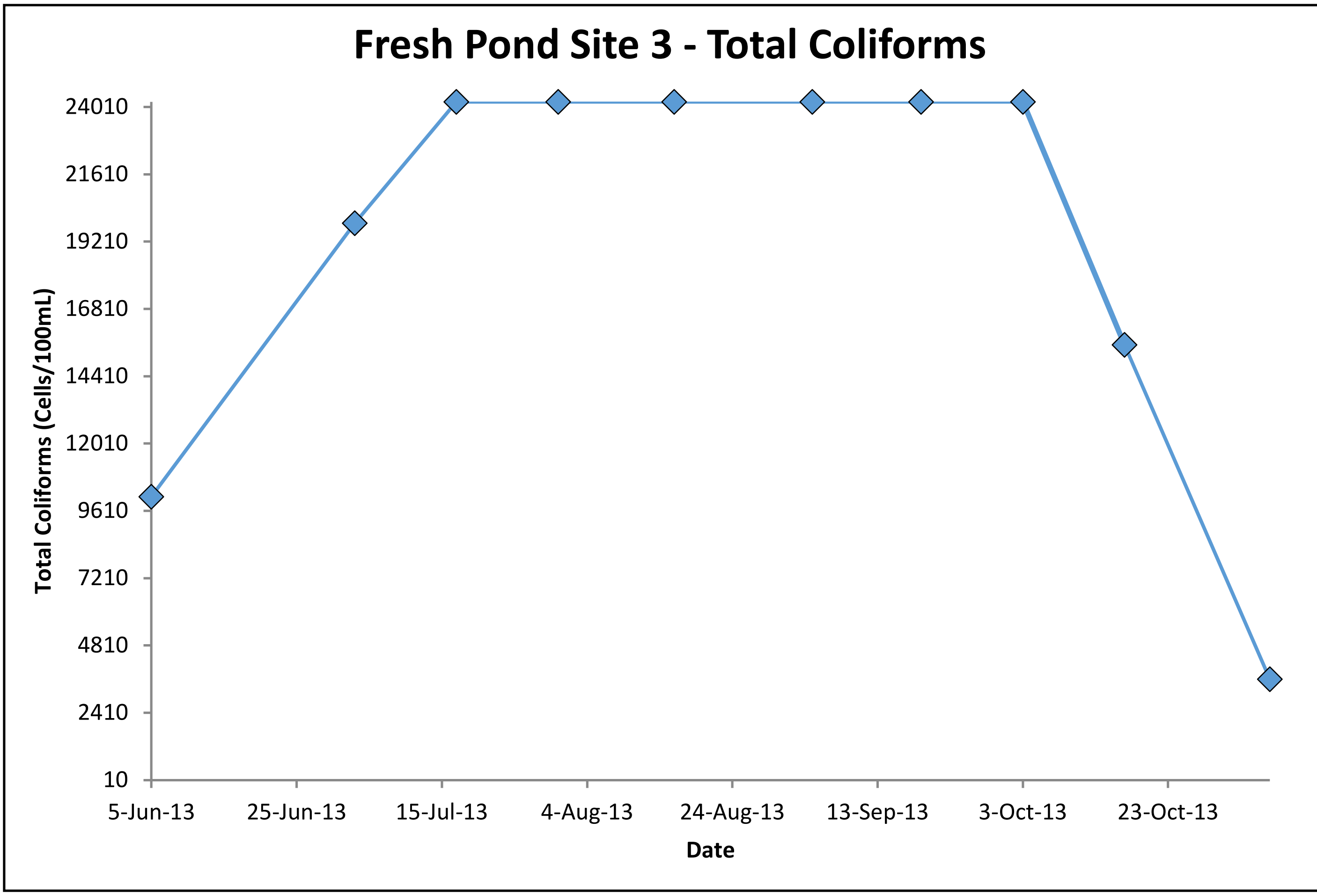


Figure 3: Total coliform values from June – November 2013 for Site 3: the outflow of Fresh Pond, Amagansett. Upper samples have broken the curve.

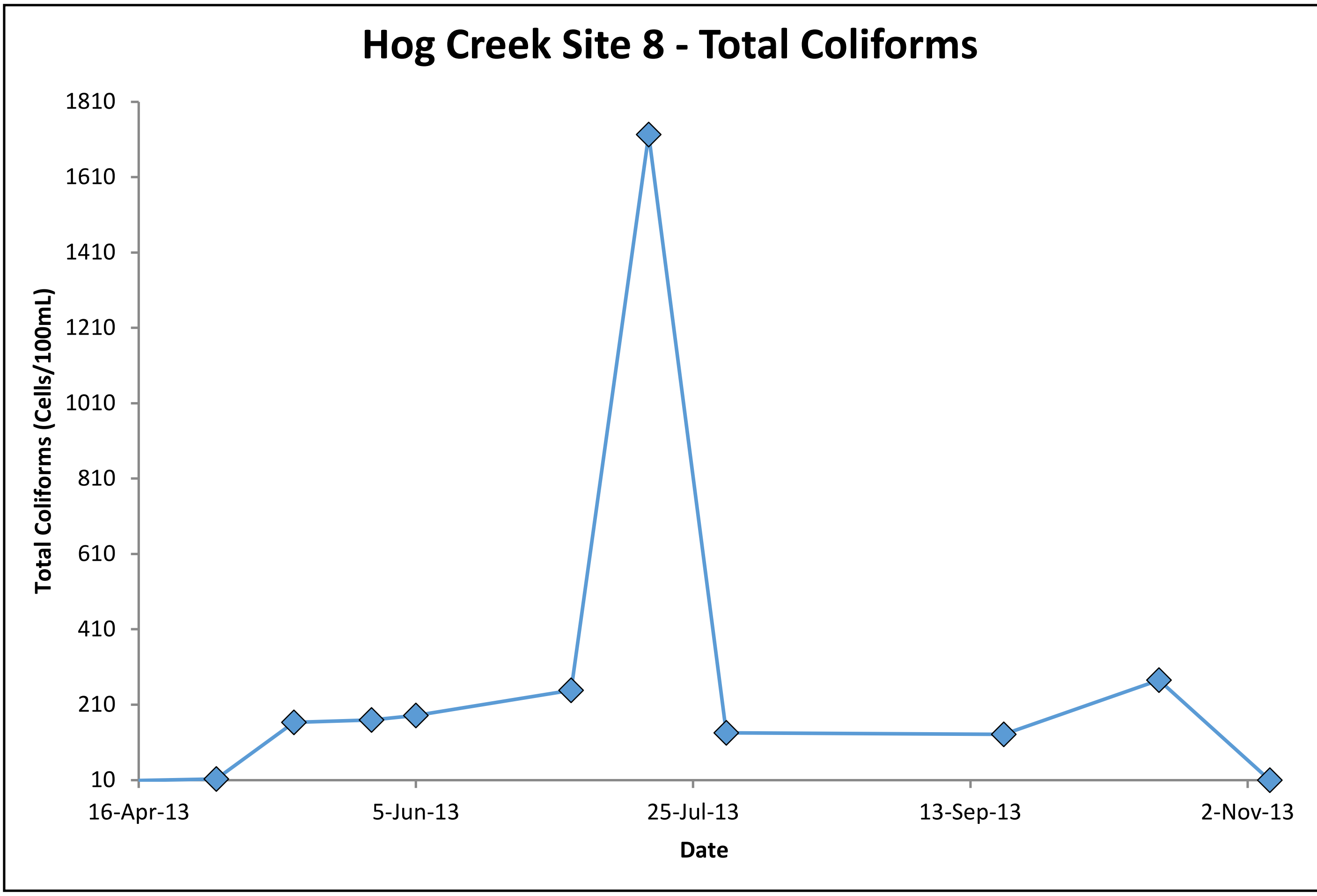


Figure 4: Total coliform values from April – November 2013 for Site 8: the inlet of Hog Creek at the Clearwater Association.

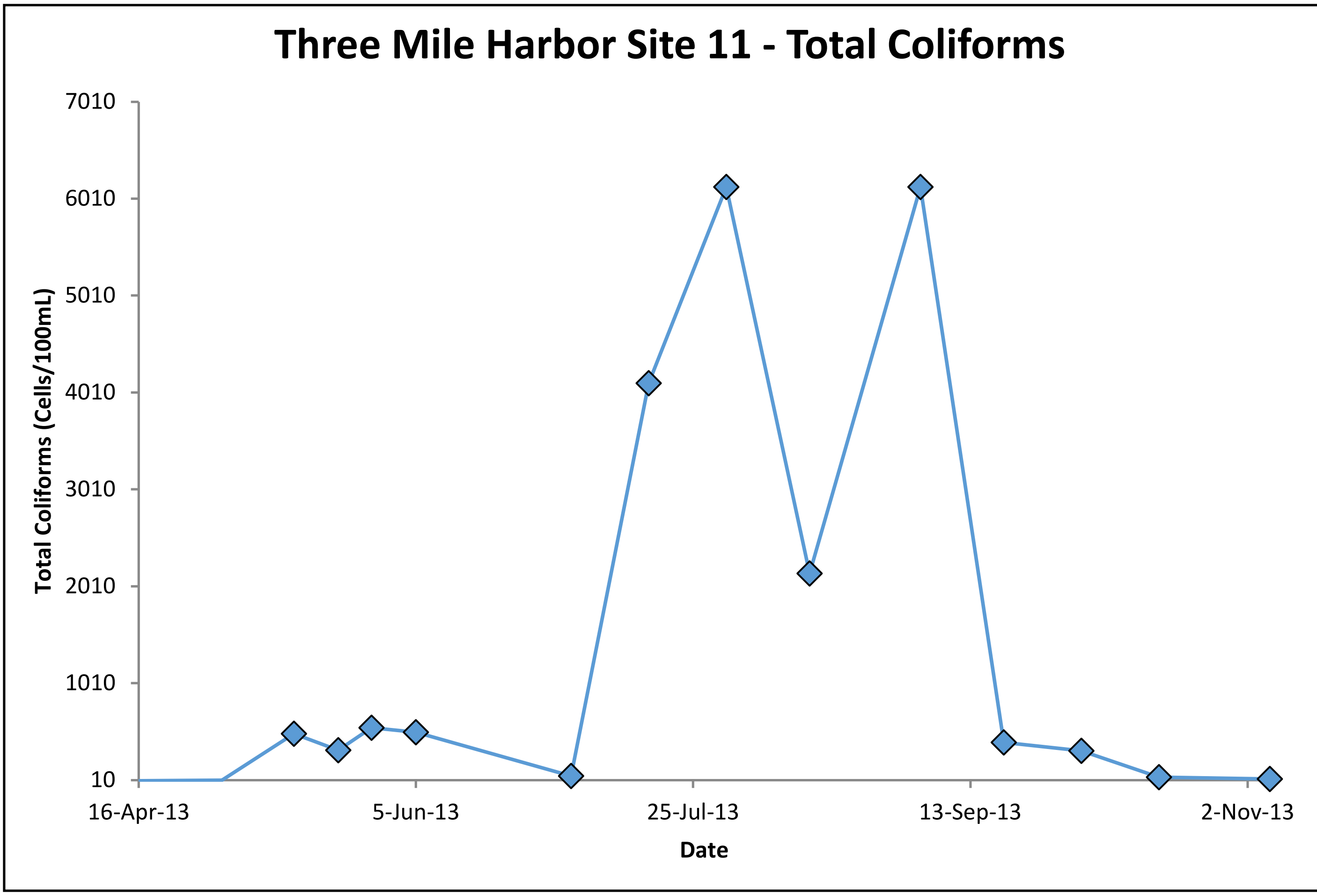


Figure 5: Total coliform values from April – November 2013 for Site 11: Head of the Harbor, Three Mile Harbor.

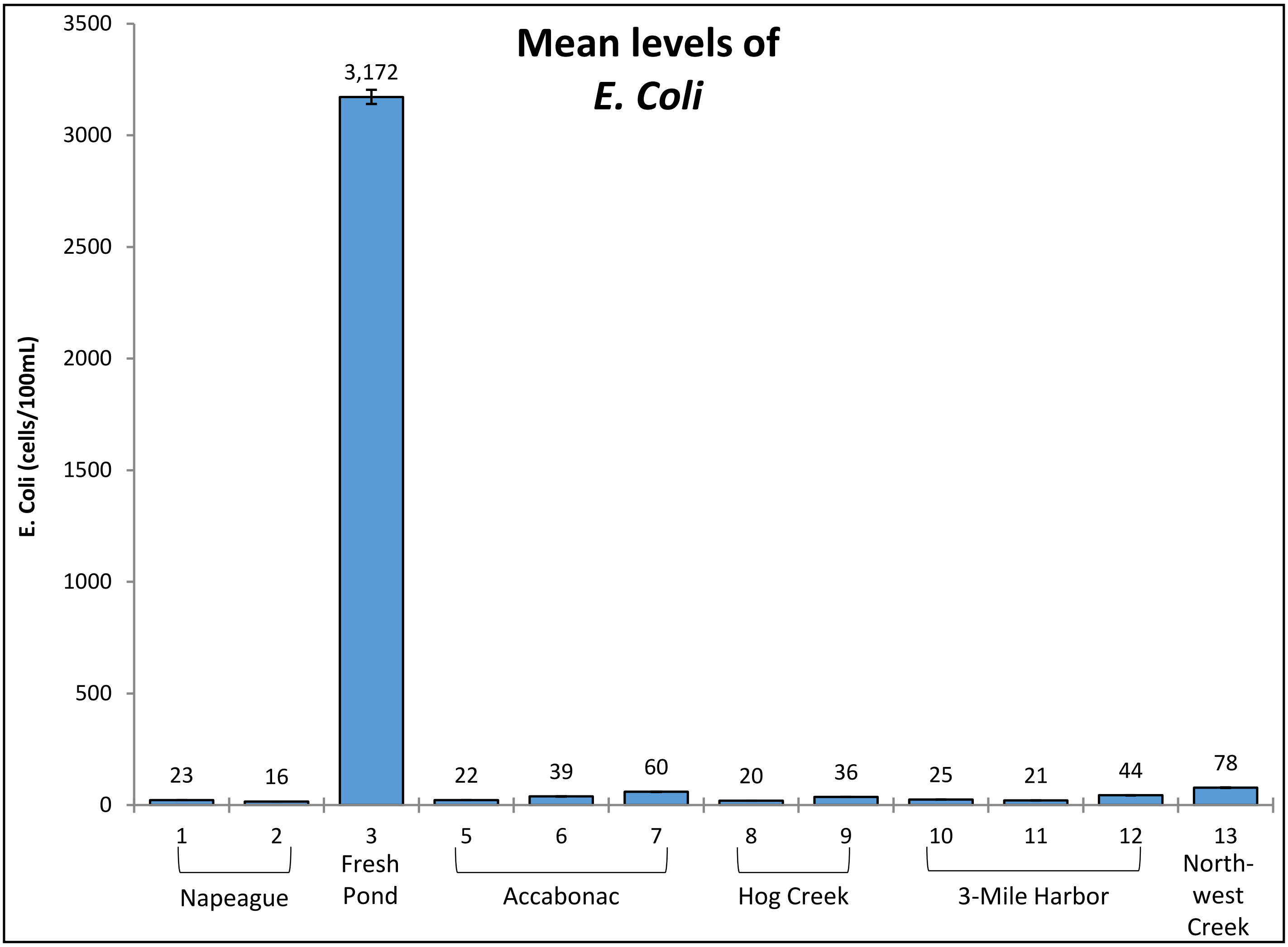


Figure 6: Average *E. coli* values for April – November 2013.

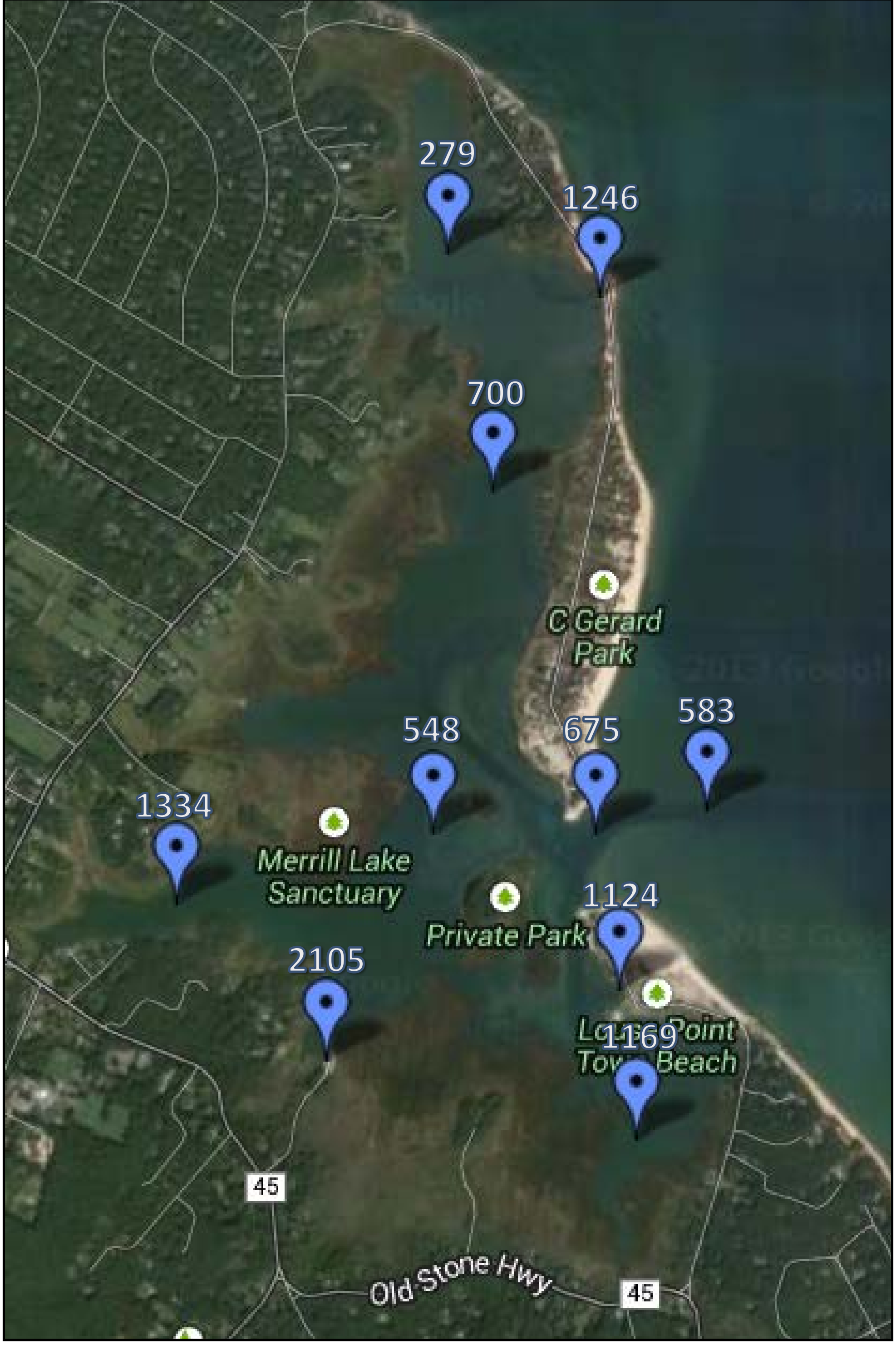


Figure 7: Map of Accabonac Harbor land and cruise sampling sites from September 5th, 2013 with total coliforms values.

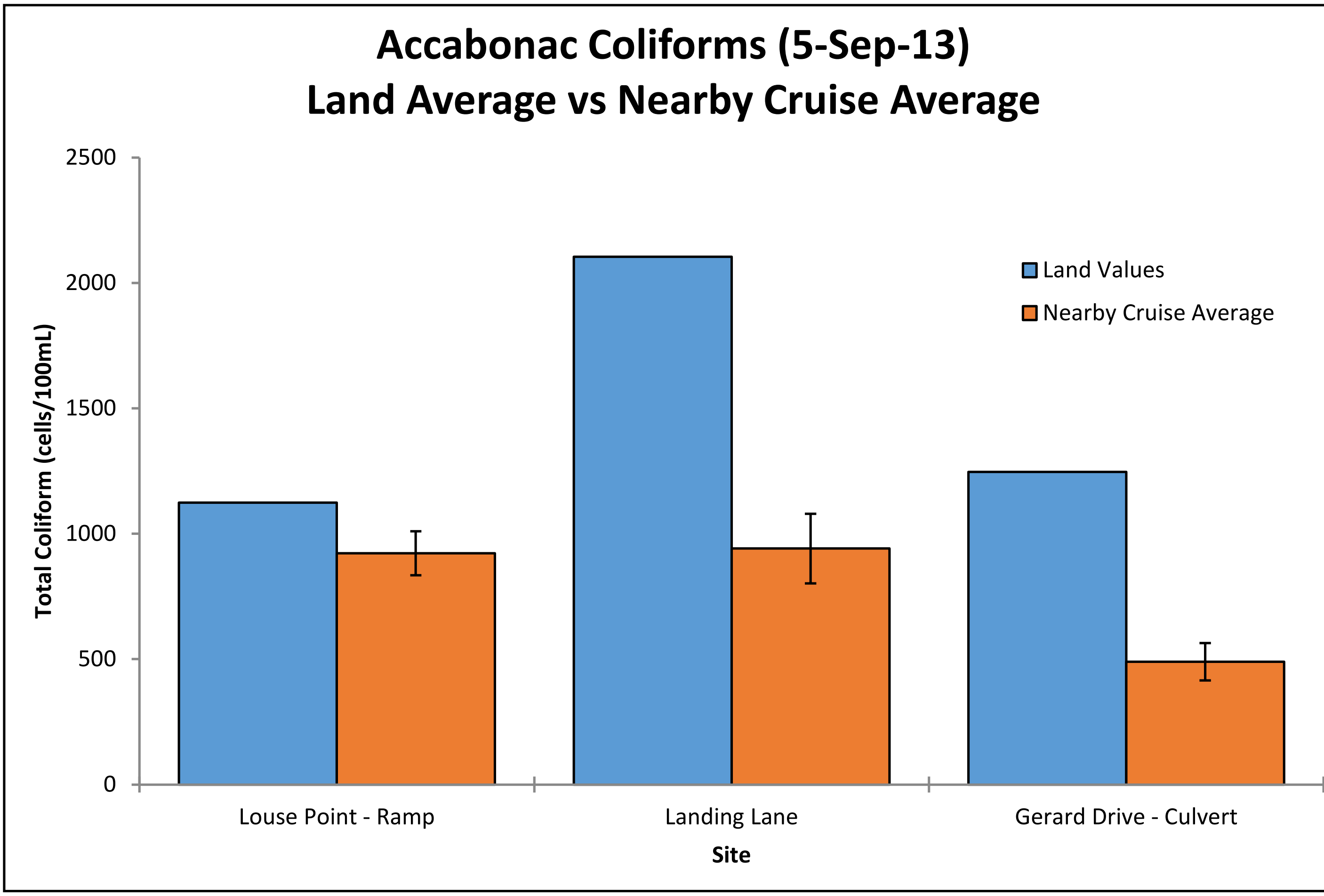


Figure 8: Comparison between land sampling and nearby cruise sampling sites of total coliforms for Accabonac Harbor on September 5th, 2013.

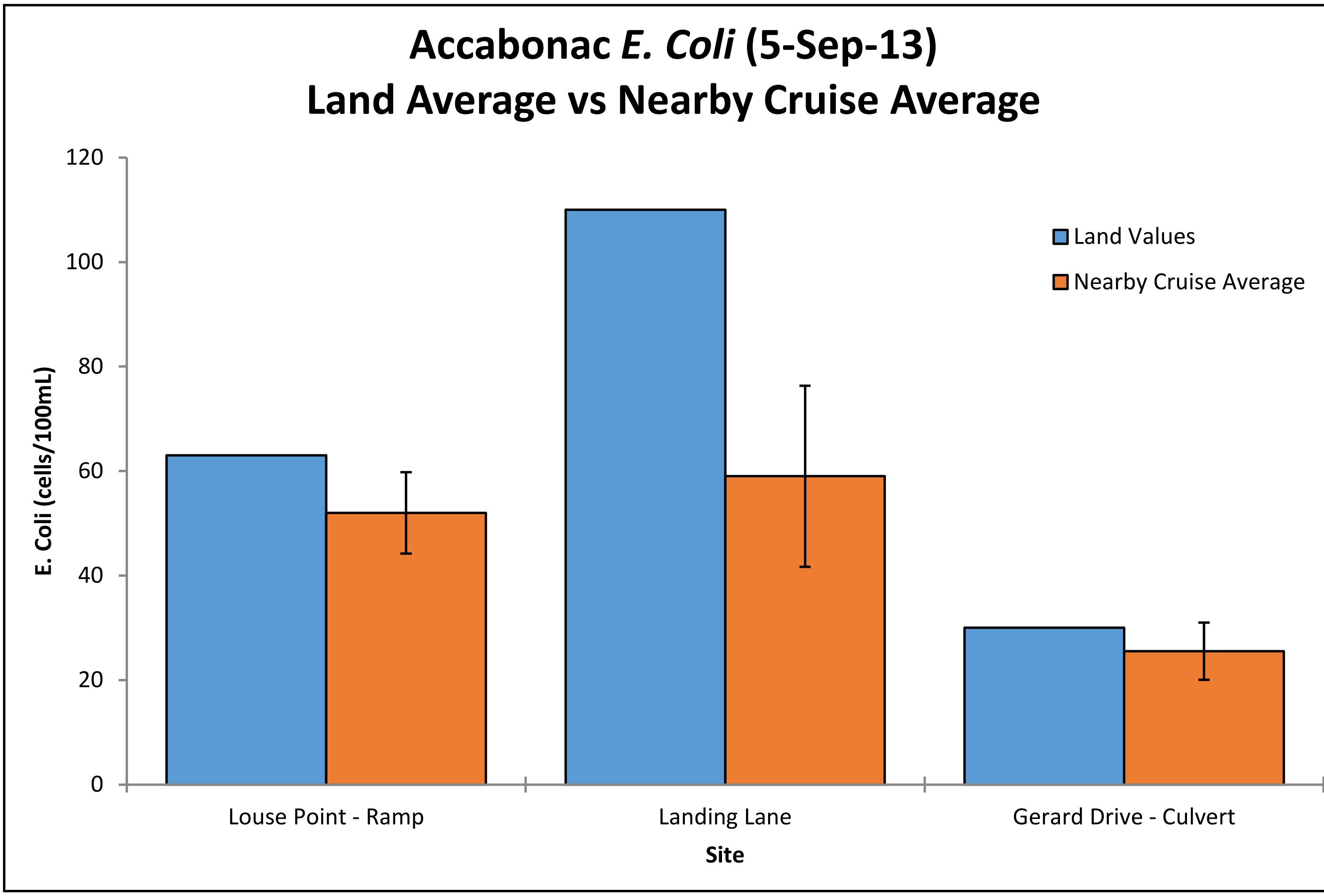


Figure 9: Comparison between land sampling and nearby cruise sampling sites of *E. coli* for Accabonac Harbor on September 5th, 2013.

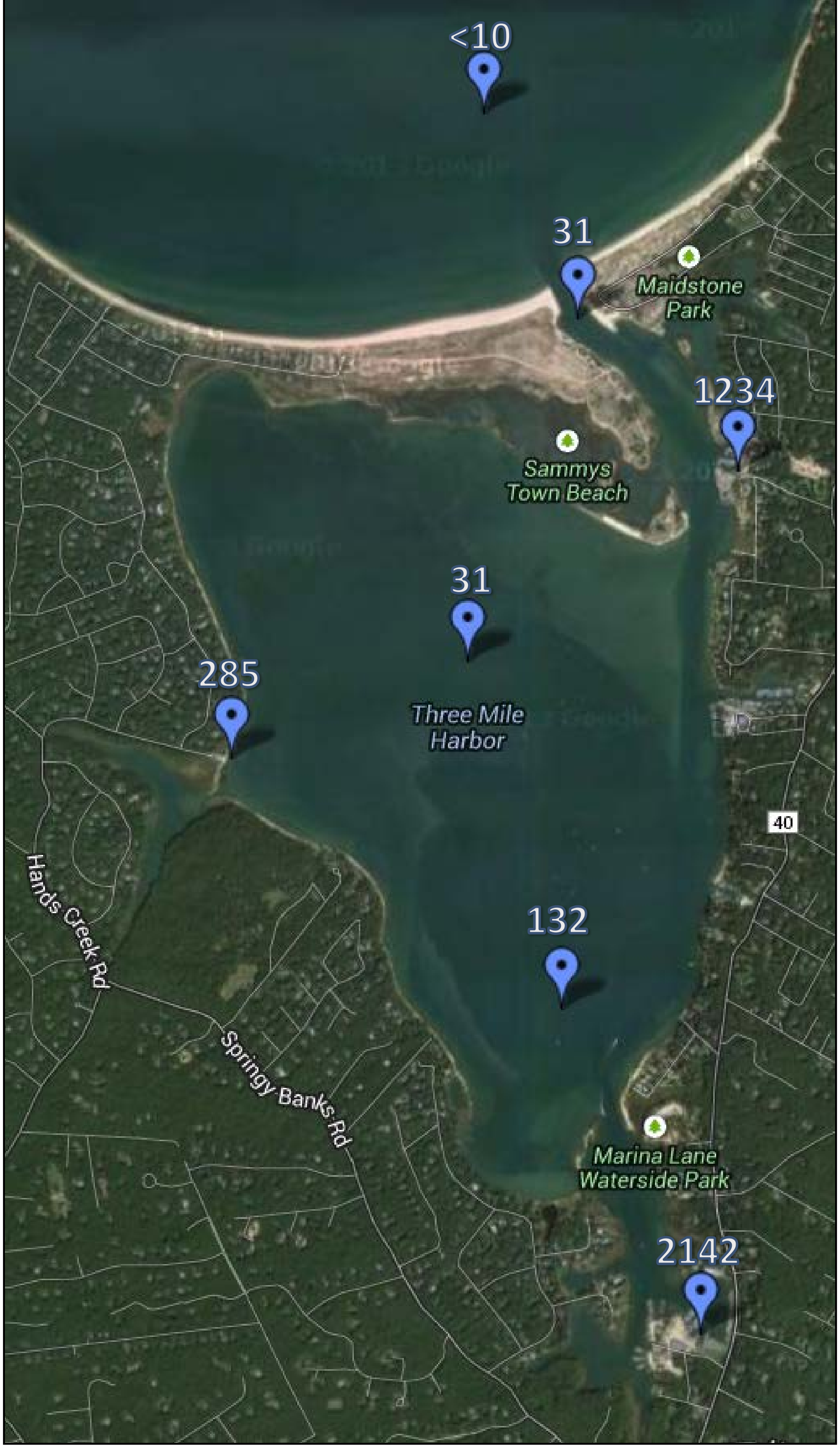


Figure 10: Map of Three Mile Harbor land and cruise sampling sites from August 15th, 2013 with total coliforms values.

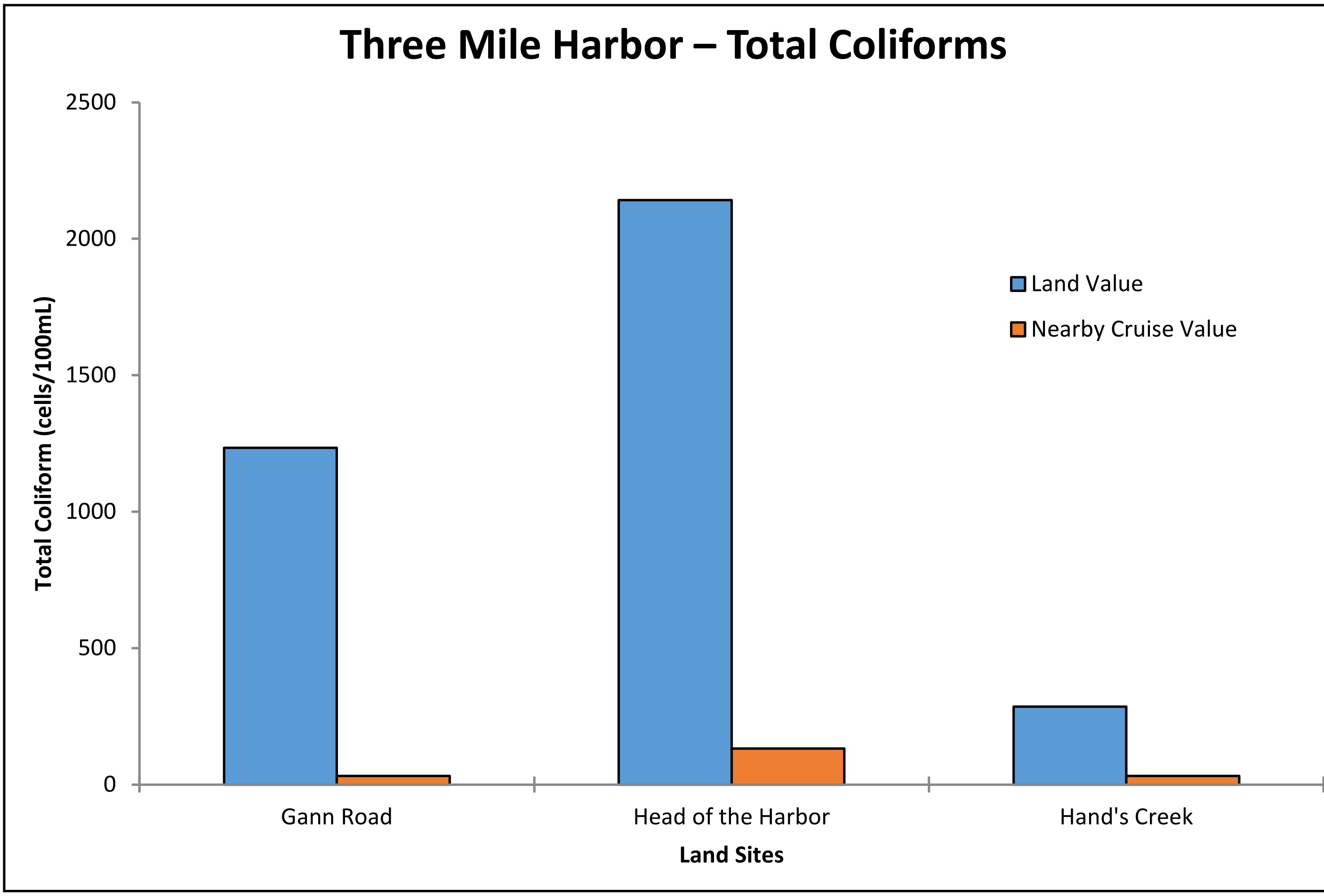


Figure 11: Comparison between land sampling and nearby cruise sampling sites of total coliforms for Three Mile Harbor on August 15th, 2013.

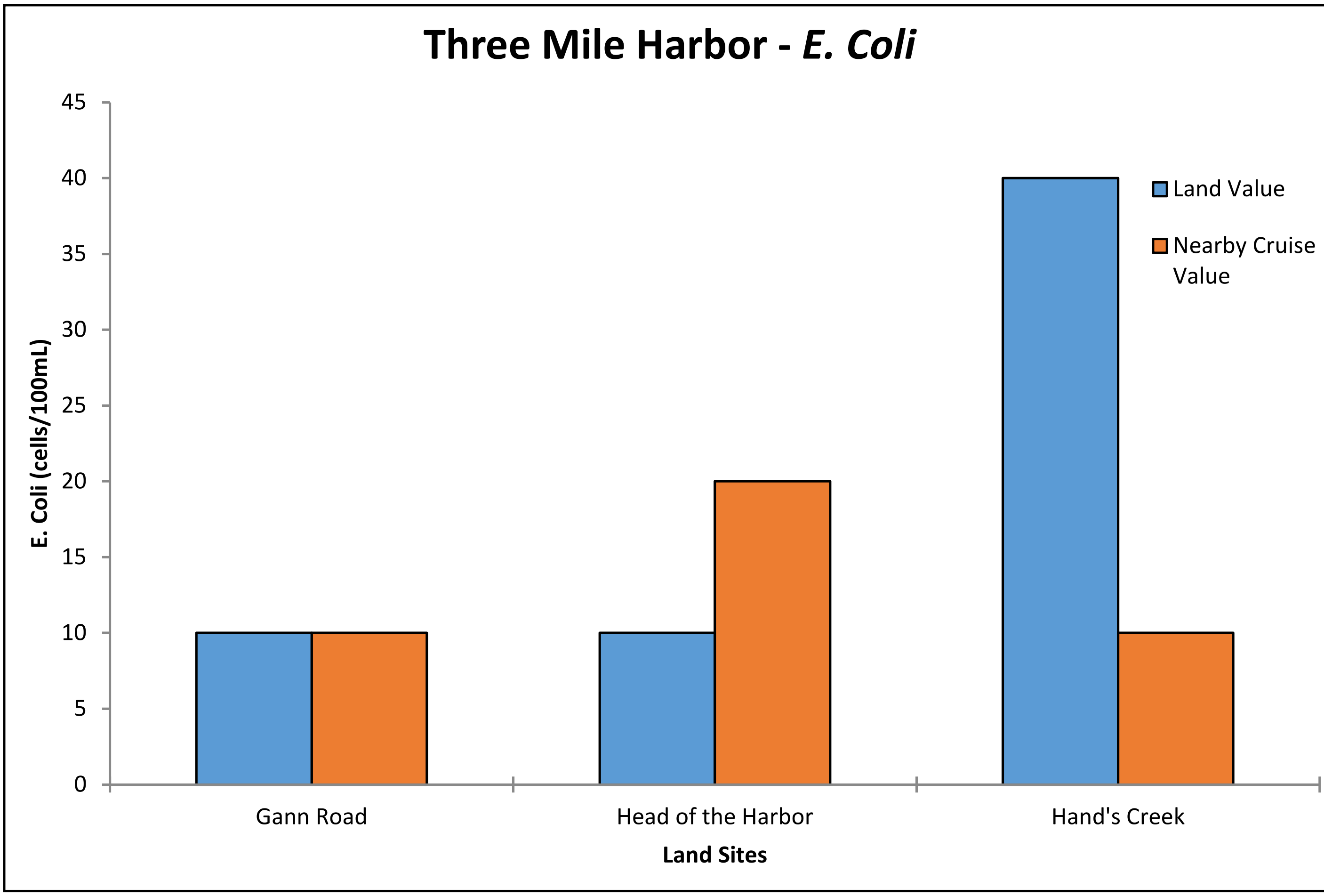


Figure 12: Comparison between land sampling and nearby cruise sampling sites of *E. coli* for Three Mile Harbor on August 15th, 2013.

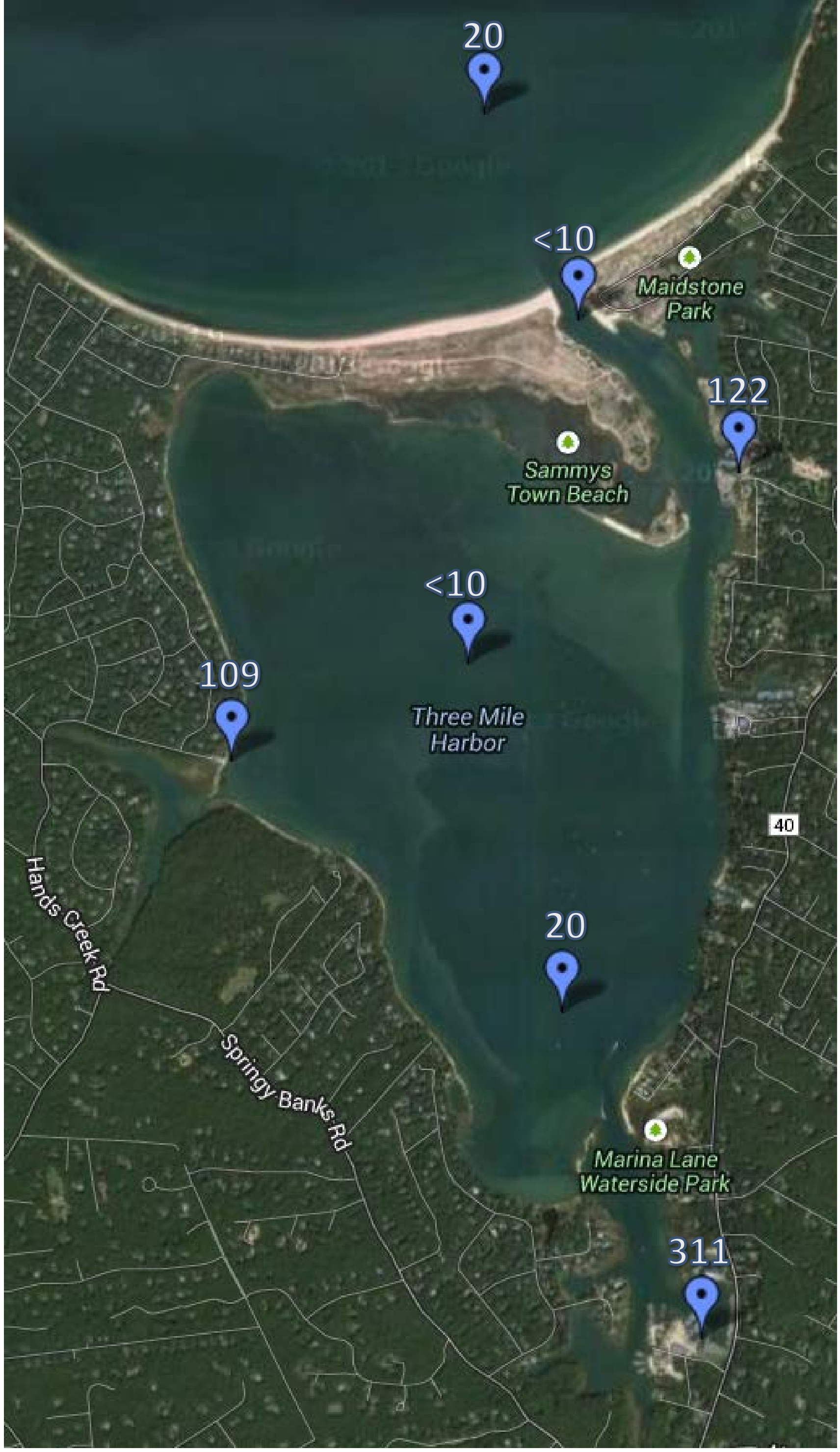


Figure 13: Map of Three Mile Harbor land and cruise sampling sites from October 3rd, 2013 with total coliforms values.

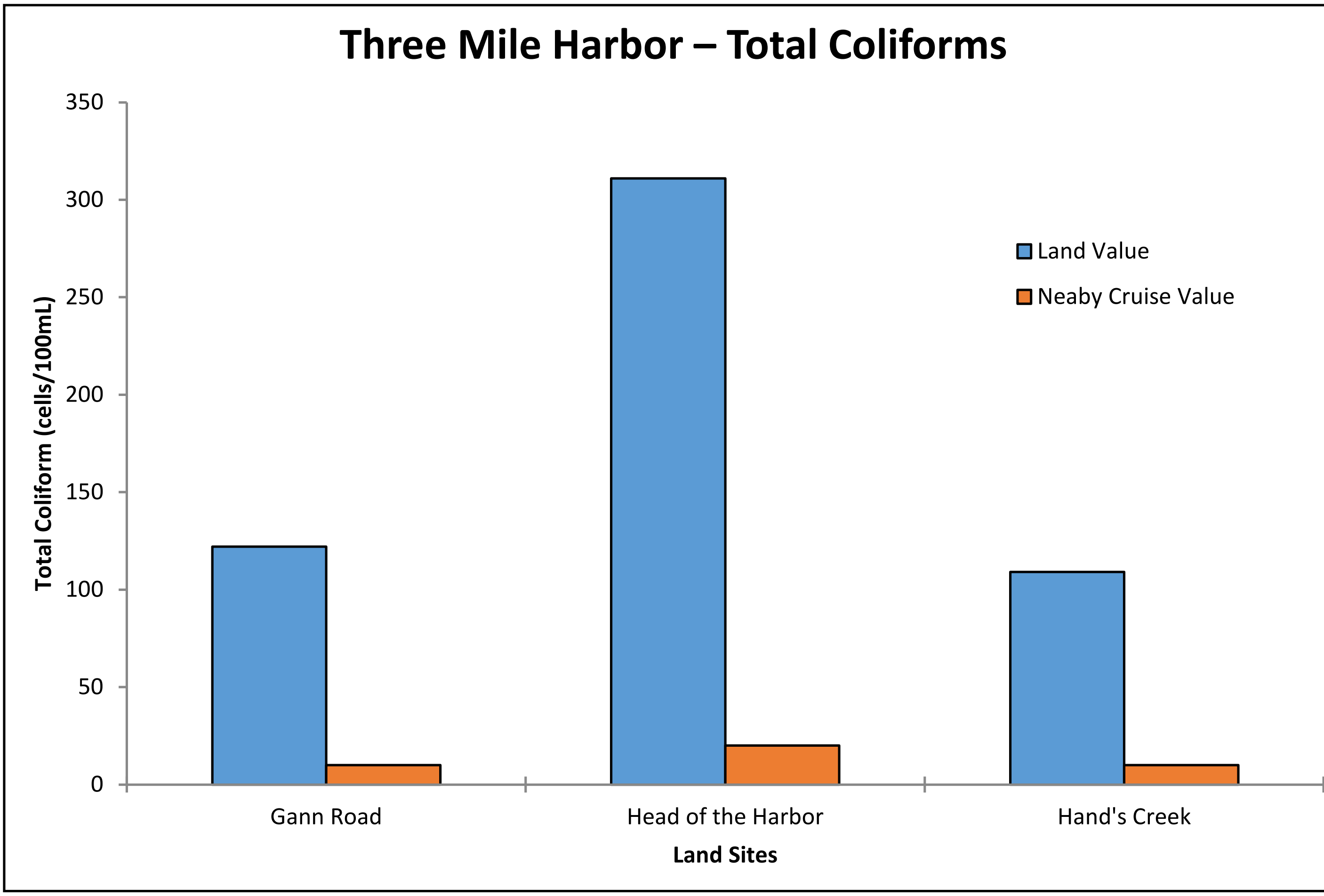


Figure 14: Comparison between land sampling and nearby cruise sampling sites of total coliforms for Three Mile Harbor on October 3rd, 2013.

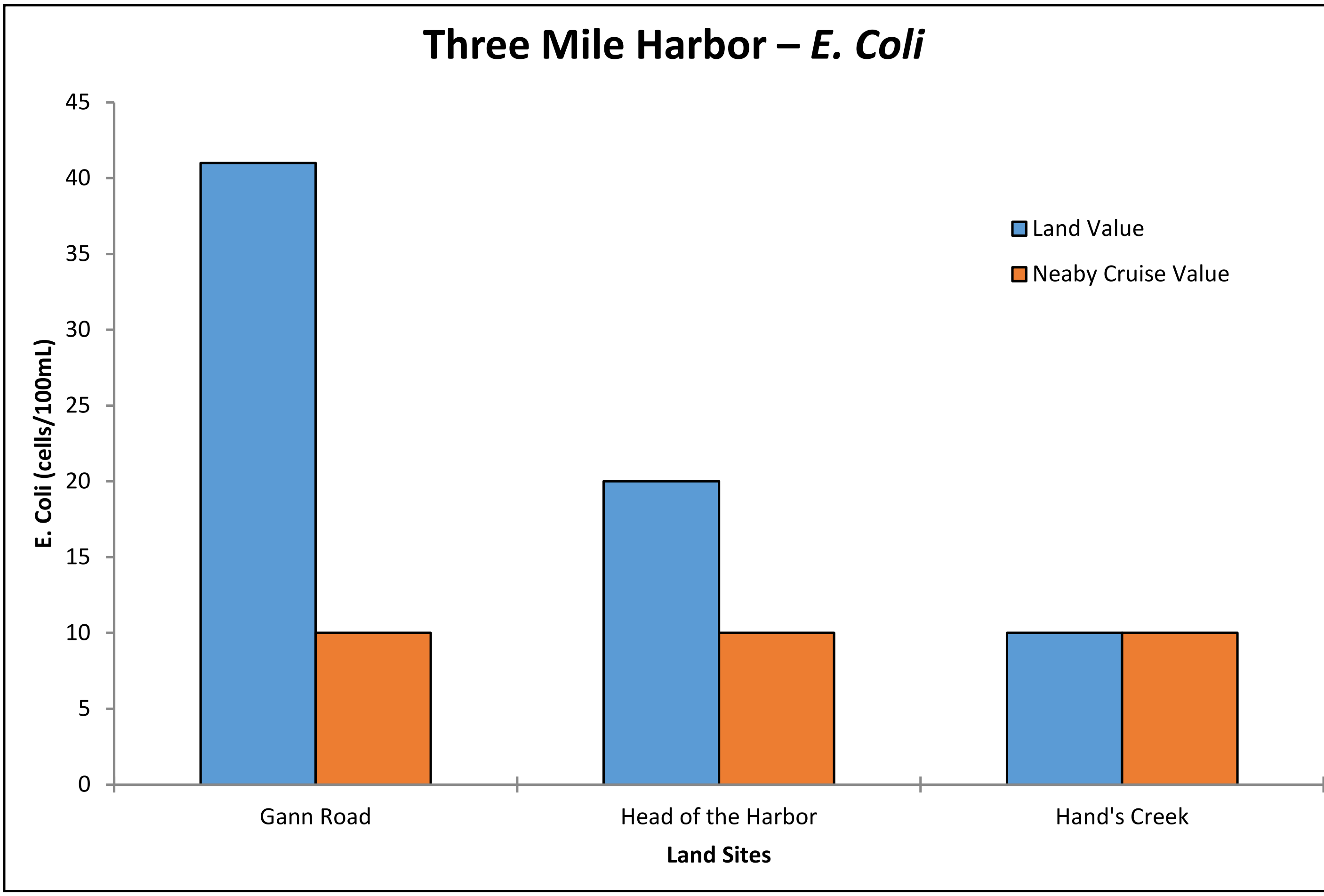


Figure 15: Comparison between land sampling and nearby cruise sampling sites of *E. coli* for Three Mile Harbor on October 3rd, 2013.

Site #	Site Name	Measured Values	DEC Status	
1	Napeague	Over: May-Oct	Open	Should be Seasonally Closed
2	Napeague - Lazy Point	Over: Jul-Sep	Open	Should be Seasonally Closed
3	Fresh Pond – Outlet	Over	Uncertified	Closed and Confirmed
4	Fresh Pond	Over	Uncertified	Closed and Confirmed
5	Accabonac - Louse Point	Over: May-Sep	Seasonally Uncertified: May 1 – Nov 30	Closed and Confirmed
6	Accabonac - Landing Lane	Over: Apr-Oct	Seasonally Uncertified: May 1 – Nov 30	Closed and Confirmed
7	Accabonac - Gerard Drive	Over: May-Sep	Open	Should be Seasonally Closed
8	Hog Creek – Clearwater	Over: May-Oct	Seasonally Uncertified: May 1 – Nov 30	Closed and Confirmed
9	Hog Creek - Isle of Wight	Over: Apr-Oct	Seasonally Uncertified: May 1 – Nov 30	Closed and Confirmed
10	Three Mile Harbor - Gann Road	Over: May-Oct	Seasonally Uncertified: May 15 – Oct 15	Closed and Confirmed
11	Three Mile Harbor - Head of the Harbor	Under: Nov-Apr	Uncertified	Could be Seasonally Open
12	Three Mile Harbor - Hand's Creek	Over: May-Nov	Seasonally Uncertified: May 1 – Nov 30	Closed and Confirmed
13	Northwest Creek	Under: Apr-May	Uncertified	Could be Seasonally Open
16	Georgica Cove	Over	Uncertified	Closed and Confirmed

Figure 16: Table comparing measured values with NYSDEC shellfish bed closures.

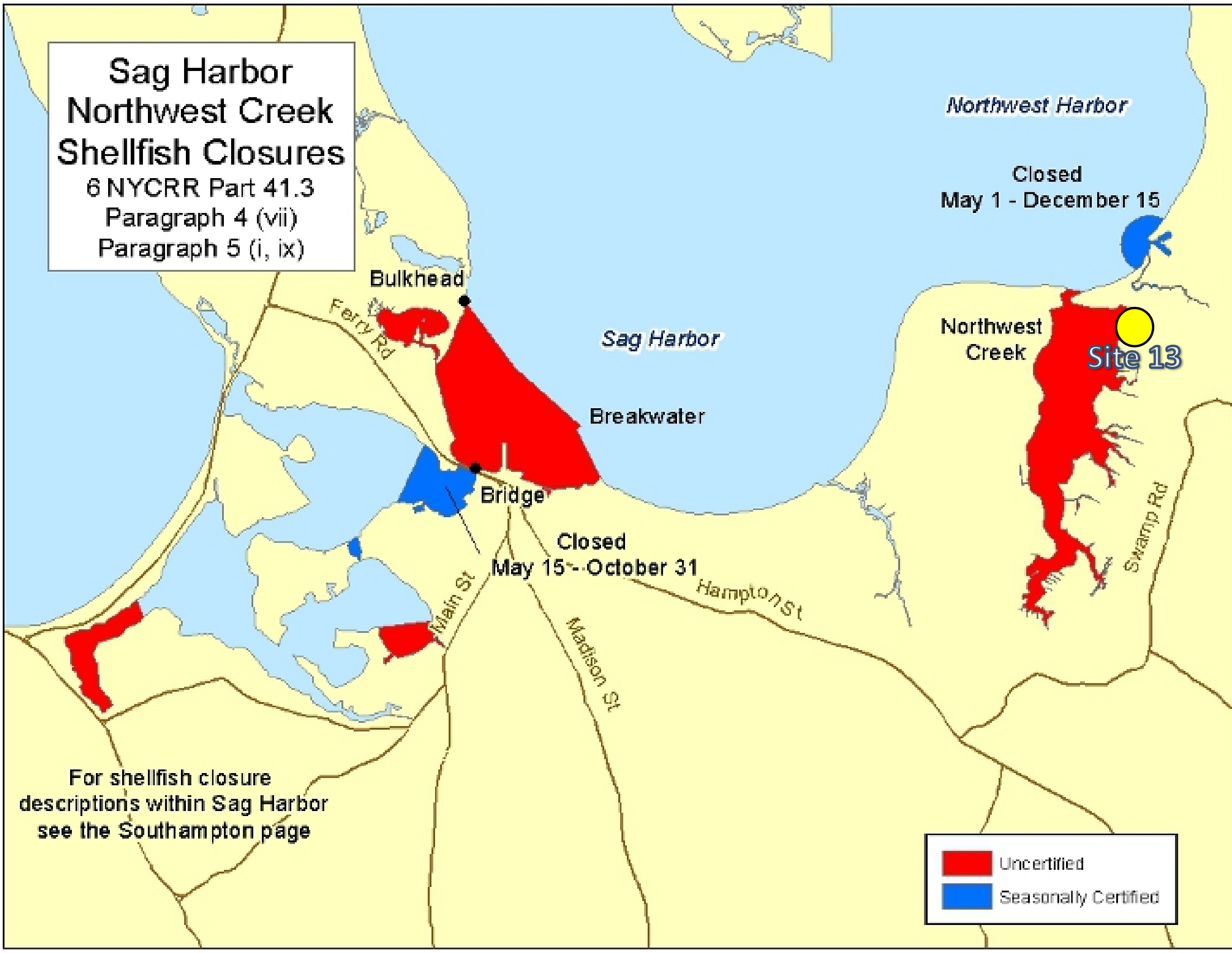


Figure 17: NYSDEC shellfish closures for Sag Harbor and Northwest Creek. Total coliforms for Site 13 pass the safe limit June through November. Suggesting it may be seasonally opened.

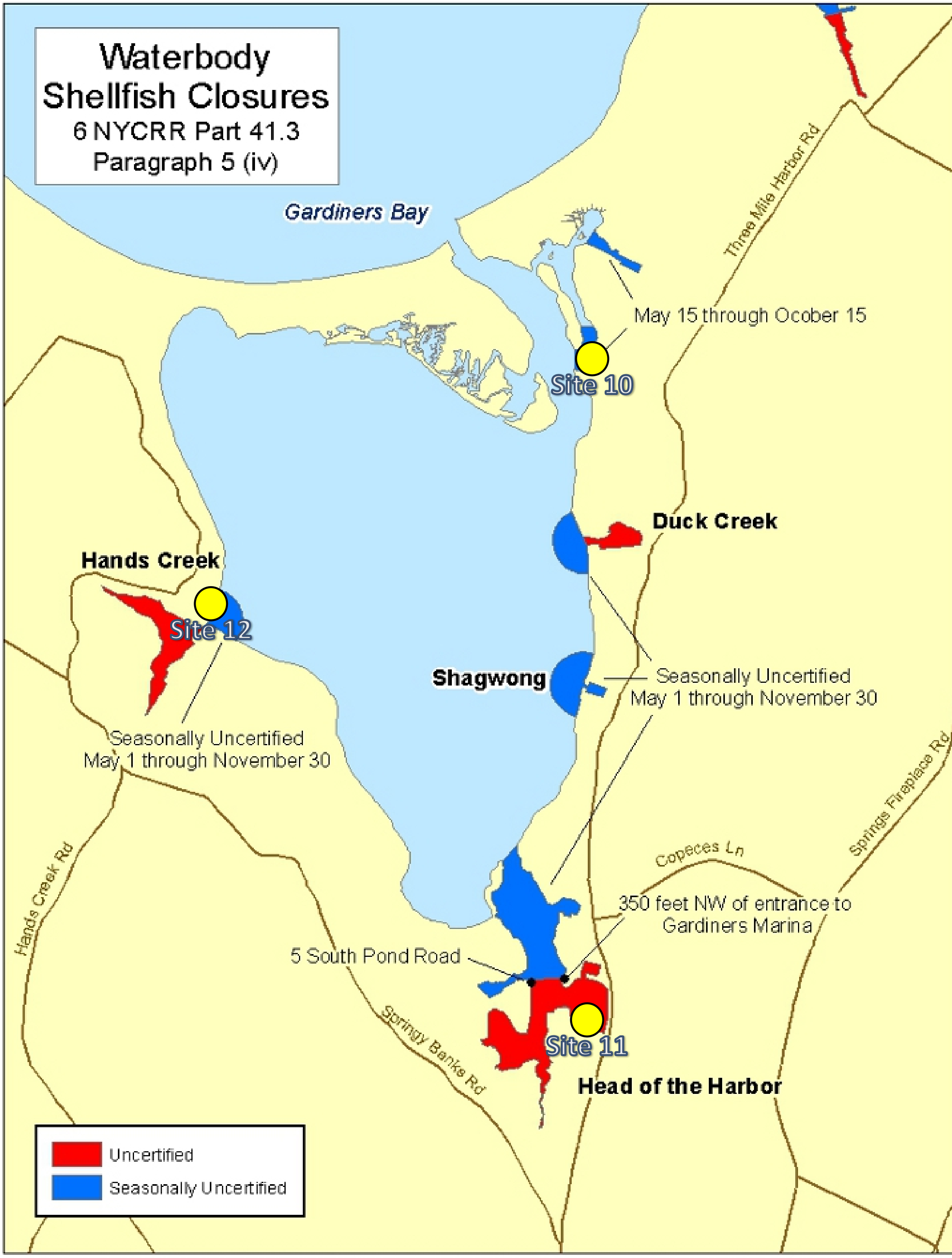


Figure 18: NYSDEC shellfish closures for Three Mile Harbor. Seasonal closures for Sites 10 and 12 were supported. Total coliforms for Site 11 passed the safety limit May through October. Suggesting it may be seasonally opened.

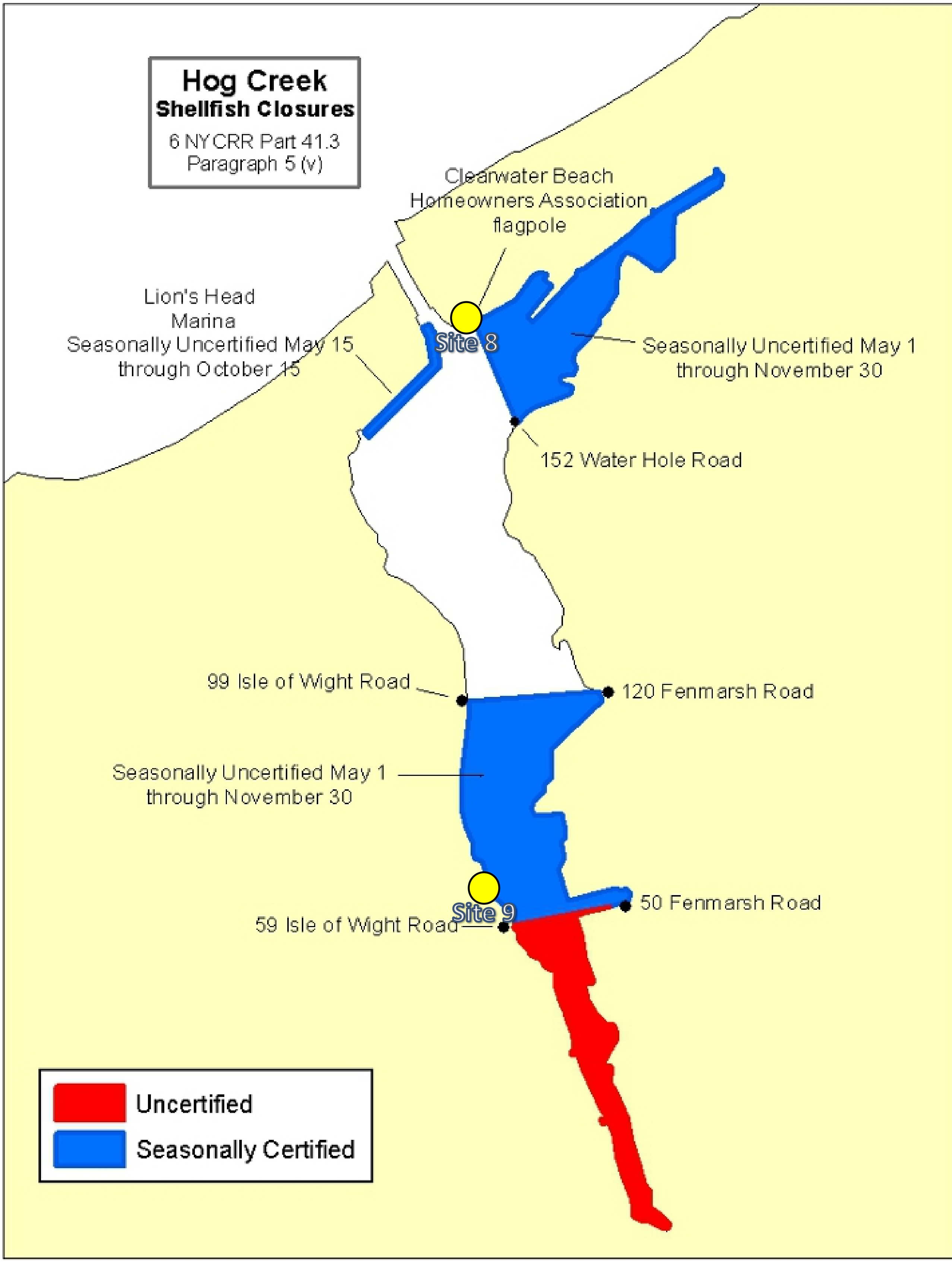


Figure 19: NYSDEC shellfish closures for Hog Creek. Seasonal closures for both sites are supported.

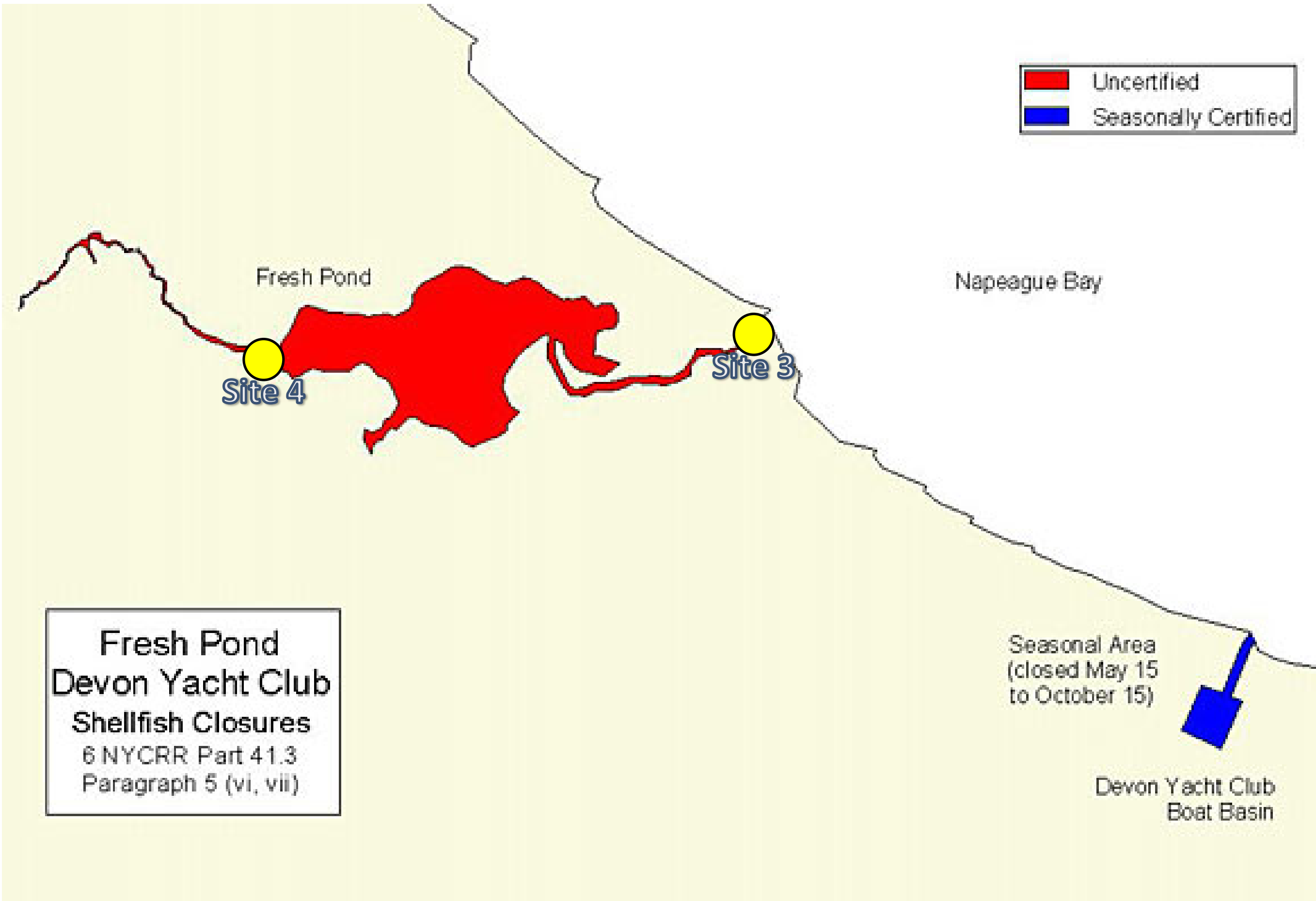


Figure 20: NYSDEC shellfish closures for Fresh Pond. Closure at both sites is supported.

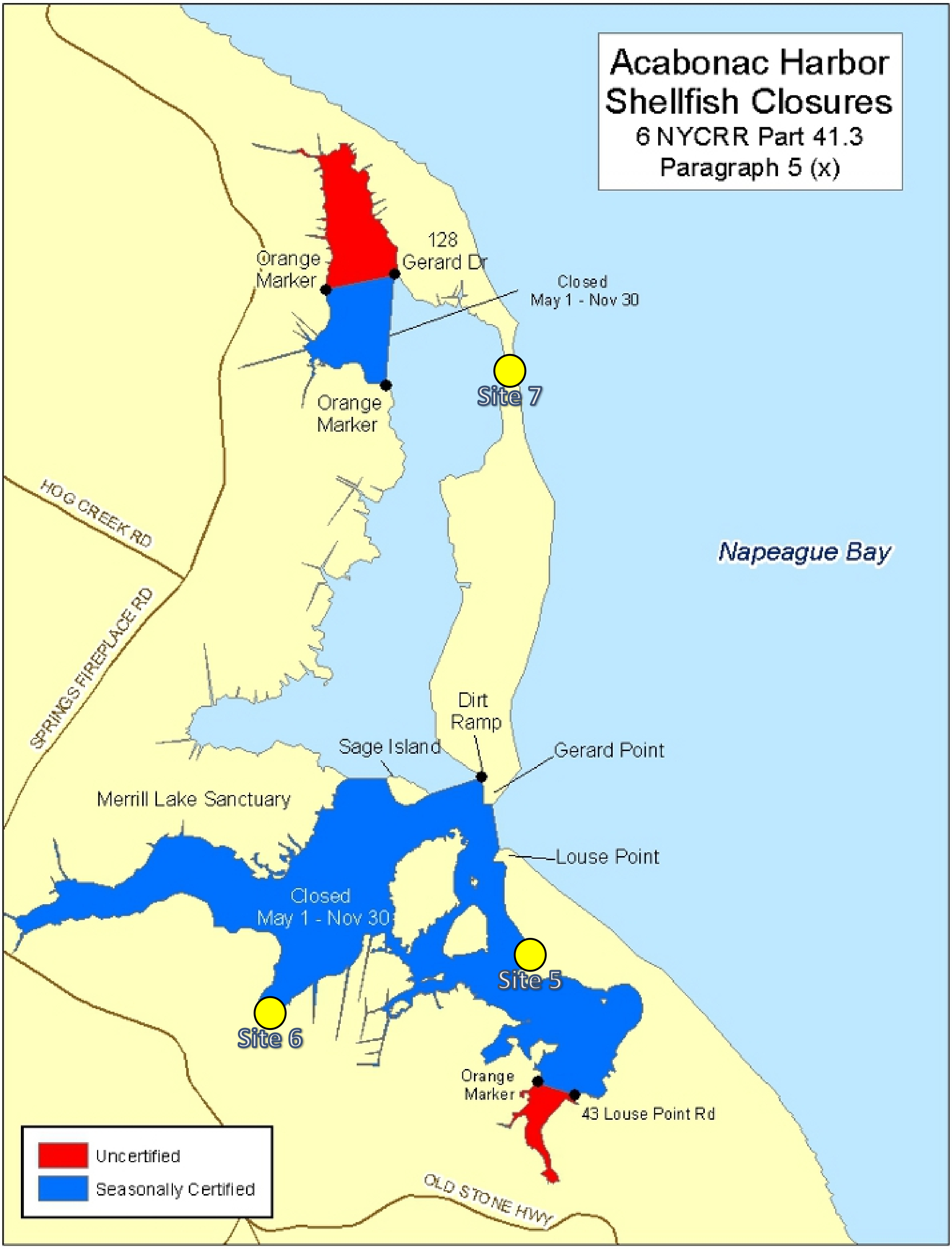


Figure 21: NYSDEC shellfish closures for Accabonac Harbor. Seasonal closure of Sites 5 and 6 is supported. Total coliforms for Site 7 pass the safe limit May through September, suggesting it should be seasonally closed.

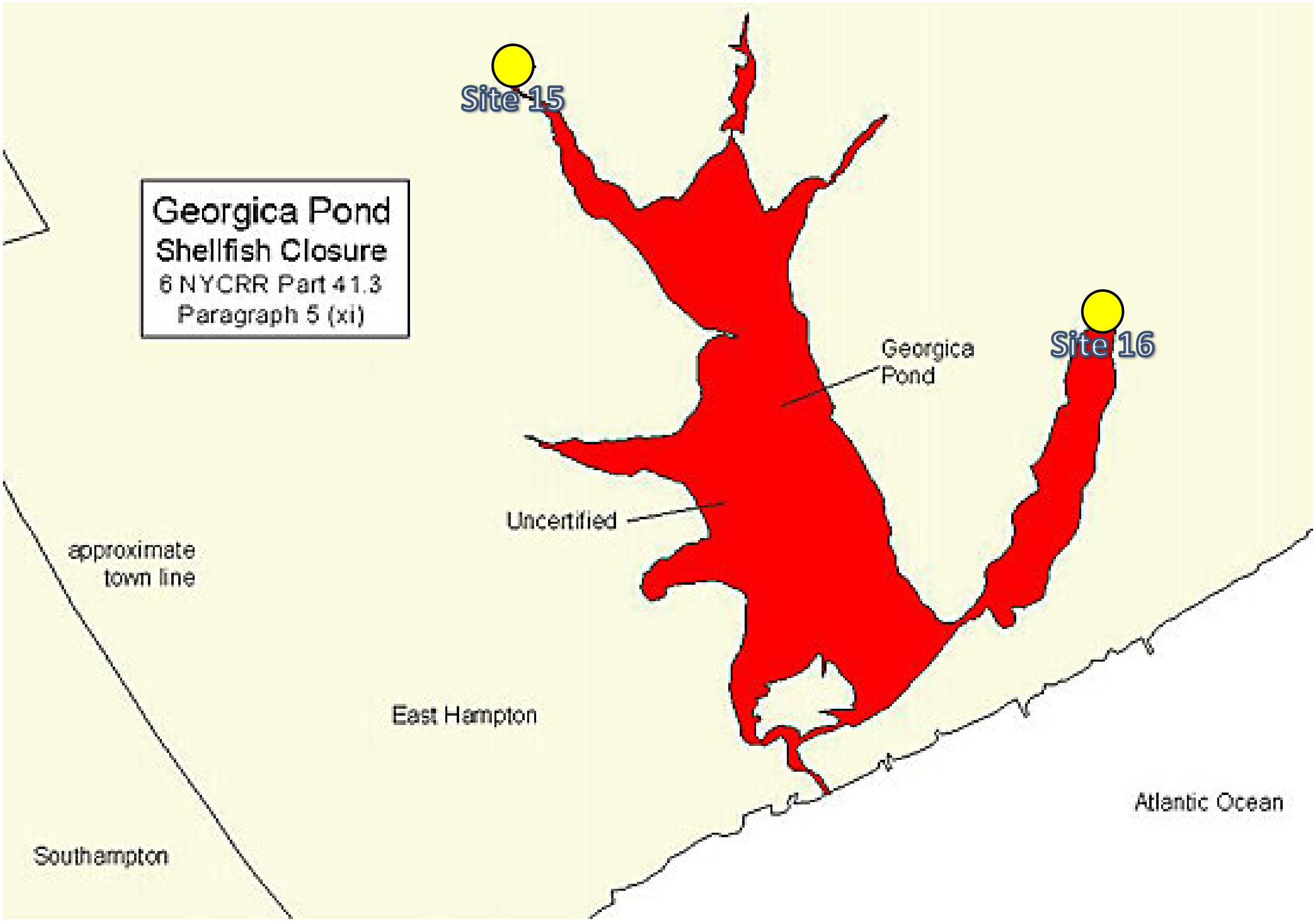


Figure 22: NYSDEC shellfish closures for Georgica Pond.

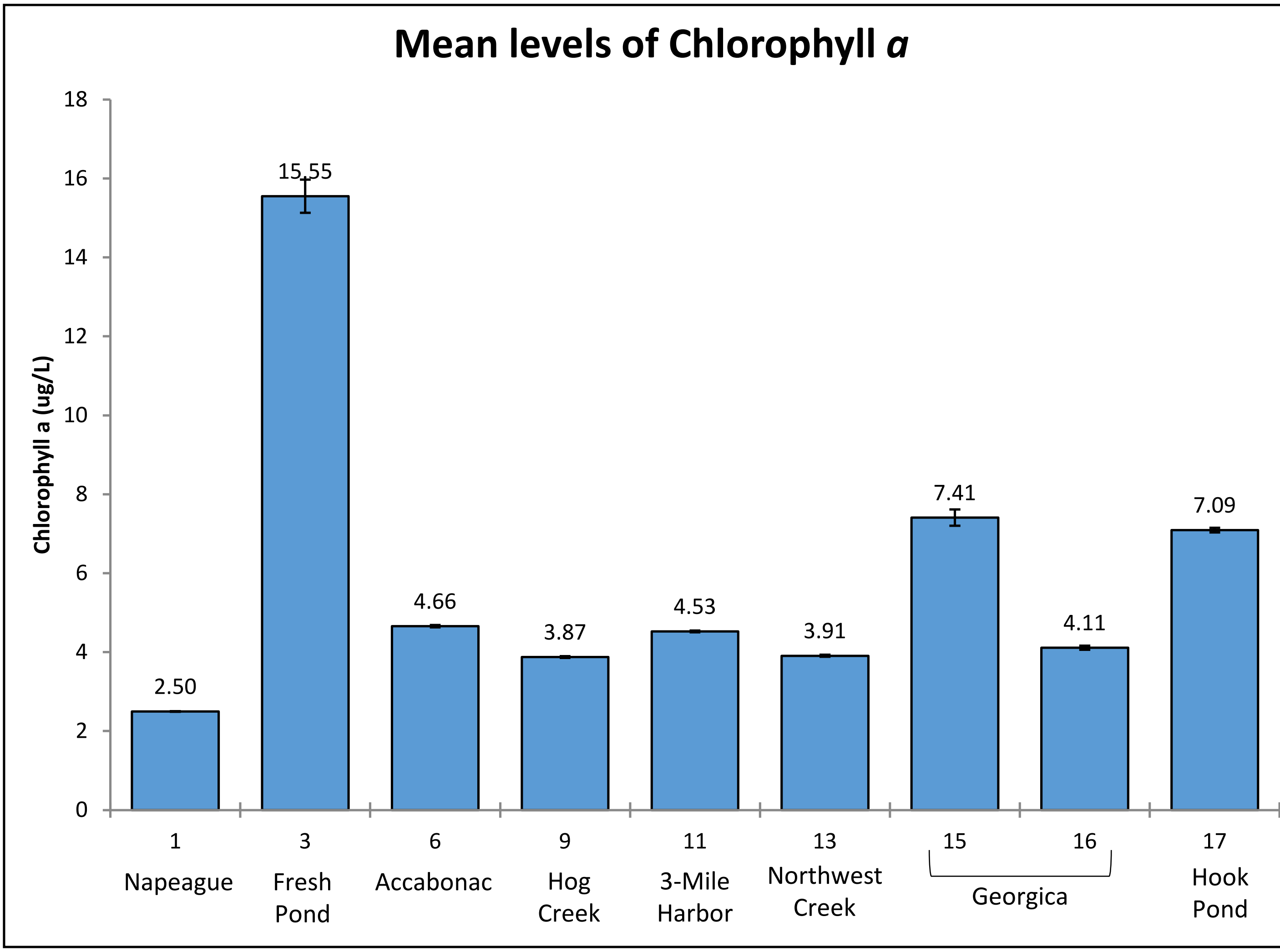


Figure 23: Average chlorophyll a values for April – November 2013.

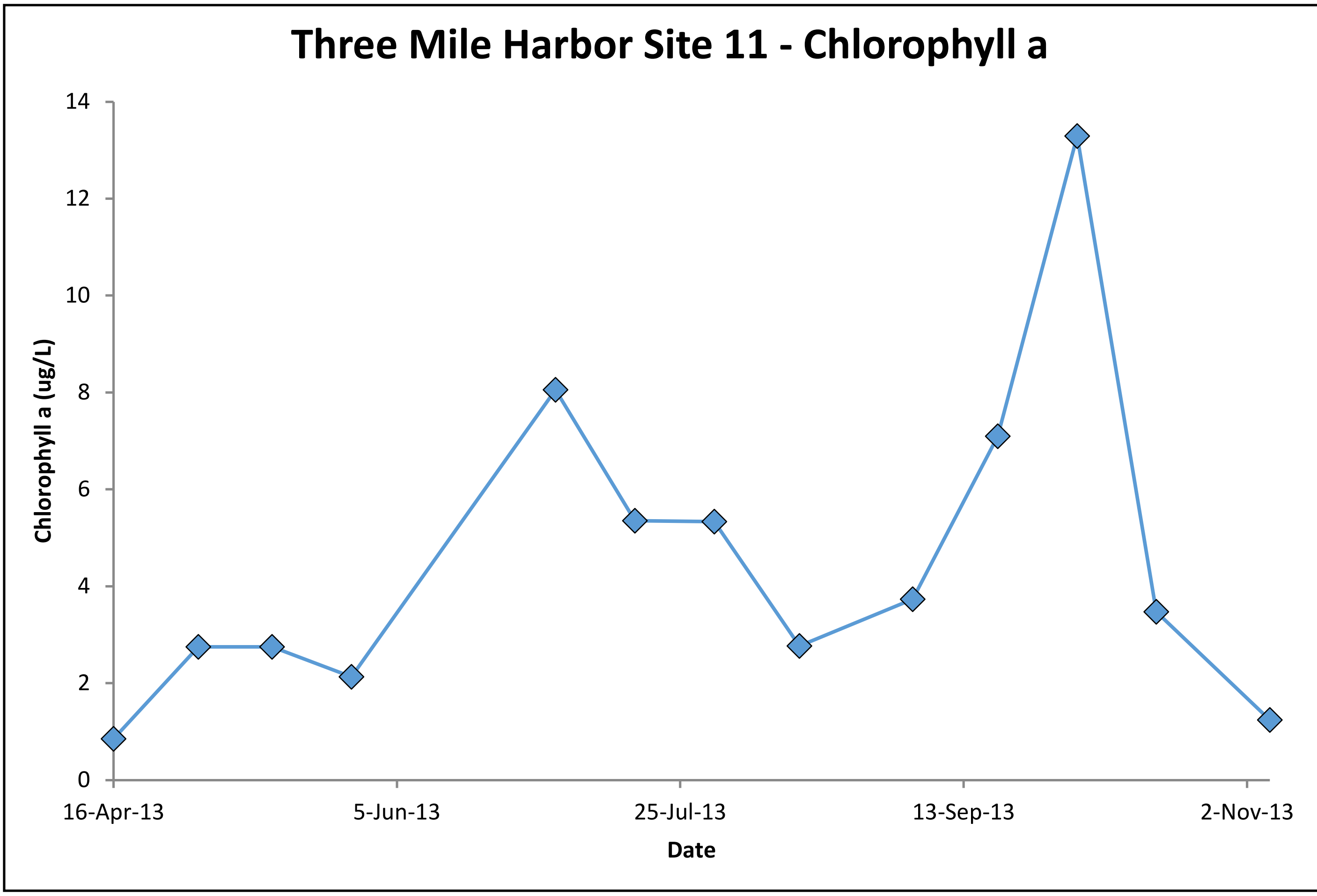


Figure 24: Chlorophyll a values from July – November 2013 for Site 11: Head of the Harbor, Three Mile Harbor.

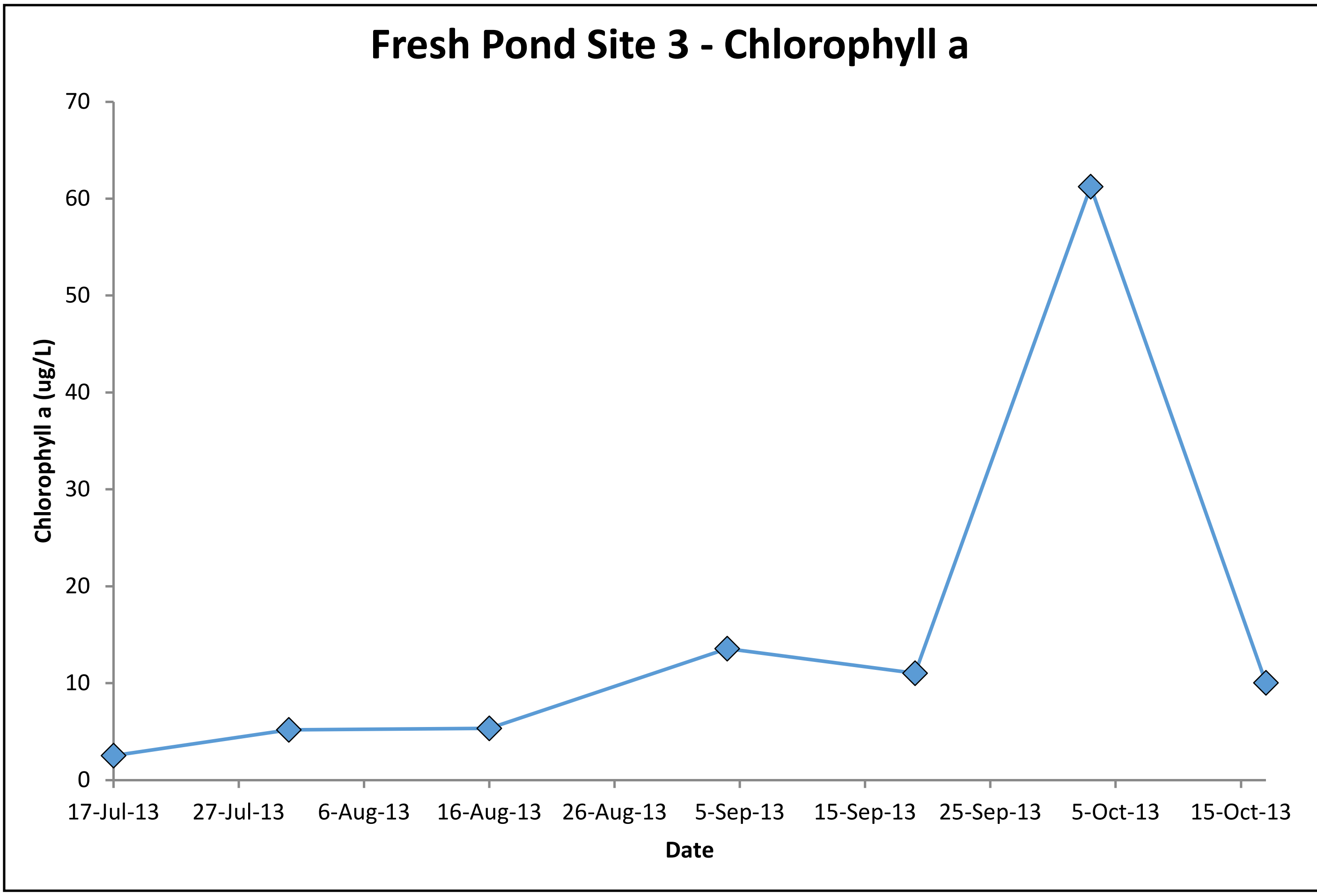


Figure 25: Chlorophyll a values from July – November 2013 for Site 3: the outflow of Fresh Pond, Amagansett.

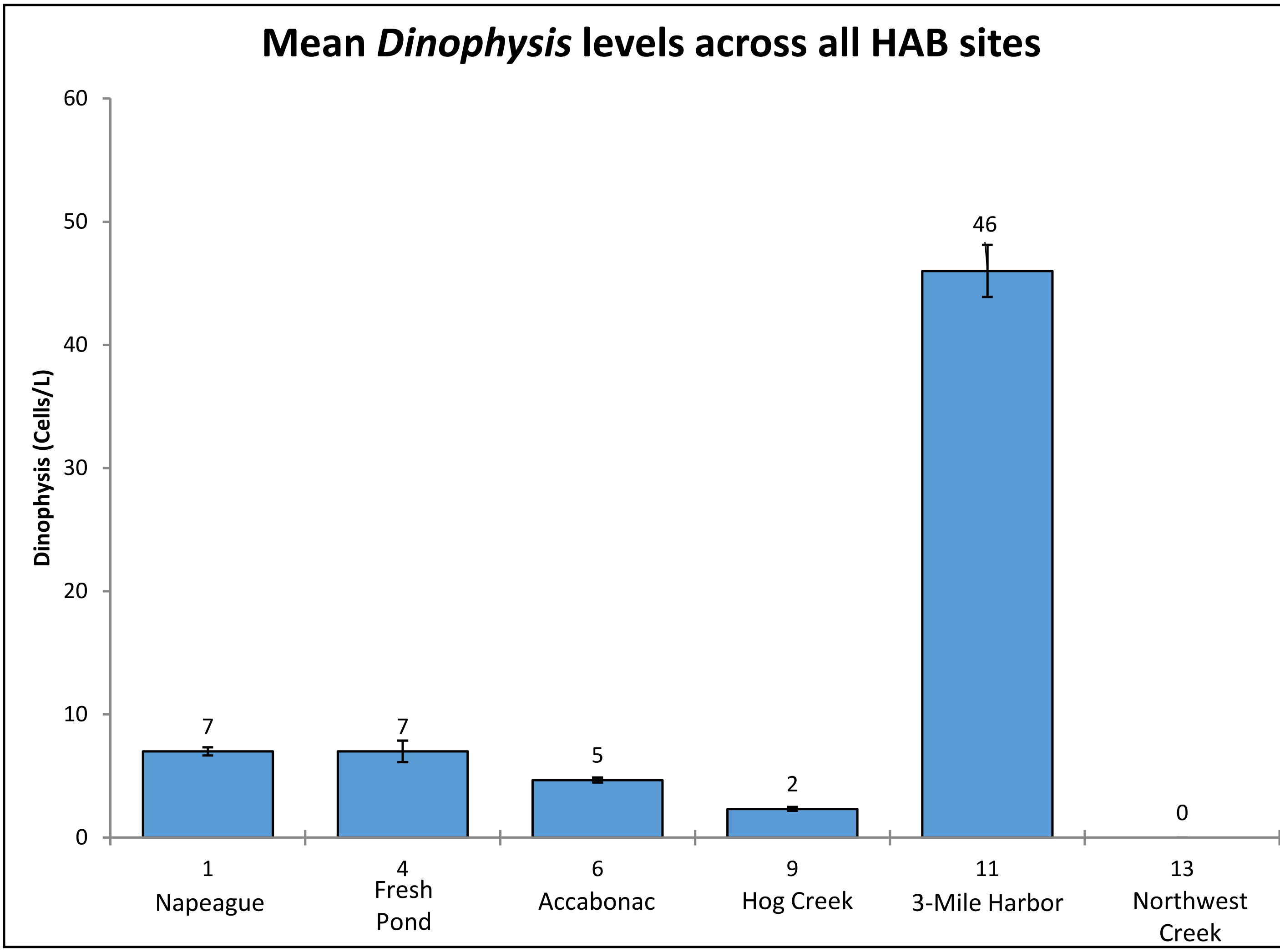


Figure 26: Average *Dinophysis* values for April – July 2013.

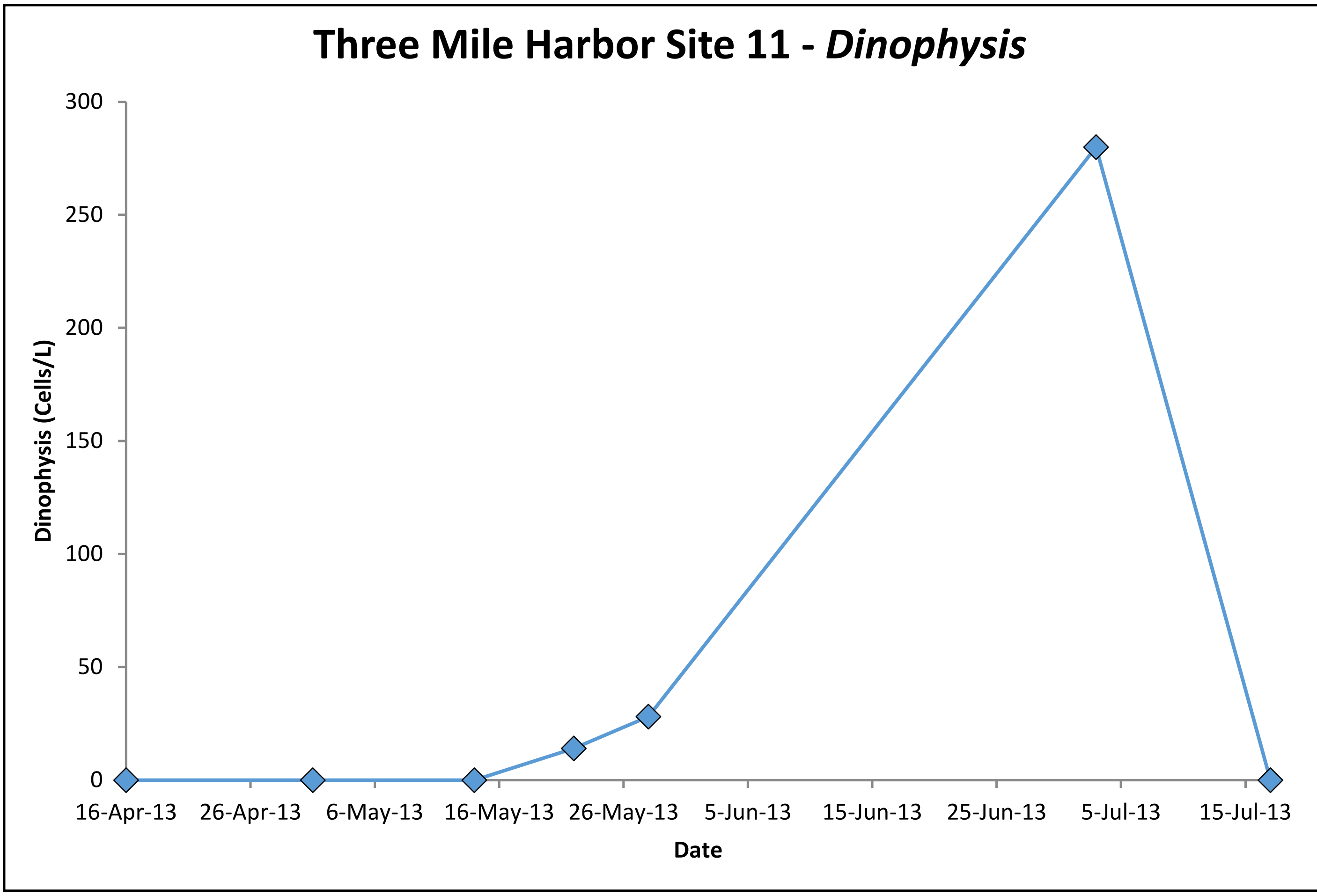


Figure 27: *Dinophysis* counts for April – July 2013 for Site 11: Head of the Harbor, Three Mile Harbor.

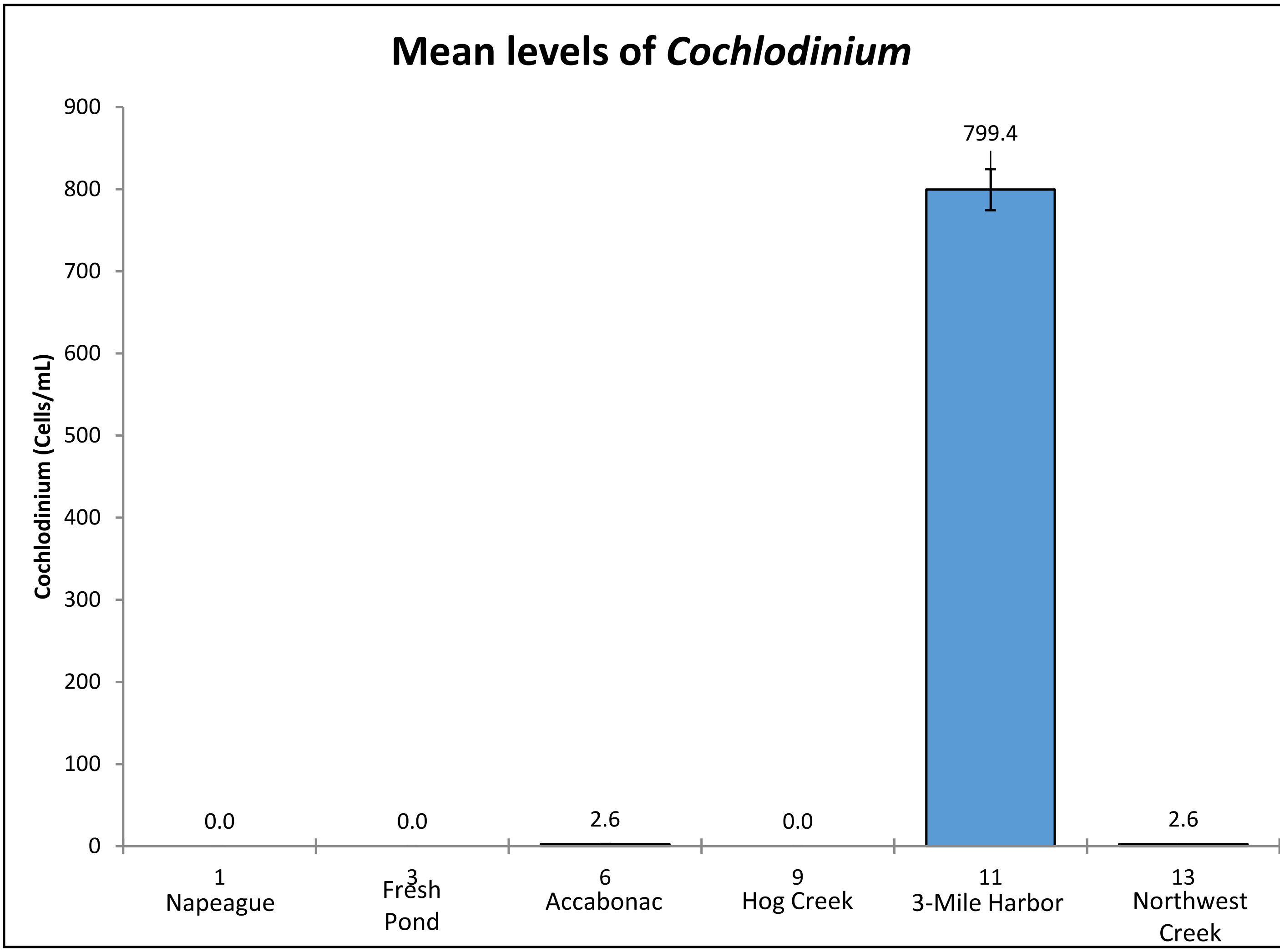


Figure 28: Average *Cochlodinium* values for July – November 2013.

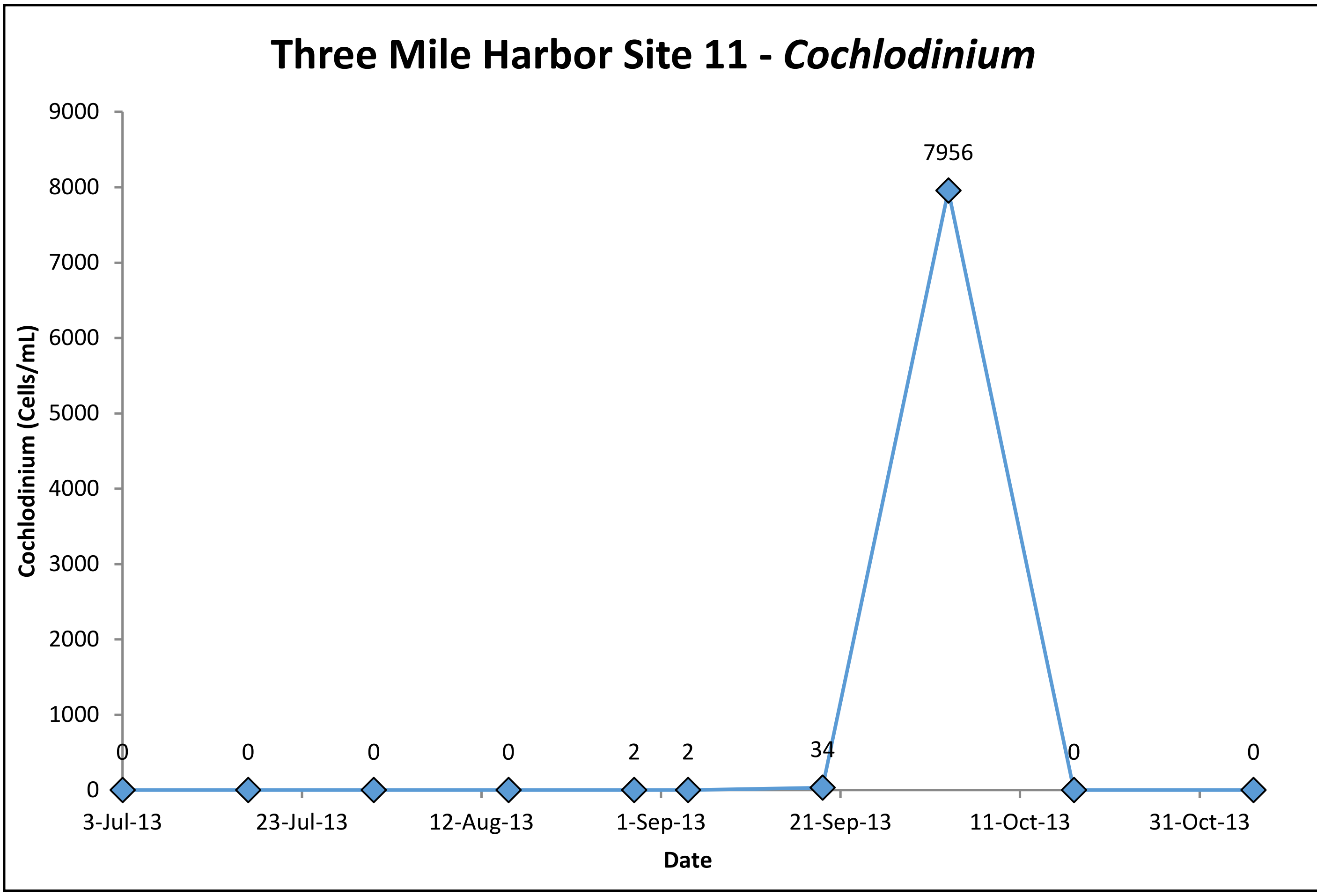


Figure 29: *Cochlodinium* counts for July – November 2013 for Site 11: Head of the Harbor, Three Mile Harbor.

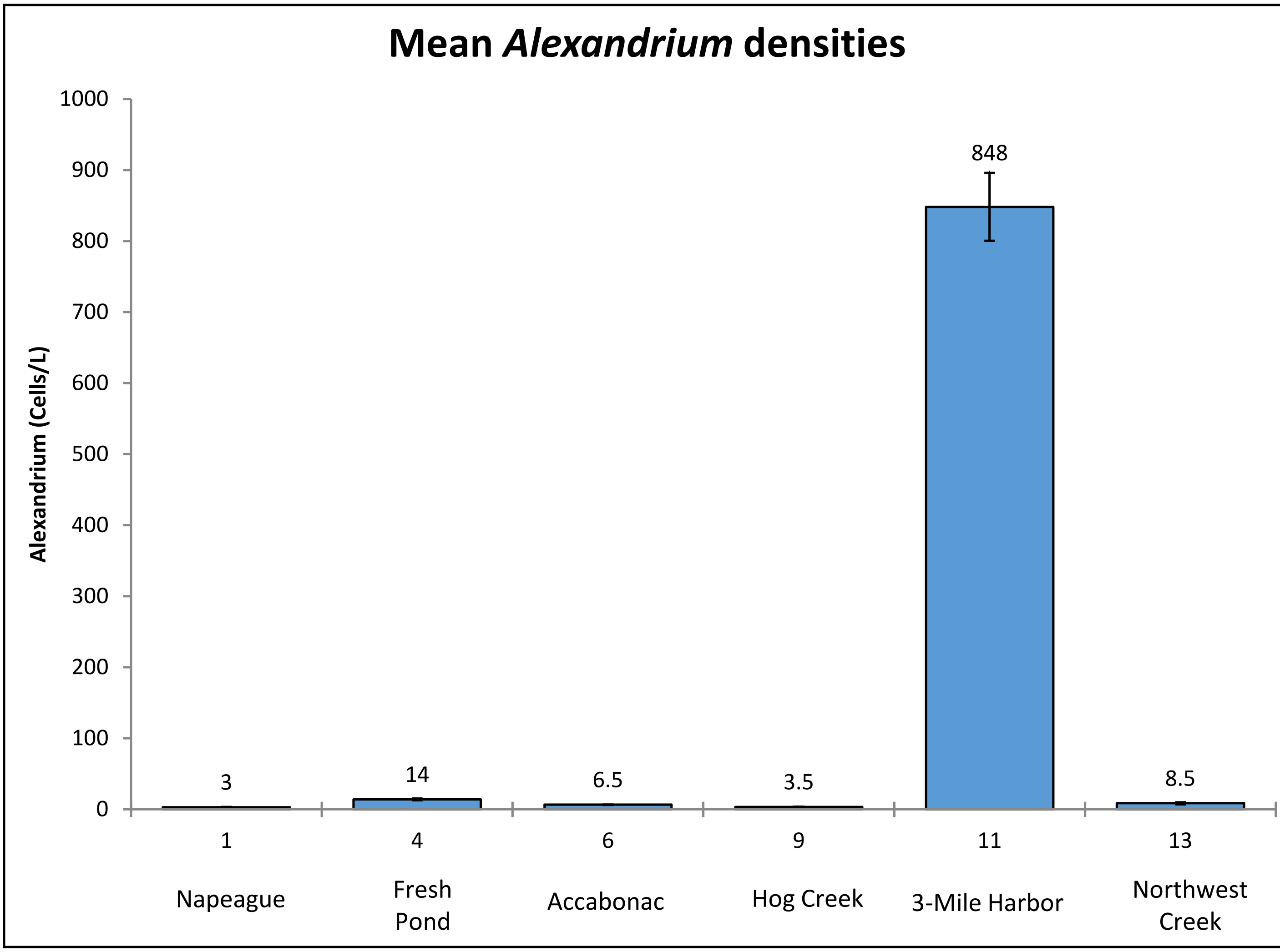


Figure 30: Average *Alexandrium* values for April – May 2013.

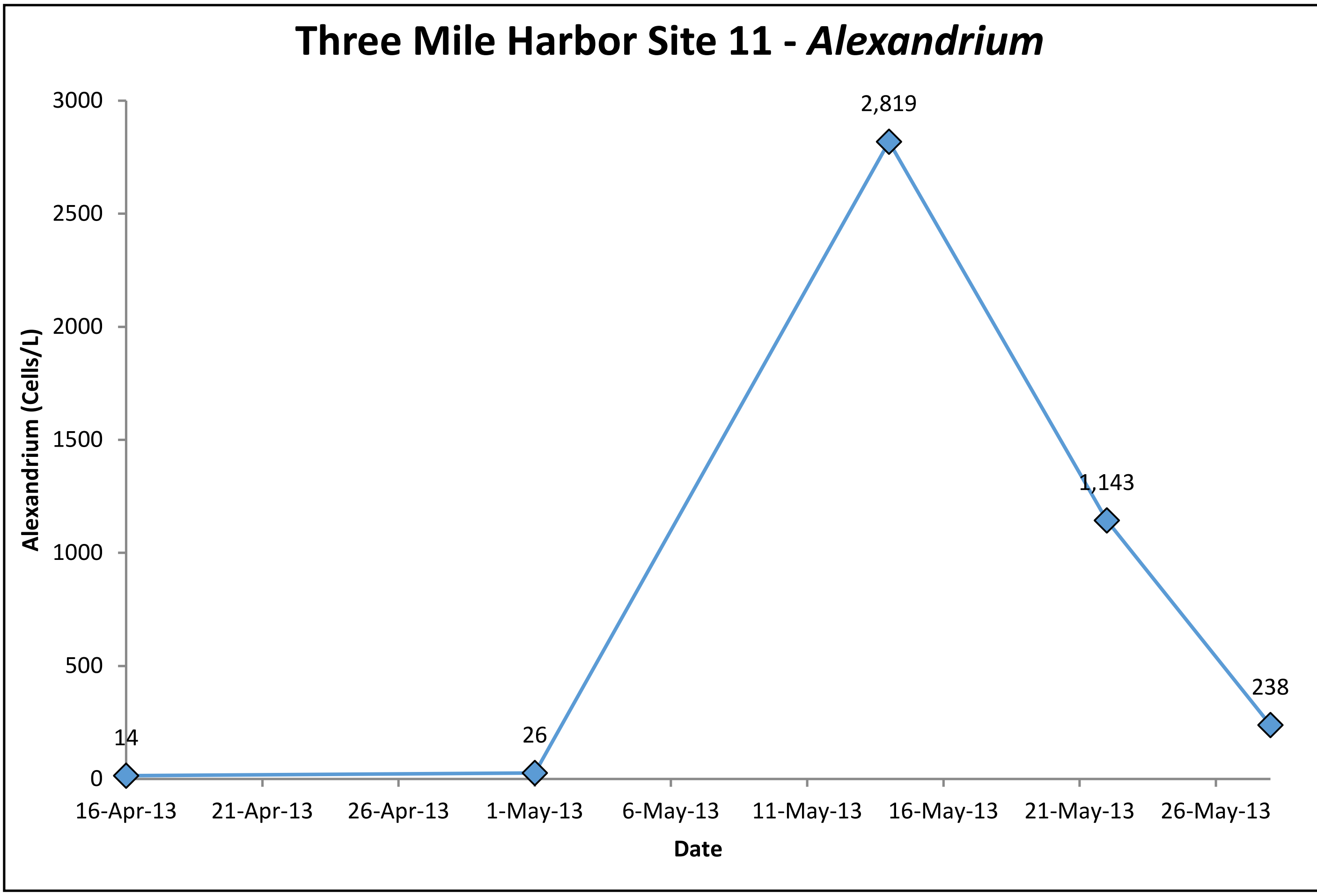


Figure 31: *Alexandrium* counts for April – May 2013 for Site 11: Head of the Harbor, Three Mile Harbor.

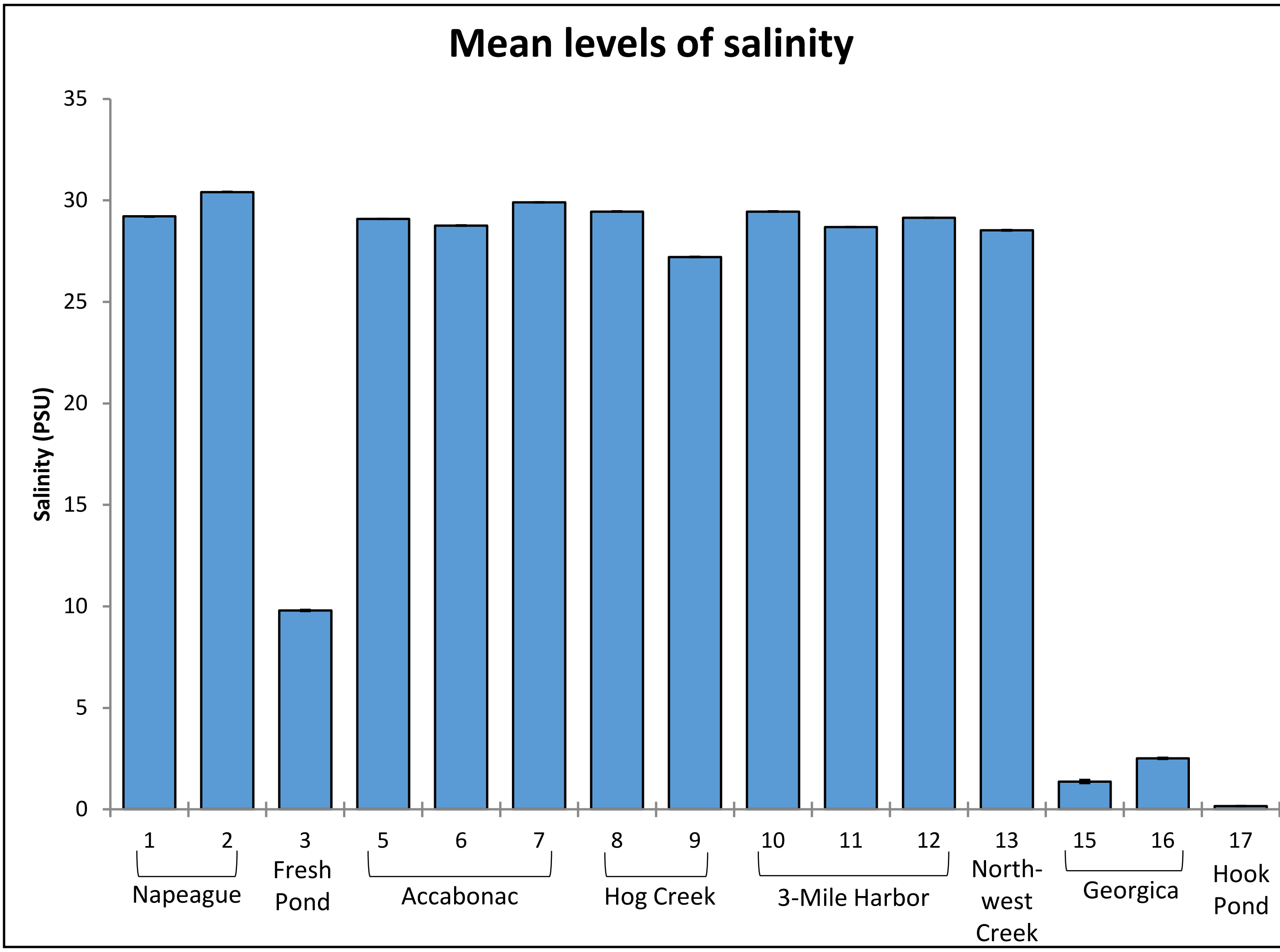


Figure 32: Average salinity values for April – November 2013.

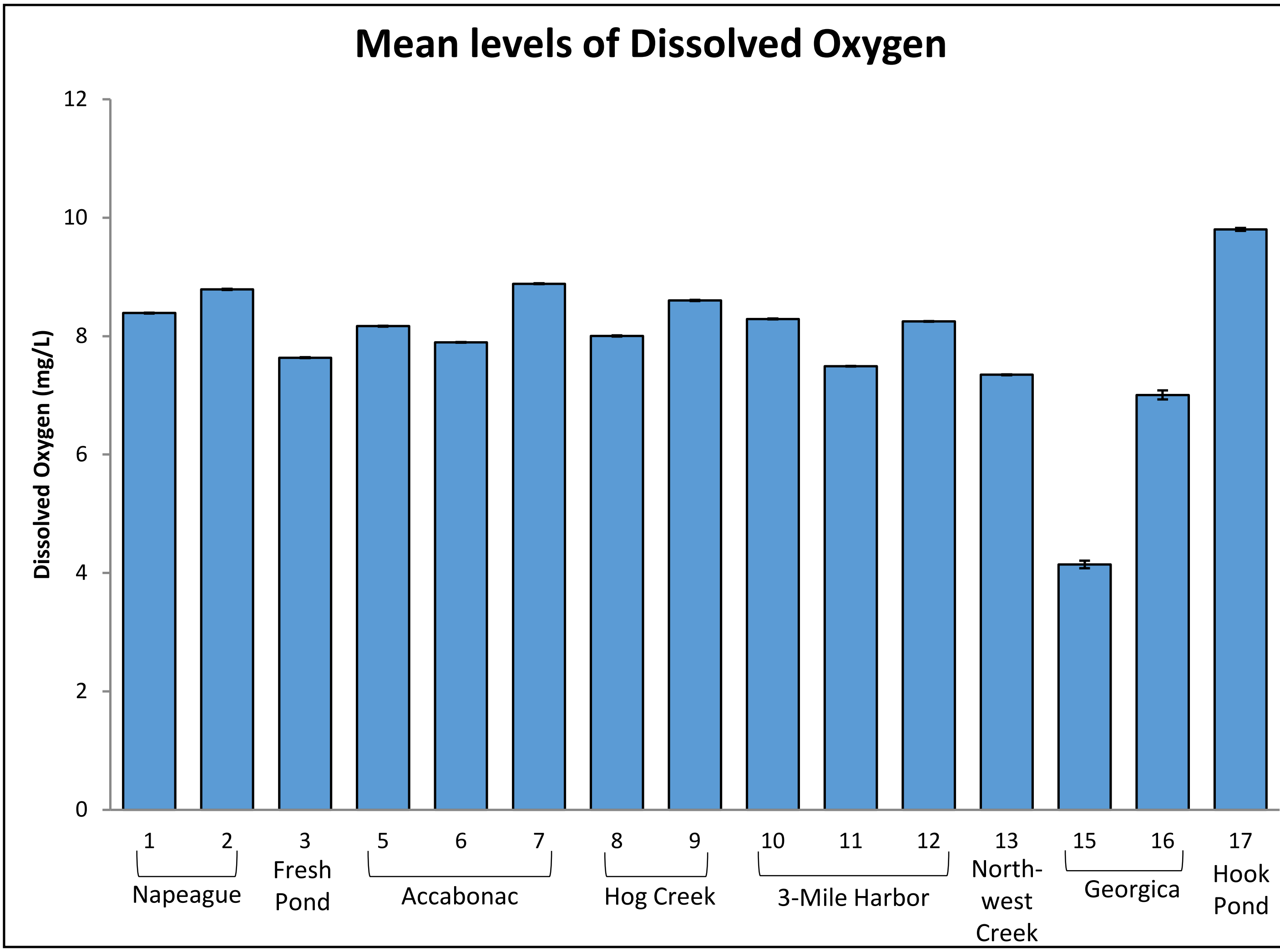


Figure 33: Average dissolved oxygen values for April – November 2013.

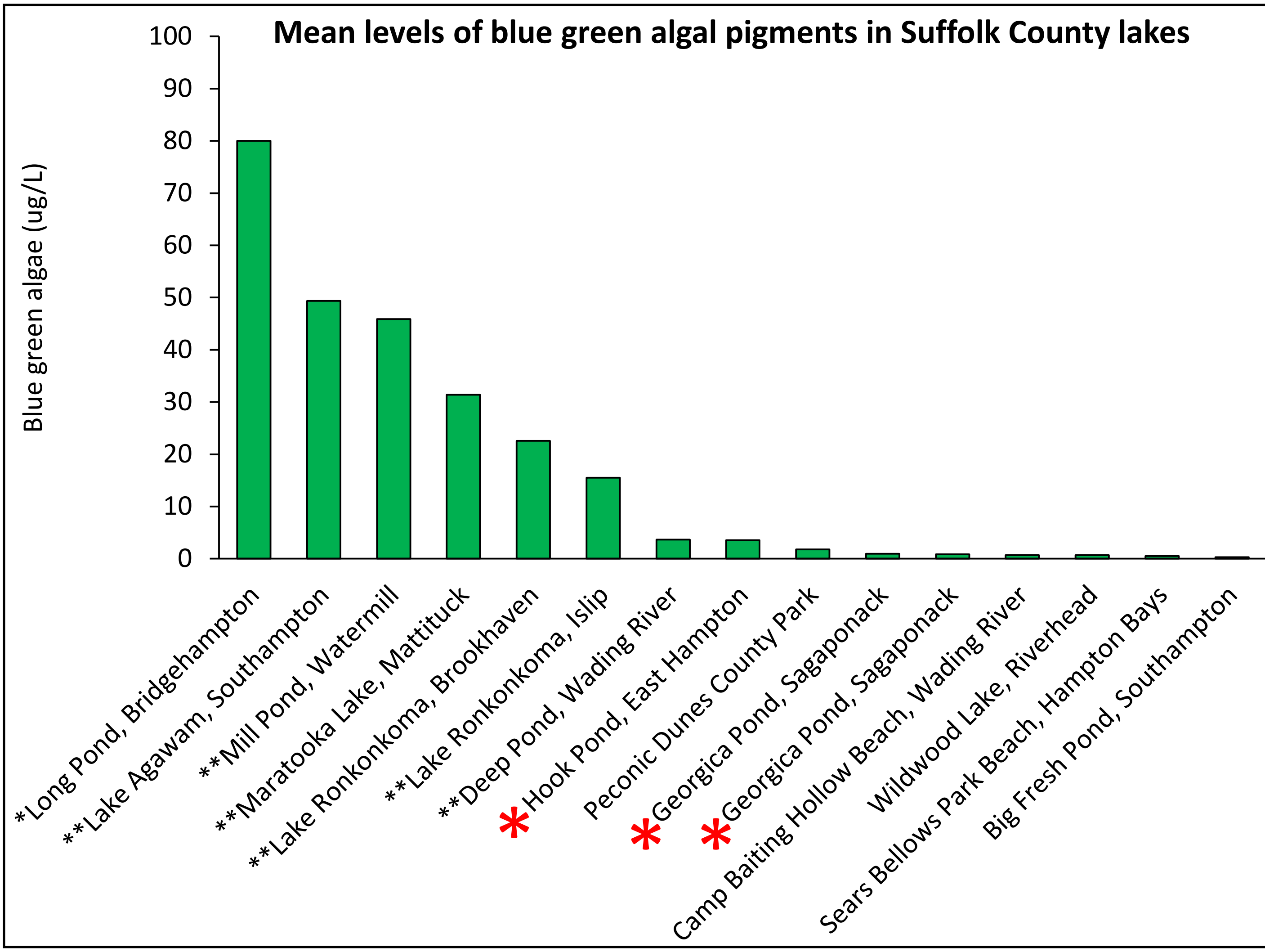


Figure 34: Blue green algae values. Sites with red stars were part of the present study while sites with black stars were listed by NYSDEC in 2013 due to blue green algal blooms.

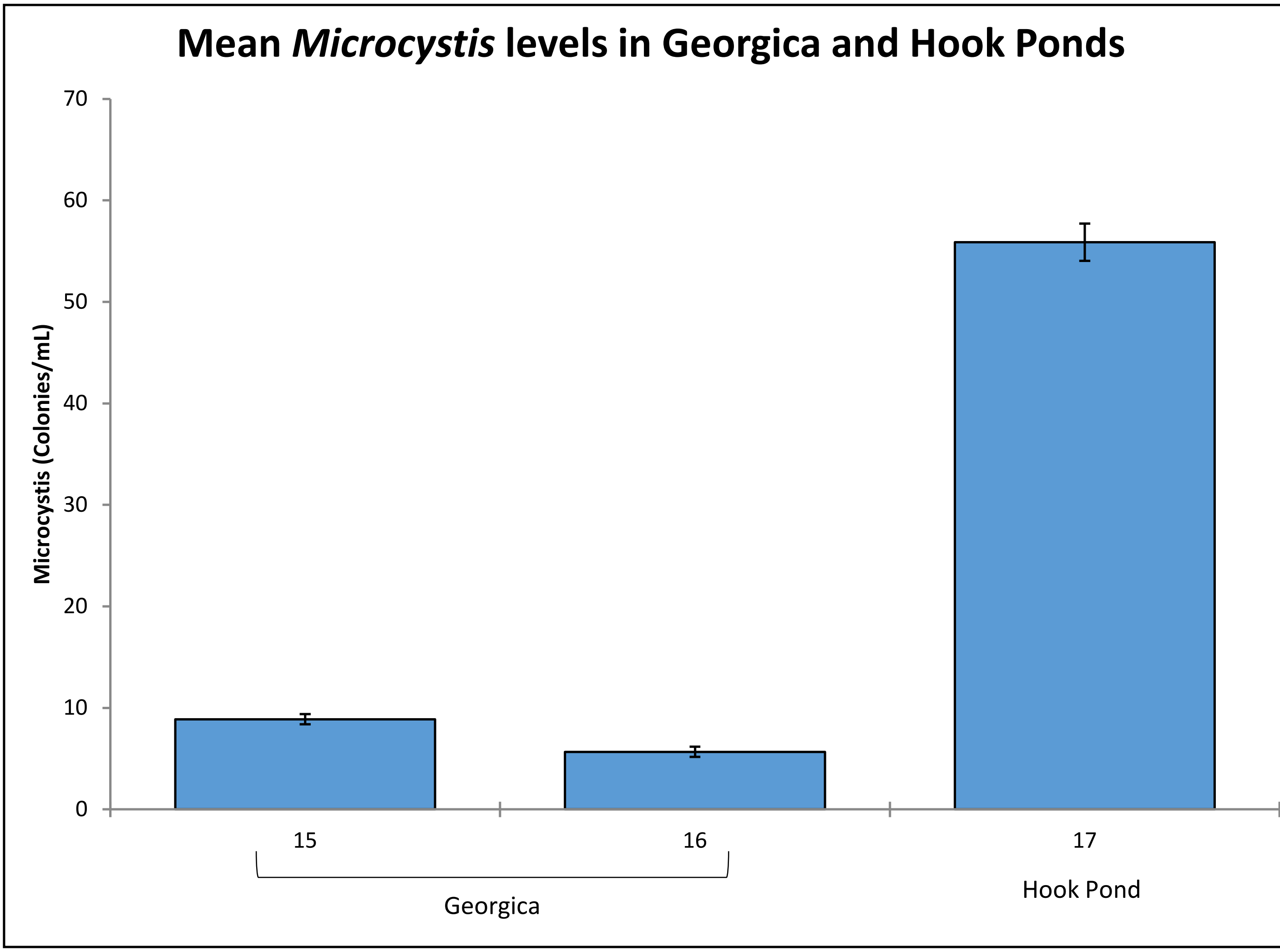


Figure 35: Average Microcystis counts for July – September 2013.

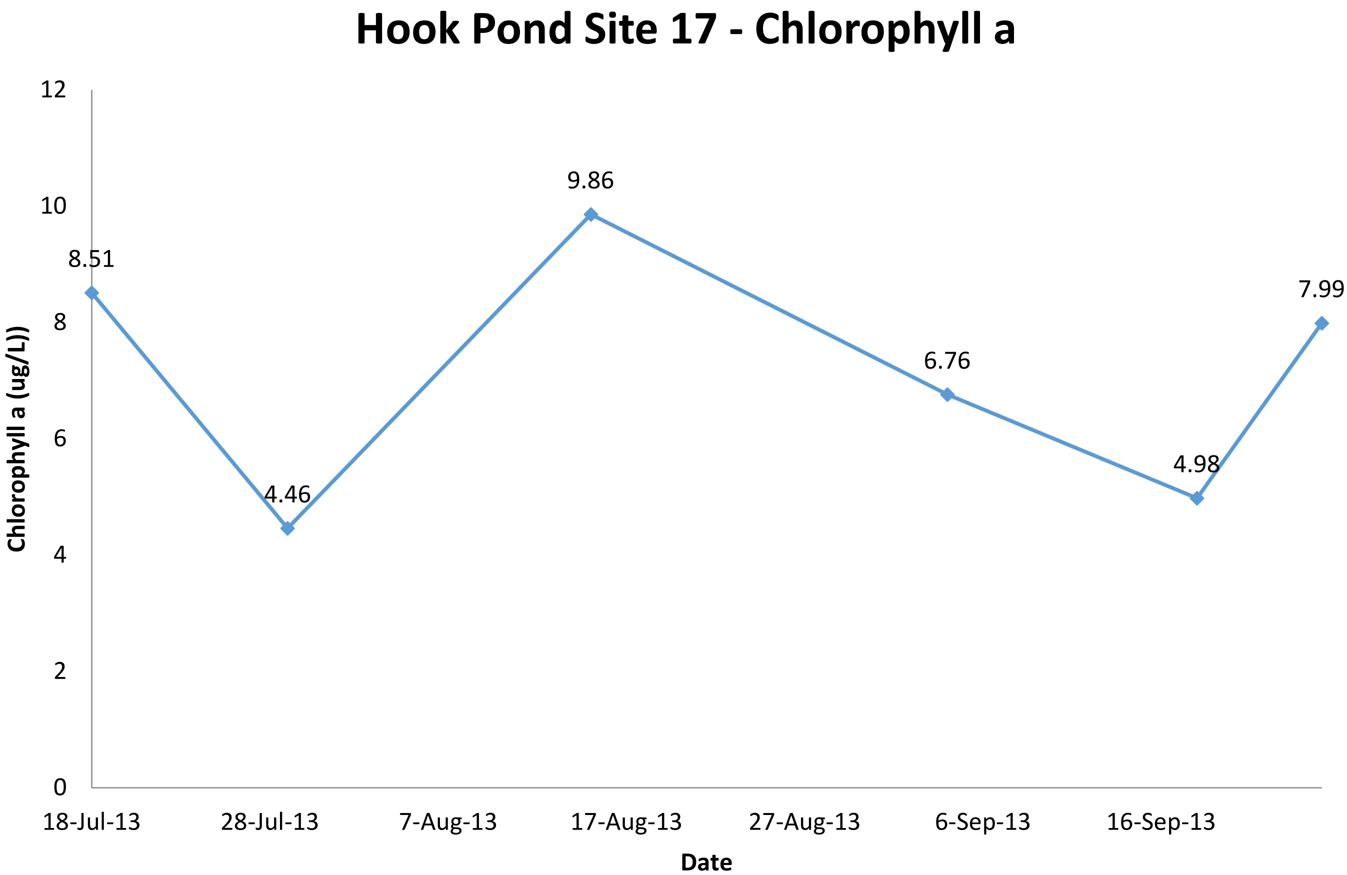
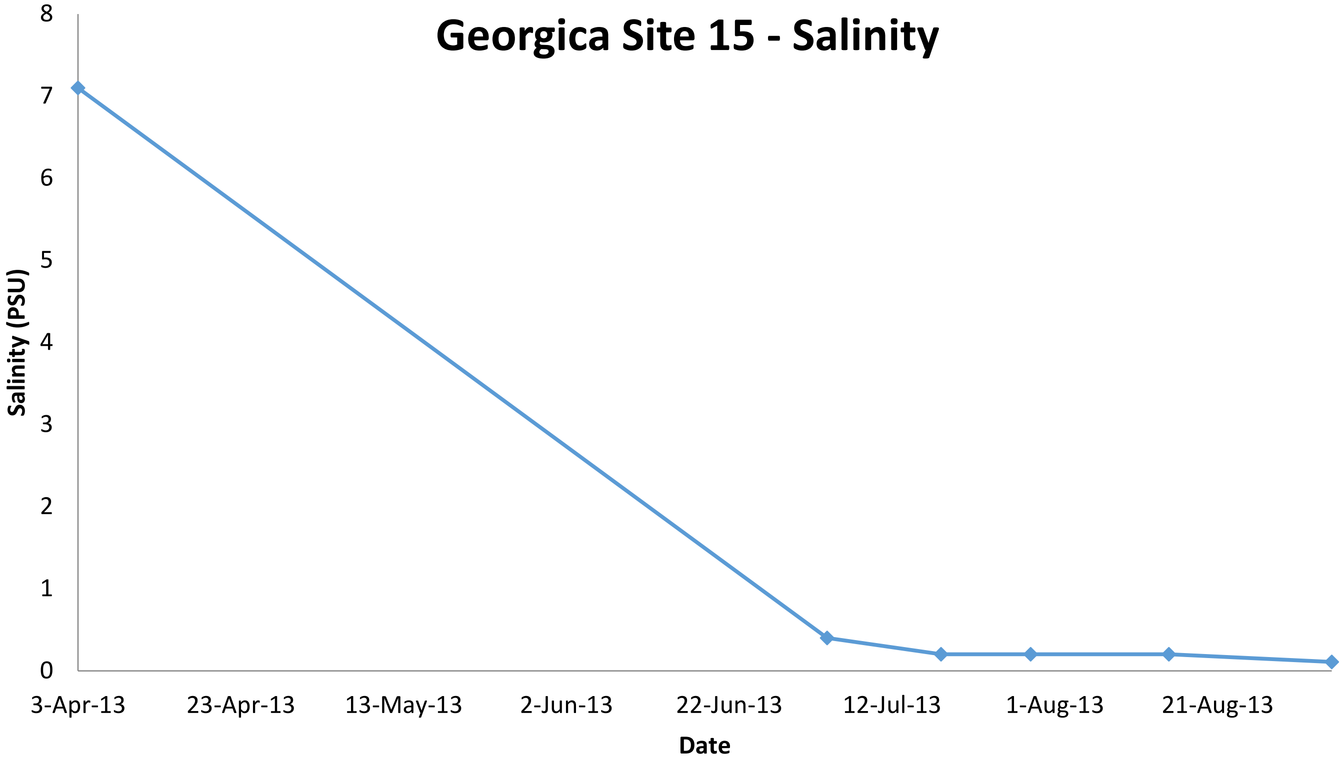


Figure 36: Chlorophyll a levels in Hook Pond, 2013.



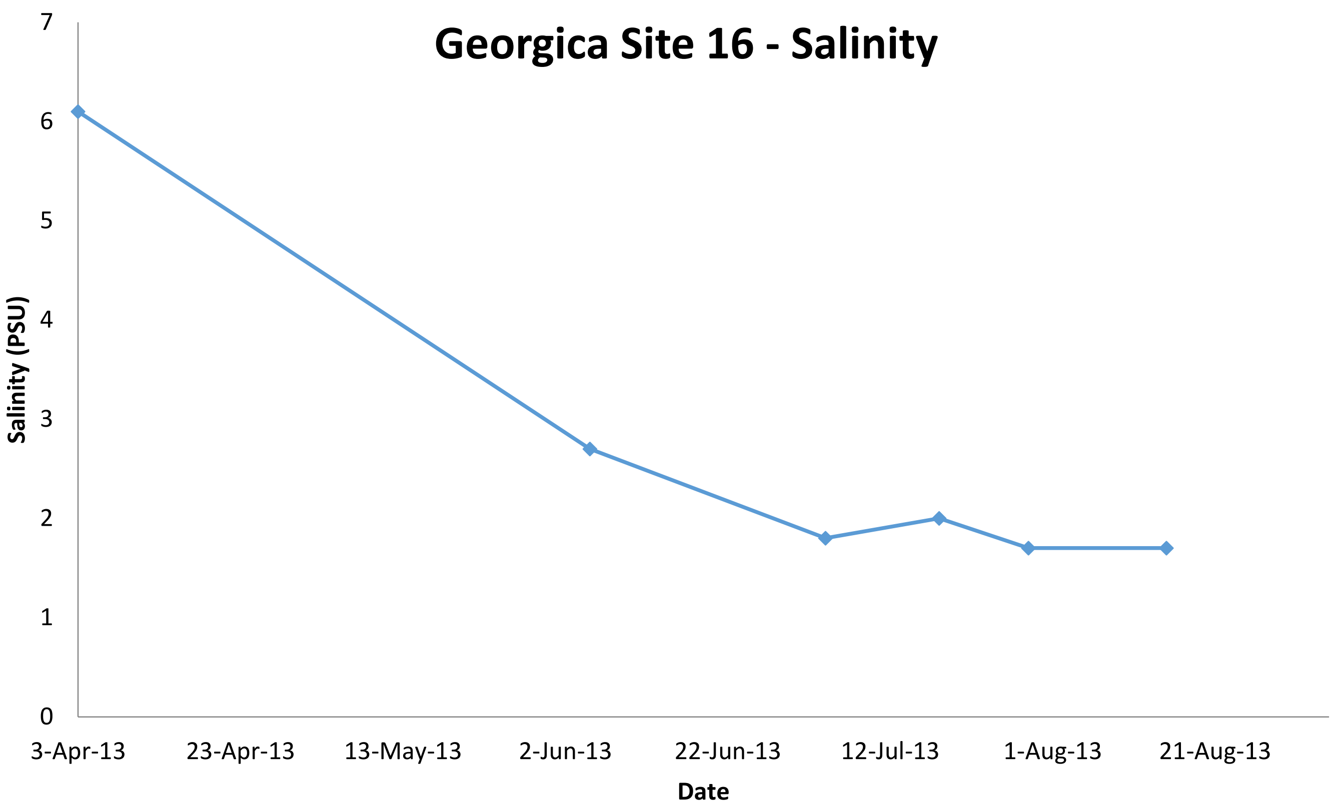


Figure 37: Salinity in Georgica Pond during 2013.

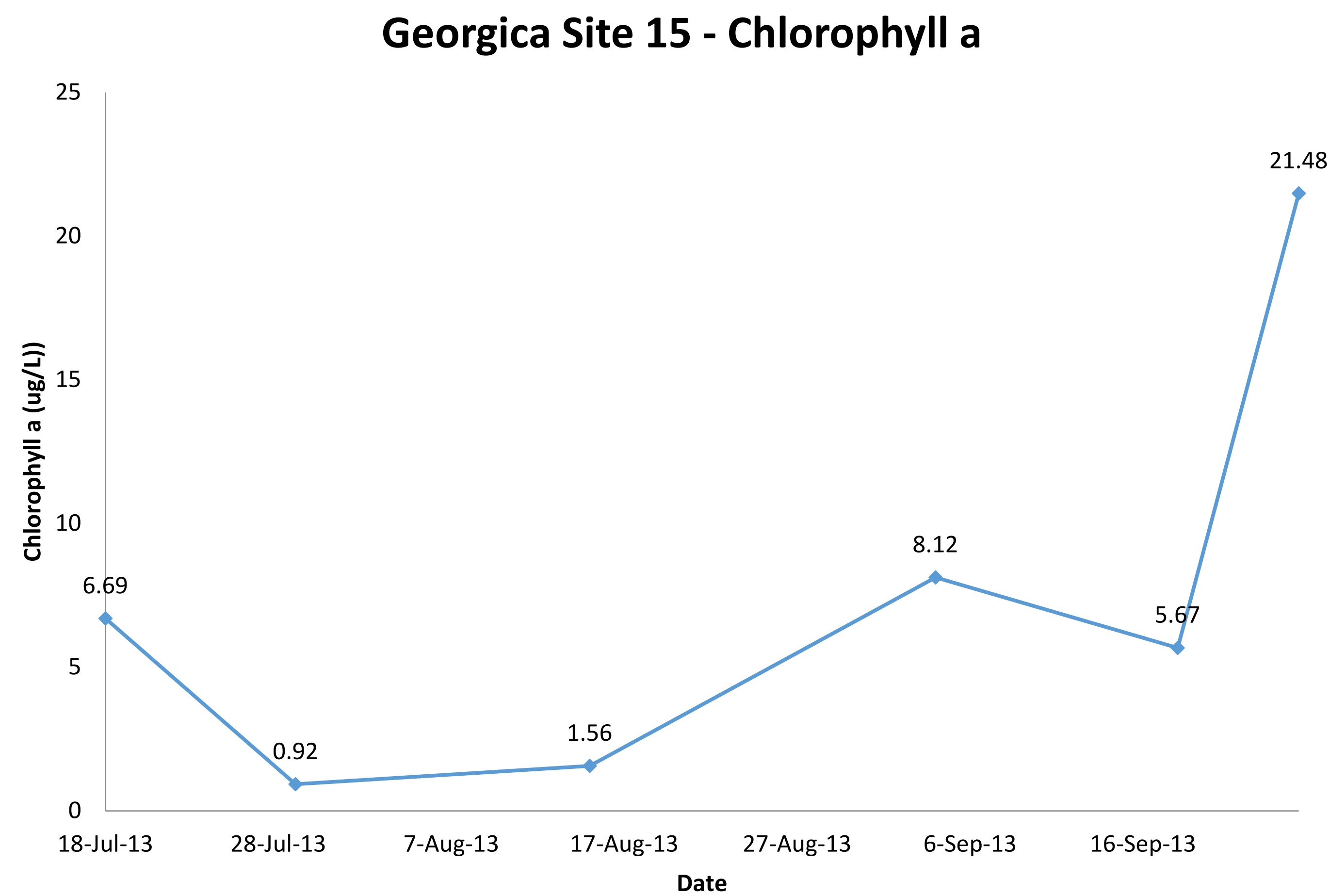
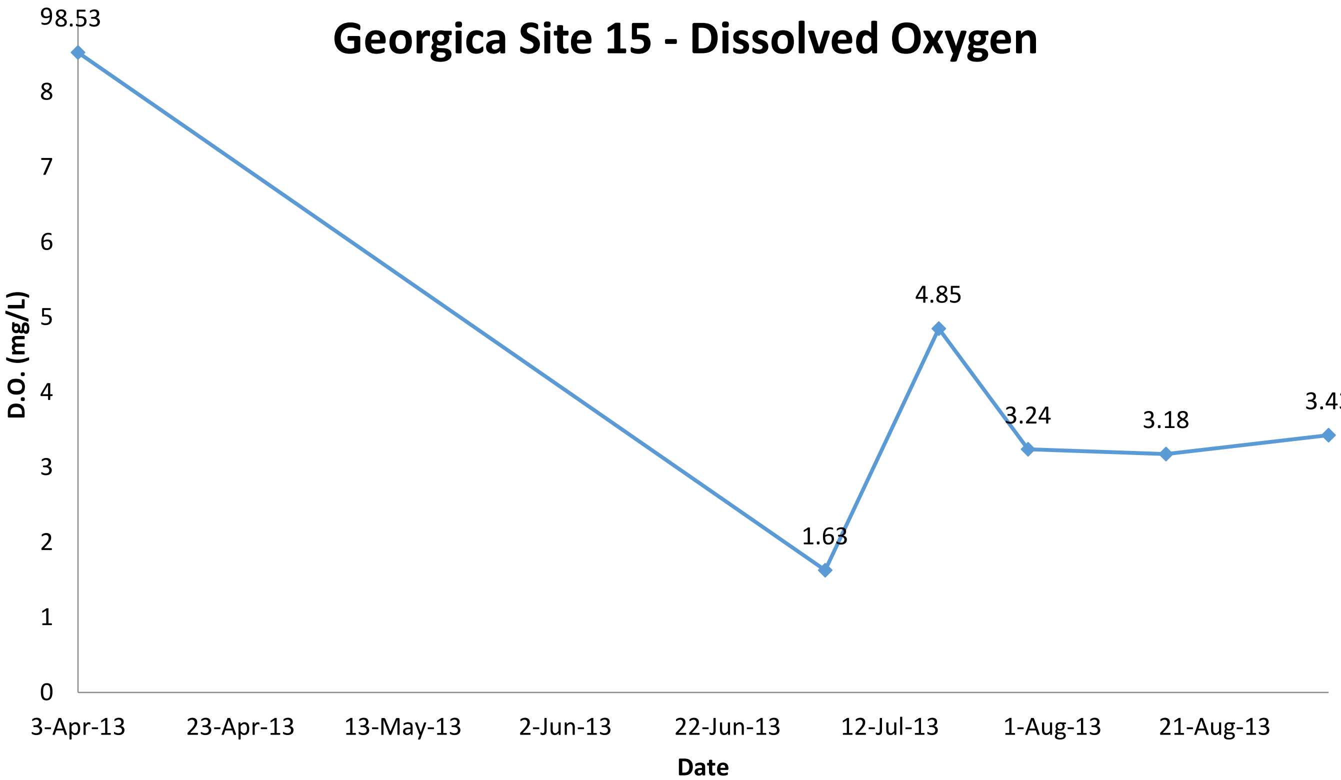


Figure 38: Chlorophyll in Georgica Pond during 2013.



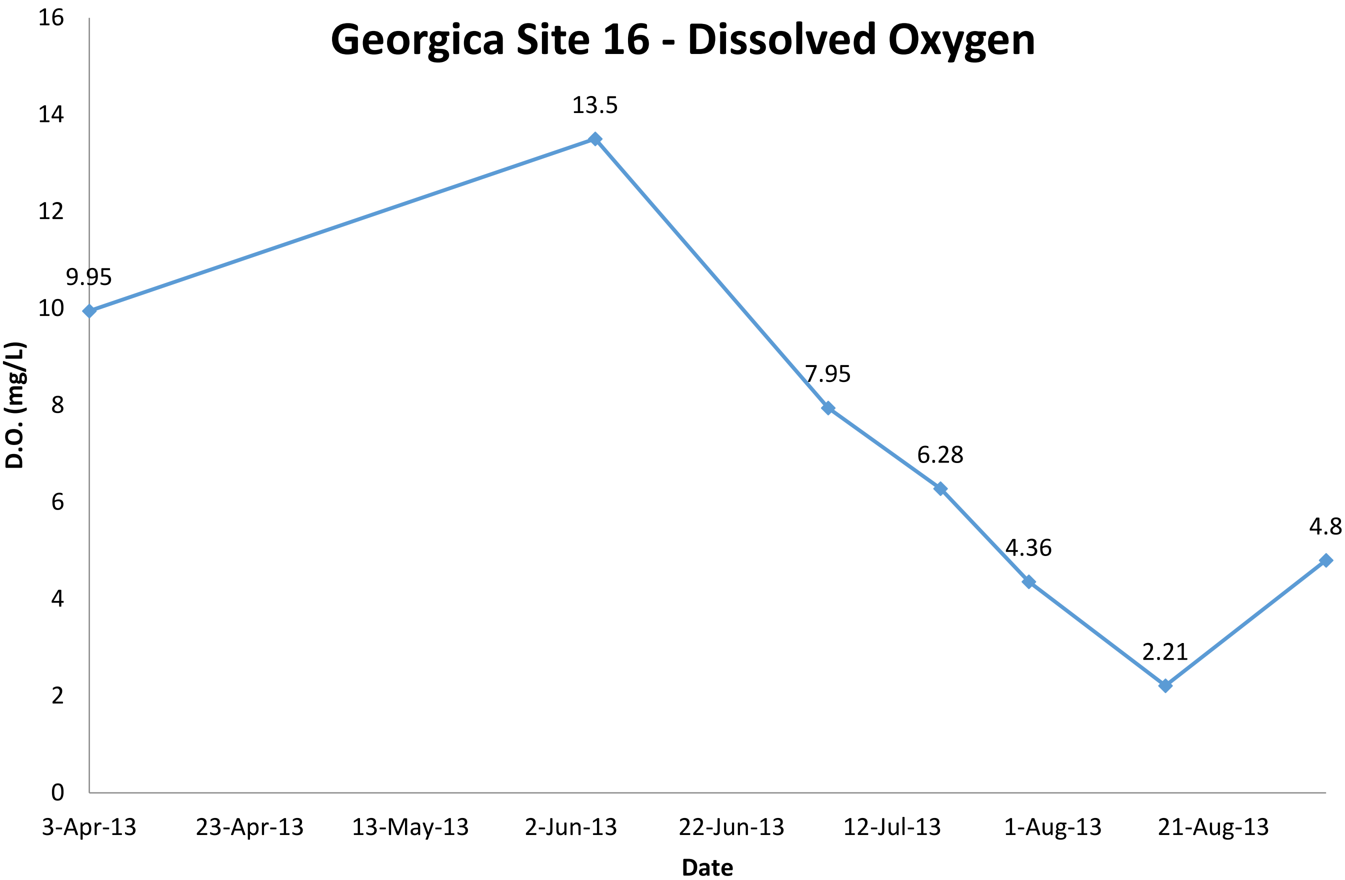


Figure 39: Dissolved oxygen in Georgica Pond during 2013.