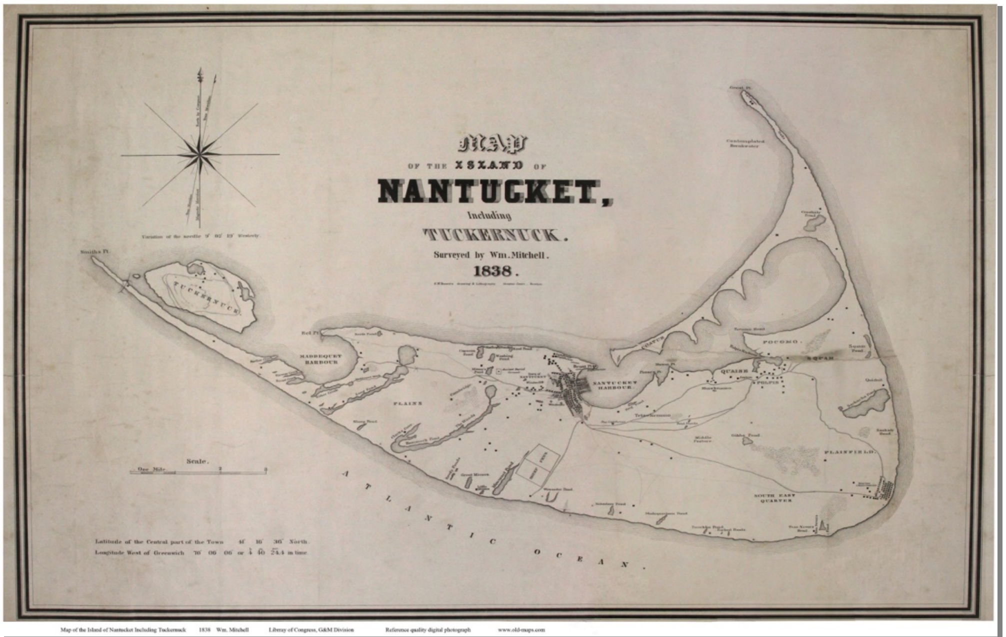
Nantucket Island Ponds and 2020 Water Quality

Capaum Pond and Gibbs Pond

A Summary of Physical, Chemical and Biological Monitoring



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Nantucket Island Ponds and Their Water Quality

Chapter 1

A Basic Water Quality Primer

1.0 Introduction

What is "water quality"? Water quality is a measure of the suitability of water for a particular use based upon certain physical, chemical and biological characteristics. To determine water quality, scientists measure and analyze water characteristics such as temperature, dissolved oxygen, dissolved mineral content, and biological organisms. Selected characteristics are compared with numeric standards and guidelines to determine whether the water is suitable for a particular use.

How is water quality measured? Some aspects of water quality such as temperature, dissolved oxygen, pH and conductance can be determined right in the lake, pond or stream (*in-situ*); other measurements, such as certain chemical constituents, are measured in the laboratory.

Why are there water quality standards and guidelines? Water quality standards and guidelines are established to protect water for specific uses such as drinking, recreation, agricultural irrigation, or the protection of aquatic life. The U.S. Environmental Protection Agency (US EPA) and individual states are responsible for establishing standards for water constituents that are known to pose a human health risk.

How do natural processes affect water quality? Water quality varies from one geographical place to another, with the seasons, with climate and with the types of soils and rocks through which water moves. When water from rain or snow moves over land or through the ground, it may dissolve minerals in rocks and soils and also percolate through organic matter and react with algae and microorganisms, which will change the composition of the water. Water also may transport sand, silt, clay and other materials to streams and rivers, making the water appear cloudy or turbid. When water evaporates from streams, ponds and lakes, the dissolved minerals in the water remain is solution and become more concentrated, which can affect water quality.

What occurs "naturally" in water? Common constituents found dissolved in water include calcium, sodium, bicarbonate and chloride. Water also contains plant nutrients such as nitrogen and phosphorus and certain trace elements such as selenium, chromium and arsenic. The common constituents of water are not considered harmful to human health, although some can affect the taste, smell or clarity of the water. The plant nutrient and trace elements can become harmful to human health or aquatic life if they exceed standards or guidelines.

The effect of human activities on water quality. The water quality of lakes, ponds, streams, rivers and ground water is affected by urban and industrial development, farming, mining practices, combustion of fossil fuels, and other human activities. The most well-known effects of human activities on water quality include nitrogen and phosphorus fertilizers that are applied to crops and lawns, become dissolved in rainwater or snowmelt and are transported to some water body where excess concentrations of these nutrients can encourage excess growth of algae, which cause low dissolved oxygen concentrations and the possibility of fish kills. Other contamination problems can occur as a result of pesticides, herbicides, pharmaceutical products and petroleum products entering water resources.

1.1 Water Quality - Physical characteristics

Transparency. Transparency measures the ease with which light can pass through a substance. In lakes and ponds, transparency usually is measured by the depth of light penetration through the water column. Plants and algae require light to grow and photosynthesize, so their distribution in the water column and on the bottom of the water body is determined by the depth of light penetration and the quality of light at depth. The upper region of the water body that sunlight penetrates is called the *euphotic* zone; the area around the shoreline where depth is shallow enough for plants to receive sunlight transmitted through the water is called the *littoral* zone. The deep area of the lake where plants are not able to grow is the *limnetic* zone.

Water transparency is influenced by the amount of particulate matter in the water. The particulate matter can be algae or sediment from either erosion or wind-based disturbance of the bottom sediment which can suspend material in shallow areas. Some lakes and ponds located in forested regions, such as the Adirondack Mountains of upstate New York, have a dark, stained appearance which is attributed to the leaching of humic and fulvic acids, organic compounds which are constituents of soil and result from the breakdown of vegetation in these geographic areas.

The Secchi disk is the international standardized method for measuring transparency in lakes and ponds and was developed in 1865 by Angelo Secchi. The original disk has undergone several modifications and the current standard for measuring transparency is an 8-inch diameter disk divided into alternating black and white quadrants. The Secchi depth transparency is reached when the reflectance back from the disk equals the intensity of light backscattered from the water. This depth, in meters, divided into 1.7 yields an attenuation coefficient (extinction coefficient) for available light averaged over the Secchi disk depth.

1.2 Water Quality - Chemical characteristics

Specific conductance. The phenomenon of specific conductance is a measure of water's resistance to flow of an electrical current; resistance decreases as ionized salt content of the water increases and promotes the flow of electrical current. Water with a low concentration of major ions, e.g. HCO_3 (bicarbonate), CO_3^{-2} (carbonate), K^+ (potassium), Na^+ (sodium), Ca^{2+} (calcium), Cl^- (chloride), SO_4^{-2} (sulfate) and $Mg^{=2}$ (magnesium) has the greatest resistance to electron flow, while water with a high concentration of ions, e.g. seawater, has less resistance to electron flow.

Total dissolved solids (TDS). **TDS** include inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, sulfates) and some small amounts or organic matter dissolved in water. In general, the total dissolved solids concentration is the sum of the cations ('**+**' charged ions) and anions ('**-**' charged ions). Sodium and particularly chloride ions originating from road salt application in the sub-catchment provide a substantial component of both specific conductance and total dissolved solids and very often it is possible to demonstrate linear relationships among these parameters.

pH. 'pH' is a mathematical transformation of the hydrogen ion $[H^+]$ concentration and expresses the acidic or basic nature of water. The lowercase 'p' in pH refers to 'power' or exponent, and pH is defined as the negative logarithm of the hydrogen ion $[H^+]$ concentration. A change of one (1) pH unit represents a ten-fold (10x) change in the hydrogen ion concentration. Conditions become more acidic as pH decreases, and more basic as pH increases, below and above the mid-point pH level of 7.0, respectively.

Within freshwater and estuarine ecosystems, the pH can fluctuate considerably within daily and seasonal time-frames, and many organisms living within these systems have evolved to tolerate a relatively wide range of environmental pH. Animals and plants can, however, become stressed or even die when exposed to pH extremes or when pH changes rapidly. In addition to the direct effects of pH on aquatic organisms, the hydrogen ion $[H^+]$ concentration affects the aqueous equilibria that involve lake-water constituents such as ammonia, hydrogen sulfide, chlorine and dissolved metals, and can cause pH toxicity.

Carbon dioxide within the aquatic ecosystem is controlled by internal biological activity. All living animals continuously produce carbon dioxide as a by-product of respiration. Algae and plants in lakes and ponds remove carbon dioxide from the water during photosynthesis. The rates of respiration and photosynthesis determine whether there is net addition or removal of carbon dioxide, and whether pH will fall or rise, respectively.

Dissolved oxygen concentration/percent saturation. Oxygen constantly is consumed in lakes and ponds and oxygen consumption results from the respiration of aerobic organisms and from decomposition in the lower waters by organisms (primarily bacteria) that metabolize the organic material settling down from the productive upper levels of the lake or pond.

The two primary mechanisms that replenish oxygen supply are (1) exchange with the atmosphere at the air-water interface, which is particularly effective under windy conditions, and (2) photosynthetic activity of plant material, both phytoplankton and rooted plants, living in the water column.

In general, the maximum concentration of dissolved oxygen that can occur in water is a function of water temperature. Higher concentrations of dissolved oxygen occur in low water temperatures than at high temperature. Dissolved oxygen levels in water often are reported in 'percent saturation' since the calculation corrects for temperature and removes bias from the oxygen concentration readings.

1.3 Water Quality - Plant Nutrients

Nitrogen. **Nitrogen** is an important nutrient used by phytoplankton and aquatic plants to produce biomass in lakes and ponds. **Total nitrogen (TN)** is a measure of all forms of nitrogen found in water, and consists of organic forms and inorganic forms including nitrate (NO_3^-), nitrite (NO_2^-), ionized ammonia (NH_4), un-ionized ammonia (NH_3^+) and nitrogen gas (N_2). The relationships of these forms of nitrogen is as follows

Total nitrogen (TN) = Organic nitrogen (ON) + Ammonia-nitrogen (NH_3-N) + Nitrate-nitrogen (NO_3-N) + Nitrite (NO_2)

Amino acids and proteins are naturally-occurring organic forms of nitrogen. All forms of nitrogen are harmless to aquatic organisms except un-ionized ammonia and nitrite, which can be toxic to plants and fish. **Nitrite** usually is not a problem in water-bodies since it is readily converted to **nitrate** if enough oxygen is present for oxidation. Bacterial oxidation and reduction of various nitrogen compounds in lake water produces forms of nitrogen that are assimilated by aquatic plants during photosynthesis. There are several forms of nitrogen that are important to the biota of lakes and ponds including inorganic **nitrate** and **ammonia**, and the **organic nitrogen** fraction.

Ammonia-nitrogen, **NH_3-N**, is the first inorganic nitrogen product of organic decomposition by bacteria and is present in lake water primarily as NH_4^+ and NH_4OH. Ammonia is un-ionized and has the formula NH_3; ammonium is ionized and has the formula NH_4^+. The major factor that determines the proportion of ammonia or ammonium in water is pH. The activity of ammonia also is influenced by ionic strength and by temperature. This is important since the un-ionized NH_3 is the form that can be toxic to aquatic organisms, while the ionized NH_4 is harmless to aquatic organisms. The relative proportions of NH_4^+ to NH_4OH in lake water depend primarily upon pH as follows (Hutchinson, 1957):

pH 6	3000:1
pH 7	300:1
pH 8	30:1
pH 9.5	1:1

At pH values ≤7.00, NH_4^+ predominates and is a good source of nitrogen for plants. At higher pH values, NH_4OH can occur in concentrations that are toxic to biological growth.

Nitrate-nitrogen, **NO_3-N**, is produced by the bacterial conversion of organic and inorganic nitrogenous compounds from a reduced state to an oxidized state and is readily assimilated by algae and green plants. Collectively, **nitrate** and **ammonia** provide most of the nitrogen available for assimilation by green plants. **Organic nitrogen** in lake water consists of dissolved and particulate forms, and represents nitrogen contained in the plankton and seston.

Although **total nitrogen** (**TN)** is an essential nutrient for plants and animals, an excess amount can lead to low levels of dissolved oxygen and negatively alter plant life and organisms. Sources of nitrogen include wastewater treatment plants, runoff from fertilized lawns and croplands, failing septic systems, runoff from animal manure and storage areas, and industrial discharges that contain corrosion inhibitors. The primary sources of nitrogen to Nantucket ponds include fertilizer and failing or improperly maintained septic systems.

Phosphorus. Phosphorus has a major role in biological metabolism and often limits the amount of productivity in lakes and ponds since it is the least abundant of the major structural and nutritional components of the biota such as carbon, hydrogen, nitrogen, etc. Although phosphorus occurs as organic and inorganic forms, more than 90 percent of the phosphorus that occurs in lake water is bound organically with living material or associated with decaying material (Wetzel, 1975).

Most important in lake and pond metabolism is the **total phosphorus** (**TP**) content of unfiltered lake water which contains **particulate phosphorus** (in suspension as particulate matter) and the **dissolved**, or **soluble**, **phosphorus** fraction. Particulate phosphorus can include three forms (1) phosphorus in living organisms (e.g. plankton), (2) mineral phases of rock and soil with absorbed phosphorus, and (3) phosphorus adsorbed onto dead particulate organic matter. The relative importance of each form of phosphorus seems to vary in lakes and ponds, probably as a function of allochthonous material (from outside the system) containing phosphorus, which enters the pond at different times of the year.

A 'typical' body of water would receive significant inputs of phosphorus during periods of high runoff, such as spring snowmelt. In fact, in many north temperate lakes and ponds in the northeastern United States, the period of spring runoff represents about 60-70 percent of the average annual runoff that enters the system from the surrounding watershed (Sutherland et al., 1983).

1.4 Water Quality – Biological

The diversity, composition, dominance and biomass of the planktonic algae reveal the water quality of lakes and ponds. As discussed by Hutchinson (1967), certain algal associations occur repeatedly among lakes with different levels of nutrient enrichment, and the associations are used to characterize trophic status (the degree of eutrophication of a water body). These characterizations are useful since they demonstrate the connection between available nutrient supply and the qualitative and quantitative abundance of algal taxa.

Phytoplankton are single-celled microorganisms that drift in sea water or fresh water and, at times, can grow in colonies large enough to be seen by the human eye. As a group, phytoplankton can be divided into two classes, the algae and the cyanobacteria, and are photosynthetic, which means that they contain the pigment chlorophyll and can utilize sunlight to convert carbon dioxide and water into energy.

World-wide, microscopic phytoplankton living in the oceans and fresh-water lakes and ponds play some of the biggest roles in climate control, oxygen supply and food production, and they form the basis of the aquatic food web. An imbalance of phytoplankton levels, often caused by too many nutrients, can cause blooms in salt and fresh water and lead to an imbalance in other parts of the aquatic food web. Certain species of phytoplankton, especially within the cyanobacteria, can produce harmful toxins which, if ingested by humans can cause neurological and hepatic symptoms.

1.5 Water Quality - Trophic Status

'Trophic' means nutrition or growth. The trophic state of lakes refers to biological production, plant and animal, that occurs in the lake and the level of production is determined by several factors but primarily phosphorus supply to the lake and by the volume and residence time of water in the lake. Many different indicators are used to describe trophic state such as phosphorus, water clarity, chlorophyll, rooted plant growth and dissolved oxygen.

The following trophic categories are used to classify lakes and ponds and provide a basis for comparing water bodies within the same geographical area, or waters not geographically similar:

- Oligotrophic – usually large and deep water bodies with rocky or sandy shorelines, low phosphorus enrichment, limited rooted plant growth, low algal growth and adequate dissolved oxygen throughout the water column.
- Mesotrophic – an intermediate category of productivity with characteristics between the oligotrophic and eutrophic categories.
- Eutrophic – smaller, shallow lakes with organic bottom material, extensive rooted plant growth, low dissolved oxygen in the lower waters, and reduced water transparency from planktonic algal growth.

Lakes and ponds with extreme conditions at either the oligotrophic end of the spectrum or the eutrophic end of the spectrum may be considered hyper-oligotrophic or hyper-eutrophic, respectively.

Carlson's Trophic State Index (TSI) commonly is used to characterize the trophic status (overall health) of a water body (Carlson, 1977). Since they tend to correlate, the three independent variables most often used to calculate the Carlson index include chlorophyll pigments, total phosphorus and Secchi depth. Individual TSI values are calculated from the following equations:

- $Total\ phosphorus\ TSI\ (TSIP) = 14.42 * [\ln(TP\ average)] + 4.15$
- $Chlorophyll\ \text{a}\ TSI\ (TSIC) = 9.81 * [\ln(Chlorophyll\ a\ average)] + 30.6$
- $Secchi\ disk\ TSI\ (TSIS) = 60 - (14.41 * [\ln(Secchi\ average)])$

The relationships between Trophic Index (TI), chlorophyll (μg L^{-1}), phosphorus (μg L^{-1}), Secchi depth (meters), and Trophic Class (after Carlson, 1996) are as follows:

Table 11. Relationships among Trophic Index, chlorophyll *a*, phosphorus, Secchi depth and Trophic Class.

Trophic Index	Chlorophyll (μg L^{-1})	TP (μg L^{-1})	Secchi Depth (m)	Trophic Class
< 30 - 40	0.0 – 2.6	0.0 - 12	> 8 - 4	Oligotrophic
40 - 50	2.6 – 7.3	12 - 24	4 - 2	Mesotrophic
50 - 70	7.3 - 56	24 - 96	2 – 0.5	Eutrophic
70 – 100+	56 – 155+	96 – 384+	0.5 - <0.25	Hyper-eutrophic

Of these three variables, chlorophyll probably provides the most accurate index since it is the most accurate predictor of standing crop in the ecosystem. Phosphorus is a more accurate predictor of the summer trophic status of a water body than chlorophyll if the measurements also are made during the winter months, which is not always reasonable. Secchi depth probably is the least accurate predictor but also is the most affordable and easiest measure to obtain since it is a subjective visual determination.

1.6 Summary

This chapter presented the basic elements for understanding the concept of water quality including the physical, chemical and biological information and data usually collected from water resources when some sort of an evaluation is required. This information and the assessment procedure that has been described can be applied to any fresh water or salt water lake or pond but were presented here in the context of the process that has been applied and conducted on Nantucket Island ponds since 2009 when the Nantucket Land Council sponsored water quality investigations on Miacomet and Hummock Ponds.

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Nantucket Island Ponds and 2020 Quality

Chapter 2

Water Quality Sampling Protocol

2.0 Background

Water quality sampling generally occurs on Nantucket Island ponds during the ice-free period of the year between April and November. Growth and metabolism in the ponds is highly dependent upon water temperature and the most active growing period in the ponds occurs when the water temperature is 20ºC or greater. This is the time when changes in water quality can occur quite rapidly and it is prudent to adjust the frequency of any sampling schedule to detect water quality changes as they occur.

2.1 Sampling Protocol

Water quality sampling generally occurs at the deepest area of the pond from an anchored boat or kayak. The standardized protocol used when collecting water quality data from any Nantucket Island pond is as follows: (1) depth profiles of temperature and dissolved oxygen (concentration/percent saturation), (2) Secchi depth transparency, (3) the collection of pond water to be analyzed for total phosphorus, a series of nitrogen analytes, chlorophyll ***a***, algal toxins (when warranted), specific conductance, pH and (4) a preserved sample of the phytoplankton community. Table 2.1 summarizes the water quality parameters that typically are sampled on Nantucket Island ponds.

Table 2-1. Parameters monitored to assess the short-term water quality of Nantucket Island ponds.

Physical
water temperature
Secchi depth transparency
water color
Chemical
phosphorus series (total phosphorus, soluble reactive phosphorus ortho-phosphorus)
nitrogen series (total nitrogen, total Kjeldahl nitrogen, ammonia-nitrogen and nitrate-nitrogen)
pH
specific conductance
dissolved oxygen
total dissolved solids
Biological
phytoplankton community response
- Chlorophyll ***a***, species composition, diversity, relative abundance, biomass
- Harmful algal blooms including species identification and toxin analysis

2.2 Methodology

This section describes the field procedures that are used to collect samples and the processing that occurs, following sample collection.

Routine data collection, sample collection and processing. Sample and data collection occurs at the deepest area in each pond using a boat or kayak anchored at the site. All information is recorded on a field sheet. The total depth of the water column is measured with a weighted Secchi disk attached to a marked line, and then recorded. Latitude-longitude is recorded on all sampling visits using a Garmin GPS 60™ unit.

Secchi depth transparency (SDT) is measured using a standard 20 cm weighted disk. Measurements are taken on the side of the boat away from direct sunlight in order to avoid surface glare which could interfere with the readings. The disk is lowered into the water column to the depth at which it just disappears, and this depth is noted. The disk then is raised from out of the range of visibility to the depth where it first re-appears, and this depth is noted. The average of the 2 depths is recorded as the SDT on that sampling date.

Vertical profiles of water temperature-dissolved oxygen are measured *in-situ* at 1-foot or 2-foot intervals on each sampling date using a Yellow Springs Instrument (YSI) ProODO™ optical Dissolved Oxygen meter.

Water samples for chemistry, phytoplankton and chlorophyll *a* analyses are collected from the pond following a determination of whether the water column is stratified either thermally or based on oxygen saturation. The upper zone of the water column at similar temperature or dissolved oxygen percent saturation is sampled using the integrated hose technique; the lower zone of different temperature or oxygen percent saturation is sampled with a horizontal Van Dorn sampler. The collected water samples are transferred to clean, pre-rinsed 500-mL polyethylene (PE) amber sample bottles and stored on ice and in the dark until processed for shipment, usually within 2 hours of collection.

A subsample of the ***upper*** region raw water is poured into a 125 mL amber PE bottle for phytoplankton identification and enumeration, preserved with glutaraldehyde solution, labeled with collection information.

A subsample of water collected from the ***upper*** and ***lower*** regions of the water column is analyzed on-site for specific conductance, total dissolved solids, and pH using an Ultrameter II™ (Myron L Company).

The samples collected for nutrient chemistry and chlorophyll ***a*** are prepared for shipment immediately following each pond visit. The 500 mL amber PE bottles are placed in a Styrofoam cooler with gel packs and shipped via FedEx (2nd day delivery) to the Darrin Fresh Water Institute (DFWI) Laboratory in Bolton Landing, New York, a field station affiliated with Rensselaer Polytechnic Institute in Troy, New York. A Chain of Custody form accompanies the samples to the analytical lab.

N.B.: Prior to the beginning of the 2020 sampling season on the Nantucket ponds, the COVID-19 pandemic forced closure of the DFWI Laboratory during March. In view of this situation, and in an effort to complete the 2020 sampling schedule, the Nantucket Land Council (NLC) initiated a contract with the Phoenix Environmental Laboratories, Inc. in Manchester CT for the analytical chemistry related to the water quality program. In contrast to the analytes previously tested on Nantucket Island ponds, Phoenix did not include either soluble reactive phosphorus or total nitrogen in their list of analytical services, so ortho-phosphorus and total Kjeldahl nitrogen were analyzed instead (Table 2-1).

Depending upon conditions observed at each pond, a subsample of raw water collected from the near-shore upper region is tested for the presence of algal toxins (cyanotoxins) using a Eurofins Abraxis®, LLC Algal Toxin Strip Test for Finished Drinking Water. The tests were designed to screen for the presence/absence of toxins in pond water and to facilitate appropriate follow-up based upon the results. Since 2013 was the first season that this screening process was used on Nantucket Island ponds, samples of raw pond water also are shipped to GreenWater CyanoLab in Palatka, Florida for a PTOX (potentially toxigenic cyanobacteria) Screen and further cyanotoxin analysis, if warranted. A 125 PE bottle containing about 100 mL of raw pond water is placed in a small cooler with gel packs and shipped FedEx overnight to the lab.

2.3 Analytical Techniques

Water Column Measurements and Collection of Samples. The methods and protocol for water column measurements and sample collections on Nantucket Island ponds are summarized below in Table 2.2.

Table 2-2. Physical, chemical and biological parameters included in the study of water quality on Nantucket Island ponds, their collection technique and methodology.

PARAMETER	COLLECTION TECHNIQUE	ANALYTICAL METHODOLOGY
Physical Characteristics (Light, Dissolved Oxygen, Secchi, Temperature)	Vertical profiles at 2-foot intervals (except Secchi) at deep site	Standard Secchi protocol; YSI Pro ODO dissolved oxygen-temperature meter;
Chemical Characteristics (pH, TDS, conductivity, NO_3, TN, TKN,TP, SRP, Ortho-P	Integrated upper region sample; lower region grab sample at least 1 foot above bottom sediment	Ion Chromatograph, Atomic Absorption, Autoanalyzer, Spectrophotometer, pH meter
Biological Characteristics - Phytoplankton	Integrated photic zone sample	chlorophyll ***a***, genus and species identification and enumeration
Biological Characteristics - Phytoplankton	Integrated photic zone sample	cyanotoxin analysis (if warranted)

The analytical procedures for water chemistry generally are determined by the specific analytical laboratory that receives the collected samples for analysis. The DFWI analytical procedures are shown in Table 2-3.

Phytoplankton quantification methods. During the 2020 sampling season, the NLC established a contract with Dr. Barry Rosen, a professor at Florida Gulf Coast University who specializes in the study of harmful algal blooms (HABs), for the identification and enumeration of Nantucket phytoplankton samples. The following protocol describes the process used by Dr. Rosen for the microscopic examination of phytoplankton for identification and enumeration of pond samples collected with the integrate hose technique.

Table 2-3. Chemical parameters and analytical methods utilized in the water quality studies on Nantucket Island ponds.

Parameter	Analytical Method
pH	Electrometric, Standard Methods (2017), Method 9040C
Specific Conductance, TDS	Wheatstone Bridge-type meter, Standard Methods (2017), Method 9050A
Oxygen, Dissolved	Optical Probe Method, Standard Methods (2017), Method 4500-O
Inorganic Anions (Cl, NO_3, SO_4)	Ion Chromatograph, Standard Methods (2017), Method 300.0
Total Nitrogen	Persulfate Method, Standard Methods (2017), Method 4500-N D
Phosphorus (total)	Persulfate Oxidation, Ascorbic Acid Method, Standard Methods (2017), 4500-P E
Phosphorus (soluble reactive)	Ascorbic Acid Method, Standard Methods (2017), 4500-P E
Chlorophyll	Fluorometric, Standard Methods (2017), 10200

Samples received for quantification and identification were preserved with 2 percent glutaraldehyde and shipped cold within 24 hours. The samples are processed by measuring/recording volume with a 500 mL graduated cylinder. One mL of Lugol's (iodine and potassium iodide) is added to the sample in the graduated cylinder assist with settling of organisms. After 24 hours, the liquid above the 100 mL is aspirated and discarded, leaving a concentrated sample. The remaining sample is transferred to a 100 mL graduate cylinder for another 24-hr settling period; the upper 90 mL is aspirated and discarded, leaving a 10 mL concentrate of the original sample. These samples are stored in labeled, 10 mL plastic centrifuge tubes and kept refrigerated until examined microscopically, typically within a 3-day period. In some instances, the preserved samples do not require any concentration due to the abundance of organisms present in the original sample. All concentration values and subsequent calculations to determine the final cells or natural units per mL are recorded in an Excel spreadsheet.

The microscopic method utilizes a calibrated nanoplankton counting chamber (PhycoTech Inc.) with known volume and depth of the 16 mm circular chamber. The same chamber is used for the entire project. To fill the chamber, the 10 mL (or unconcentrated sample) is vigorously shaken for 15 seconds, and a new clean Pasteur pipet is used to fill the chamber. Counting proceeds by identifying and enumerating the number of cells or natural units (identified in the Excel spreadsheet) at 400x. With low-density samples, the entire chamber is counted, with the goal of encountering a minimum of 400 organisms. In a few instances, the samples have too few organisms to achieve this goal. In high-density samples, 1-4 "strips" down the full length of the chamber, is sufficient to achieve or exceed the target of 400 organisms. The width of the field of view is measured with a stage micrometer, and along with the known depth of the chamber (calibrated by PhycoTech), the volume counted and enumerated is calculated and subsequently used to determine the number of cells or natural units in the Excel spreadsheet.

Images are generated for most of the organisms encountered and assigned a column in the spreadsheet and arrayed by phytoplankton division to create a permanent record of the count/identification notes even if future taxonomic changes lead to organism name changes. New columns are inserted as needed throughout the season as different organisms are encountered. Live samples are cultivated to ensure key morphological features (akinetes and heterocytes) develop for species identification of the filamentous cyanobacteria.

Taxonomic treatment followed the characteristics described by Komárek (2013).

HABs-related analyses. All samples that require additional analyses related to HABs are submitted to GreenWater Laboratories (CyanoLab) in Palatka Florida 32177. During any particular year of water quality sampling, these samples could include raw water and either glass fiber filters or liquid aerosol samples collected by the 2 prototypes of Air Sampling Devices (ASDs) described in the next section of this chapter.

The raw water samples would first be subjected to a potentially toxigenic (PTOX) cyanobacteria screen (see below) and then analyzed for specific cyanotoxins if warranted by the results of the screen. The filters and liquid aerosol samples from the ASDs would be subjected to cyanotoxin analyses as described below.

Sample Preparation

Potentially toxigenic (PTOX) cyanobacteria screen

One mL aliquots of each non-preserved sample are prepared using Sedgwick Rafter cells. The samples are scanned at 100X for the presence of potentially toxigenic (PTOX) cyanobacteria using a Nikon TE200 Inverted Microscope equipped with phase contrast optics. Higher magnification is used as necessary for identification and micrographs.

Water Sample Ultrasonication

The received samples are inverted for 60 seconds to mix. A subset from the sample is removed prior to cell lysis for algal identification purposes. A second subset (100 mL) from the sample is sonicated to release toxins and prepared for analyses. Dilution (DI) is used for Adda MC ELISA to achieve data within range of the calibration curve.

ASD Liquid Impinger Sample Freeze-Thaw and Preparation

The samples are inverted for 60 seconds to mix. A subset from each sample is transferred to a 15 mL vial. Three freeze-thaw cycles are employed prior to additional sample preparation and subsequent analysis. Aliquots (300 µL) are prepared (including a Lab Fortified Sample Matrix[LFSM]), blown to dryness (60°C N_2), reconstituted (1x) with 10 mM phosphate buffer (pH 7) for analysis using ELISA. Aliquots prepared for ATX are spiked with Internal Standard with a LFSM, and filtered 0.2 µm PVDF prior to LC-MS/MS.

ASD Glass Fiber Filter Homogenization and Extraction

The filter is folded, cut into strips (<1 mm), and transferred to a glass 15 mL tube. Batch control filters are prepared in the same manner. IS ([13C4]-ATX) is added to each filter (Table 3). Extractant (75% acetonitrile in 0.1 M acetic acid) is added (5 mL) to each tube and sonicated for 25 min. Samples are centrifuged at 3000 RPM for 15 minutes (5°C), supernatants retained, and the pellets rinsed by vortex mixing 2 mL of extractant followed with centrifugation. The pooled supernatants are split and evaporated (N_2; 60°C). One subset is reconstituted in 0.5 mL DI, filtered (0.2 µm PVDF), and analyzed for ATX. The second subset is oxidized for MMPB analysis.

MMPB Oxidation

Filter extracts are oxidized in 0.1 M K_2CO_3, 0.05 M $KMnO_4$ and 0.05 M $NaIO_4$ for 1 hour, stopped with the addition of 40% sodium bisulfite and cleaned using 100 mg Strata X solid phase extraction (SPE). The extracts are spiked with IS (*d3*-MMPB), reconstituted in DI, filtered through 0.2 µm PVDF and analyzed for MMPB.

Analytical Techniques

Enzyme-Linked Immunosorbent Assay (ELISA)

MCs/NODs

A microcystins/nodularins Adda ELISA (Abraxis) is utilized for the quantitative and sensitive congener-independent detection of MCs/NODs (US EPA Method 546 & Ohio EPA DES 701.0). The current assay is sensitive down to a quantification limit of 0.30 ng/mL (ppb) based on kit sensitivity, dilution factors and initial demonstration of capability.

Liquid chromatography mass spectrometry/mass spectrometry (LC-MS/MS)

ATX

The [M+H]+ ion for ATX (*m/z* 166) was fragmented and the product ions (*m/z* 91, 131, 149) were monitored. The [M+H]+ ion for the internal standard [13C4]-ATX (171 *m/z*) was fragmented and the product ion (153 *m/z*) was monitored. The internal standard method was utilized for quantification.

MMPB

The [M-H]- ion of MMPB (*m/z* 207) is fragmented and the product ion (*m/z* 131) is monitored. The internal standard (*d3*-MMPB) is also fragmented and monitored (*m/z* 210□131). The internal standard method is implemented using a standard curve (0.25 – 10 ng/mL of oxidized MC-LR) to calculate LFSM returns. A signal to noise ratio of 3 is used for the method detection limit.

2.4 Air Sampling Devices

During 2019 and 2020, we attempted to collect aerosol samples along the Capaum Pond shoreline during wind events to capture airborne particles that might be either aerosolized cyanotoxins or picocyanobacteria containing cyanotoxins released from the surface of the pond. As described below, several different prototypes of Air Sampling Devices (ASDs) were developed to capture potential airborne particles

Glass Fiber Filter ASD. During 2019, air samples were collected with a prototype field-deployable ASD that used a vacuum pump to draw air through a glass fiber filter. This ASD was designed to replicate traditional air sampling methods as used in comparable industrial hygiene and air pollution studies (Lodge 1956, Kang and Frank 1989, Gordon et al. 1992).

The ASD uses a 12 V vacuum pump (-65 kpa, Hilitand, Shenzhen, Guangdong, China) to draw air through a 37 mm glass fiber filter (#IW-AE3700, Zefon International, Ocala, FL, USA). The filter has a mean pore size of 3.6 microns, although the nature of the filter matrix (i.e., deep mesh with random orientations) means that much smaller particles potentially could be captured (Lindsley 2016). The pump is housed in a weatherproof box and connected to the filter apparatus with 2 m of 6.35 mm i.d. (internal diameter) clear tubing (#3010-0252, Zefon International, Ocala, FL, USA). The filter apparatus includes a 20.32 cm i.d. PE (polyethylene) funnel (Plews & Edelmann, Dixon, IL, USA) fitted at the tapered end with a filter cassette (#37MMH-3-PP, Zefon International, Ocala, FL, USA), mounted on a tripod (#ZA0042, Zefon International, Ocala, FL, USA).

Figure 2-1 shows the Glass Fiber Filter ASD deployed along the pond shoreline and the installed filter cassette in the funnel at the head of the system.

Figure 2-1. Glass fiber filter ASD showing filter cassette installed in the intake funnel.

Individual filters were added to the cassette for the duration of each ASD deployment. Following each deployment, filter cassettes were collected, placed in a sealed sterile sample bag (Whirl-Pak®, Nasco, Madison, WI), and frozen until shipment overnight to GreenWater Laboratories.

Liquid Impinger ASD. During 2020, a second prototype ASD was developed to capture airborne particles in a liquid medium instead of on the surface of a glass fiber filter. The design of these prototypes is similar in many ways in that they both make use of small battery-operated vacuum pumps to collect air samples. The impinger sampler has the benefit of collecting aerosol particles in a liquid medium, allowing for a broader range of analyses to be run on each sample.

2.5 Sensor Deployments

The observation of HABs occurring In Nantucket ponds in recent years raises concerns over ecosystem sustainability and community health and safety. The documentation of a sustained HAB on Capaum Pond during 2019 suggests this location may present a good opportunity to study the life cycle of a HAB in these systems in order to better monitor and predict their occurrence and understand their potential harm to people and ecosystems.

During 2020, we deployed buoy-mounted and bottom-mounted environmental sensors to collect high-frequency measurement data at Capaum Pond. These types of sensors are widely deployed by the scientific community and generally have an unobtrusive presence. Our goal was to identify conditions and processes antecedent to the formation of, and perpetuation of, HABs on the pond. The sensors generate weather, water quality, chlorophyll ***a***, and phycocyanin (a pigment that HABs produce) measurements. We anticipated having access to some of the data in near real-time, allowing for some analysis as the season progresses. Other data is logged internally within the sensors and collected at the end of the season when the deployment is recovered from the pond. We envisioned a multi-year research effort including deployments during the 2020 and 2021 seasons (June-November).

A brief narrative describing the sensor equipment deployed at Capaum Pond and a schematic of the sensor arrangement on the buoy and raft is presented in Attachment #1 at the end of this report.

2.6 Summary

This chapter presented the standard protocol currently used when sampling Nantucket Island ponds for water quality. The use of consistent sampling techniques ensures that the most accurate water quality assessments and evaluations are performed even if several different personnel conduct the sampling during the growing season.

2.7 Literature Cited

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Nantucket Island Ponds and 2020 Water Quality

Chapter 3

Capaum Pond

3.0 Introduction

This chapter presents a summary and discussion of the physical, chemical and biological data collected from Capaum Pond by the Nantucket Land Council, Inc. (NLC) during 2020.

Capaum Pond was sampled at about 2-week intervals beginning on June 2nd and ending on October 20th for a total of 11 sampling excursions. Table 3-1 summarizes the 2020 sampling dates.

Table 3-1. Summary of 2020 sampling dates at Capaum Pond.

June	July	August	September	October
2nd	14th	11th	8th	6th
16th	28th	25th	29th	20th
30th				

The pond always was sampled at about the center which was the deepest region of the water column. Following the collection of temperature and dissolved oxygen profile data on all sampling dates, integrate (***upper***) and grab (***lower***) samples were collected from the pond depths as shown in Table 3-2 below.

Table 3-2. Summary of Capaum Pond integrate and grab sample depths, 2020.

Sampling Date	integrate (*upper*) sample depth	grab (*lower*) sample depth
June 2nd	0-1.8 meters	na
June 16th	0-1.8 meters	na
June 30th	0-1.8 meters	na
July 14th	0-1.2 meters	na
July 28th	0-1.2 meters	na
August 11th	0-1.2 meters	na
August 25th	0-1.2 meters	1.8 meters
September 8th	0-1.2 meters	na
September 29th	0-1.2 meters	na
October 6th	0-1.2 meters	na
October 20th	0-1.2 meters	na

Raw water samples were collected from Capaum Pond for Eurofins Abraxis® test strip analyses on 6 dates when the pond was checked visually along the shoreline for evidence of HABs. There also was extensive field work conducted with the cyanotoxin Air Sampling Device (ASD) which will be explained later in this report.

3.1 Results

3.1.1 Physical characteristics

General. Capaum Pond has an irregular shape with its long axis oriented in a north-south direction as shown in Figure 3-1.

Figure 3-1. Aerial view of Capaum Pond (from *Google*™ earth).

The pond is located along the north shore toward the western end of Nantucket Island, ~600 meters north of the intersection of Cliff, Madaket and Eel Point Roads. The pond surface area is ~18 acres. There are no tributaries flowing into the pond and the pond has no outlet. The pond is separated from Nantucket Sound, to the north, by a high sand berm that runs parallel to the shoreline.

Table 3-3 summarizes the 2020 physical data collected from Capaum Pond including (1) total depth at the sampling station, (2) Secchi depth transparency (SDT) and (3) the average water column temperature.

Table 3-3. Summary of physical data collected from Capaum Pond during 2020.

Capaum Pond 2020 Physical Data			
Sampling Date	Total depth (m)	Secchi depth (m)	Average Water Column Temperature (°C)
June 2nd	2.13	1.55	20.3
June 16th	2.03	1.42	19.0
June 30th	2.18	0.53	24.3
July 14th	1.83	0.79	26.3
July 28th	1.83	0.36	27.1
August 11th	1.83	0.33	26.8
August 25th	1.91	0.71	26.1
September 8th	1.83	0.30	24.4
September 29th	1.68	0.84	21.6
October 6th	1.68	0.58	18.1
October 20th	1.68	0.79	15.5

The maximum depth of Capaum Pond during 2020 was 2.18 meters (m), which is 7.2 feet (ft); the minimum depth was 1.68 m which is 5.5 ft. Slight differences in the total depth at the sampling locations during the 2020 season likely were due to slightly different locations for anchoring and sampling and evaporation of water from the surface of the pond.

Transparency. The 2020 SDT measured at Capaum Pond (Table 3-3) ranged from a low value of 0.30 m (1.0 ft) to a high value of 1.55 m (5.1 ft) and averaged 0.75 m (2.5 ft), indicating very low light penetration from the pond surface down through the water column. Transparency of the water column is one of the criteria that is used to define the status of water quality and will be discussed later in this chapter.

Field notes indicate that water color on the various 2020 sampling dates was listed as 'green', a term that generally indicates high algal density or an algal bloom in progress.

Temperature. The shallow nature of Capaum Pond precludes any significant temperature differences between the pond surface and bottom. Temperature differences between the surface and bottom were less than 1°C on all 11 sampling dates during 2020. Attachment 1 at the end of this report presents the 2020 temperature and dissolved oxygen percent saturation profile graphs for Capaum Pond.

3.1.2 Chemical characteristics

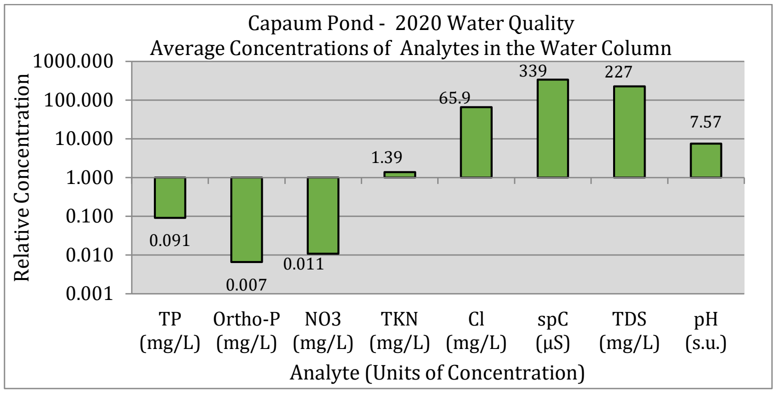
The *average* values for the 2020 chemical properties measured in the integrate water samples collected on each sampling date from Capaum Pond are summarized in Table 3-4.

Table 3-4. Summary of 2020 chemical characteristics of integrate samples collected from Capaum Pond.

	Capaum Pond 2020 Chemical Properties								
Sampling Date	Avg DO % saturation	TP (mg/L)	Ortho-P (mg/L)	TKN (mg/L)	NO_3-N (mg/L)	Cl (mg/L)	spC (µS/cm)	TDS (ppm)	pH (s.u.)
June 2nd	98.6	0.036	0.005	0.77	0.01	56.3	254	169	6.40
June 16th	105.3	0.068	0.005	0.86	0.01	57.4	310	211	6.27
June 30th	107.6	0.073	0.005	0.88	0.01	59.5	268	175	6.62
July 14th	110.6	0.074	0.005	0.81	0.01	61.7	307	210	6.72
July 28th	146.2	0.093	0.005	1.95	0.02	63.3	271	178	9.77
August 11th	126.8	0.153	0.005	1.98	0.01	65.6	277	184	9.48
August 25th	82.3	0.214	0.023	3.06	0.01	67.8	790	522	6.56
September 8th	147.5	0.088	0.005	1.24	0.01	71.5	299	199	9.62
September 29th	111.1	0.060	0.005	1.12	0.01	73.8	301	201	7.57
October 6th	127.7	0.090	0.005	1.42	0.01	73.5	349	238	7.19
October 20th	111.0	0.056	0.005	1.15	0.01	74.6	309	208	7.03
average 2020 value	115.9	0.091	0.007	1.39	0.01	65.9	340	227	7.57
all values shown are for the ***upper*** region of the water column highlighted cells = values reported are one-half the lower detection limit									

The water column data summarized above also are presented in Figure 3-2. The reader should note that the ***y*-axis** in Figure 3-2 is depicted in logarithm scale to best display the wide range of 2020 *average* analyte values presented in the figure.

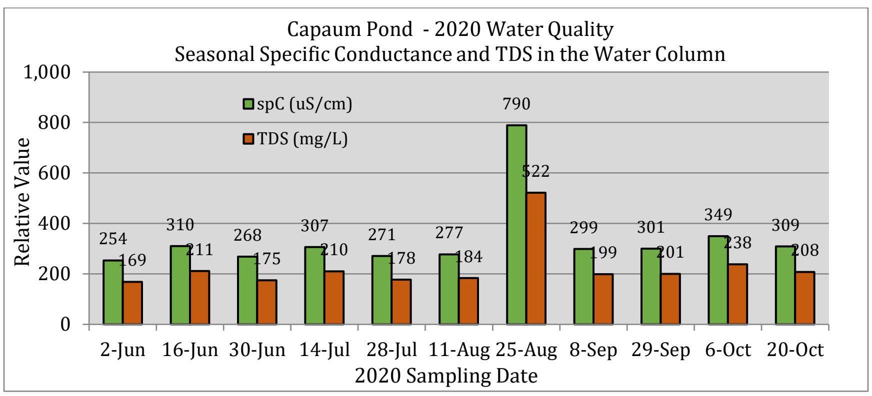
Figure 3-2. Average concentrations of 2020 water column chemical parameters measured in Capaum Pond.



A ***lower*** region sample was collected only during the August 25th field excursion and is not summarized in the table or figure above.

Specific conductance and Total Dissolved Solids (TDS). The specific conductance and corresponding TDS values measured in the water column of Capaum Pond during 2020 are presented in Figure 3-3.

Figure 3-3. Summary of 2020 specific conductance and TDS measured in Capaum Pond.



Both analytes exhibited a single high concentration which occurred on August 25th; an explanation for this substantial increase is not certain but could be due to excessive salt water spray from Nantucket Sound, which is directly adjacent to Capaum Pond, during a period of high winds from the north or northeast.

The 2020 specific conductance in the pond ranged from 254 to 790 µS·cm during the sampling season, while TDS ranged from 169 to 522 mg/L. The relationship between these two analytes in Capaum Pond is defined by the following equation

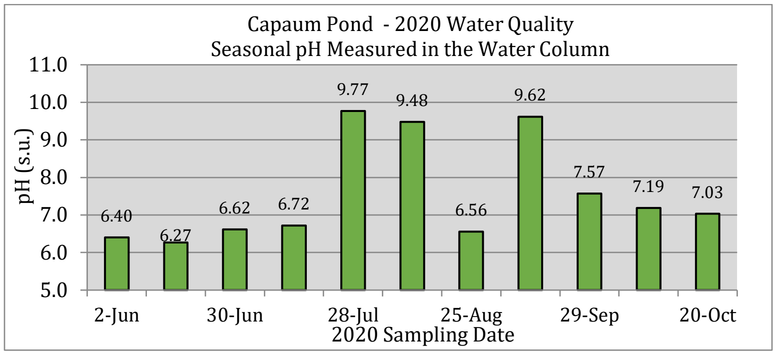
$$\boldsymbol{y = 0.6596x + 2.7851}$$

where ***y*** is TDS, ***x*** is the known value of specific conductance and R^2 = 0.9989. The relative conductance and TDS values measured in Capaum Pond are considered high within the range of values expected from ponds considered to be fresh water and this feature probably is due to the close proximity of the pond to Nantucket Sound and the influence of high winds and salt water spray which mixes with the water column periodically and increases levels of both these analytes.

pH. The pH data collected from Capaum Pond during the 2020 sampling season are summarized in Figure 3-4. The values in the water column ranged from 6.27 to 9.77 s.u. among the 11 sampling dates, and the *average* pH value for the entire season was 7.57 s.u.

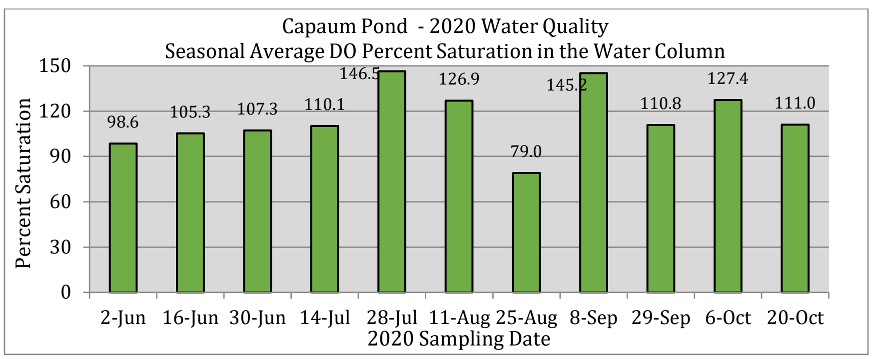
The high pH values recorded on July 28th (9.77 s.u.), August 11th (9.48 s.u.) and September 8th (9.62 s.u.) reflect a considerable imbalance between pond respiration and photosynthesis which can result when intense algal blooms occur during the growing season.

Figure 3-4. Summary of 2020 pH values measured in Capaum Pond.



Dissolved oxygen concentration-percent saturation. The 2020 *average* percent saturation values measured for the water column at Capaum Pond are presented in Figure 3-5.

Figure 3-5. Summary of 2020 dissolved oxygen percent saturation measured in Capaum Pond.5



The values were above saturation (100 percent) on all but two (2) sampling dates, June 2nd (98.6%) and August 25th (79.0%), and the 2020 values averaged 115.9 %. The highest percent saturation values during 2020 occurred on the same dates (July 28th, August 11th, and September 8th) that the highest pH values were measured in the water column.

There was little, if any, difference in the dissolved oxygen percent saturation profile values measured between the surface and the pond bottom on any of the 11 sampling dates, which likely was due to the extreme shallow nature of the ponds and the regular periods of wind that blow across the Island and mix the entire shallow water column. The DO percent saturation water column profile graphs for Capaum Pond are presented in Attachment #2 at the end of this report.

3.1.3 Plant Nutrients

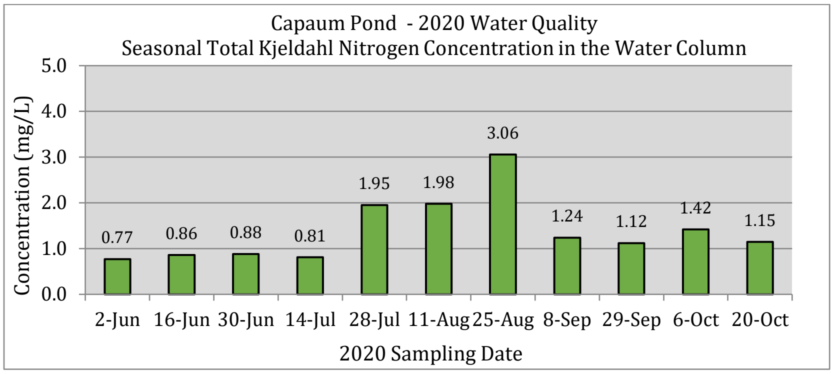
Nitrogen. Nitrate-nitrogen was detected in the water column of Capaum Pond only on the July 28th sampling date (0.02 mg N·L); otherwise, all of the other **nitrate-nitrogen** concentrations were below detection (0.005 mg $N \cdot L^{-1}$) in the remaining samples collected during 2020.

Although **ammonia-nitrogen** was not one of the 2020 analytes included in the water quality test pattern, previous experience with measuring this form of nitrogen in Nantucket Island ponds had shown that concentrations in the water column always were near or below detection (reference report). This phenomenon is not unusual in ponds during the growing season because this form of nitrogen as well as **nitrate-nitrogen** is readily taken up by phytoplankton in the water column for growth and metabolism when it is available.

As mentioned previously, **total nitrogen** (**TN**) was not measured at the Phoenix Environmental Laboratories; t**otal Kjeldahl nitrogen** (**TKN**) was analyzed instead. **TKN** includes **ammonia**, **organic** and **reduced forms** of nitrogen and along with **nitrate-nitrite nitrogen** can be used to calculate **TN**. Because **nitrate-nitrogen** was below detection in all but one sample collected from Capaum Pond during 2020, the concentration of **TKN** measured in the pond reflects the total nitrogen concentration.

The **TKN** concentrations measured in Capaum Pond during 2020 are summarized below in Figure 3-6.

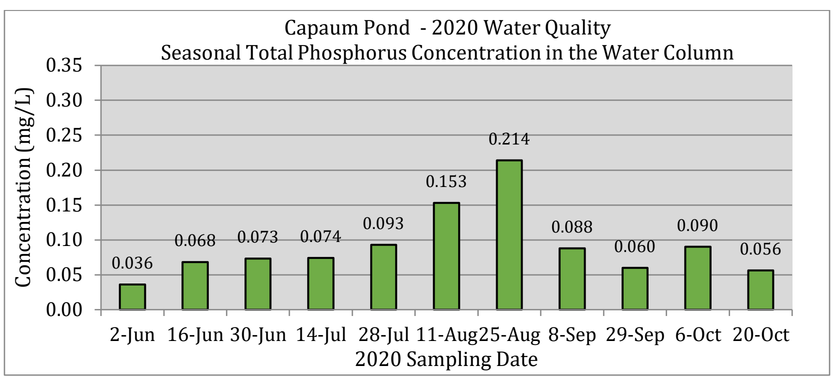
Figure 3-6. Summary of 2020 total nitrogen concentrations measured in Capaum Pond.



The **TKN** values ranged from 0.76 to 3.06 mg N·L across all sampling dates and the *average* concentration for the season was 1.39 mg N·L. Based upon the very low concentrations of **nitrate-nitrogen** and, presumably, **ammonia-nitrogen**, in the water column**,** essentially all of the **total nitrogen** measured was contained in organic material in the form of phytoplankton and seston (other organisms and non-living particulate matter floating in the water column and possibly re-suspended from the bottom sediment during periods of high wind velocity blowing across the surface of the pond).

Phosphorus. The **total phosphorus** (**TP**) concentrations measured in Capaum Pond during 2020 are summarized in Figure 3-7.

Figure 3-7. Summary of 2020 total phosphorus concentrations measured in Capaum Pond.



The **TP** concentrations ranged from 0.036 to 0.214 mg P·L during the 2020 sampling season, while the 2020 *average* value was 0.091 mg P·L (Table 3-4).

As also mentioned earlier in Chapter 3, **soluble reactive phosphorus** (**SRP**) was not analyzed by the Phoenix Environmental Laboratories; instead, **ortho-phosphorus** (**OP**), which is equivalent to **SRP**, was analyzed at the laboratory. These forms of phosphorus, when present in the water column, are available for uptake by phytoplankton and also by macrophytes (vegetation) growing in the littoral zone of a water body. The **OP** concentrations measured in the 2020 samples collected from Capaum Pond were below the lower detection limit (0.01 mg P·L) throughout the season except on August 25th, when 0.023 mg P·L was detected.

3.1.4 Phytoplankton

Description of the assemblage. Capaum Pond exhibited a robust phytoplankton community during 2020. Table 3-5 presents a summary of the Capaum Pond phytoplankton community characteristics determined from 10 samples collected during 2020.

Table 3-5. Summary of 2020 Capaum Pond phytoplankton community characteristics.

Capaum Pond Phytoplankton, 2020				
Sampling Date	Total Taxa Identified	Cell Density (cells-colonies-fragments/mL)	Density Diversity [H]	Chl ***a*** Concentration (µg/L)
June 16th	5	4179	0.182	2.31
June 30th	16	1359	0.817	6.84
July 14th	23	3614	0.795	14.9
July 28th	18	14300	0.780	92.4
August 11th	10	29628	0.457	114
August 25th	17	505	0.994	12.5
September 8th	19	2151	1.060	19.2
September 29th	22	2653	0.873	24.1
October 6th	17	16446	0.470	42.3
October 20th	12	18639	0.163	8.4
2020 average	16	9347	0.659	33.7

There were 41 different taxa identified in the 2020 phytoplankton samples collected from the pond and all six (6) major algal groups were represented (Table 3-6).

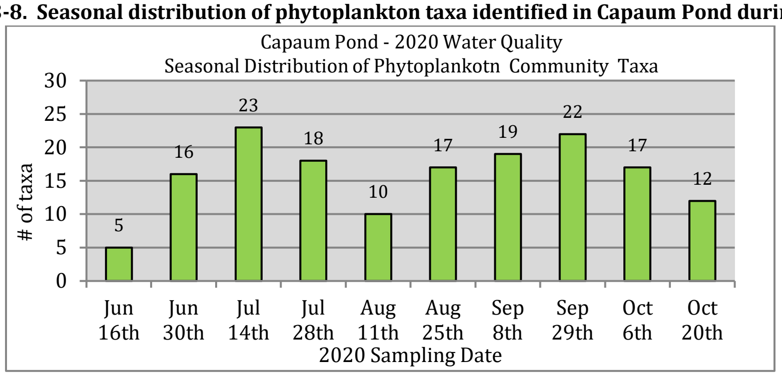
Table 3-6. Major groups, genera and species of phytoplankton identified in Capaum Pond, 2020.

Cyanophyta	Chlorophyta	Chrysophyta (Bacillariophyceae)
Anabaenopsis sp.	*Arthrodesmus* sp.	*Aulacoseria* sp.
Aphanizomenon flo- aquae	*Closterium* sp.	*Cyclotella* sp.
Aphanizomenon gracile	*Coelastrum* sp.	*Navicula* sp.
Aphanocapsa sp.	*Desmodesmus* sp.	*Nitzschia* sp.
Cuspidothrix sp.	*Dictyosphaerium* sp.	*Synedra* sp.
Dolichospermum sp.	*Gleocystis* sp.	**Chrysophyta (Chrysophyceae)**
D. crassum	*Monoraphidium* sp.	*Dinobryon* sp.
D. flos-aquae	*Mougeotia* sp.	*Mallomonas* sp.
D. mucosum	*Pediastrum* sp.	**Euglenophyta**
Limnothrix sp.	*Scenedesmus* sp.	*Phacus sp.*
Microcystis sp.	*Schroedaria* sp.	*Trachelomonas* sp.
Microcystis wesenbergii	*Staurastrum* sp.	**Pyrrhophyta (Cryptophyceae)**
Planktolyngbya limnetica	*Tetraedron* sp.	*Ceratium* sp.
Pseudanabaena sp.	*Tetrastrum* sp.	*Cryptomonad* sp.
Planktothrix sp.		
Woronichinia sp.		

The greatest representation of phytoplankton occurred within the Cyanophytes where at least 16 different taxa were identified including two (2) species of *Aphamizomenon*, at least four (4) species of *Dolichospermum* and two (2) species of *Microcystis* (Table 3-6). The next greatest representation occurred within the Chlorophytes (green algae), where 14 different taxa were identified.

The number of phytoplankton taxa identified in the water column exhibited a slight bi-modal distribution during the 2020 sampling season (Figure 3-8).

Figure 3-8. Seasonal distribution of phytoplankton taxa identified in Capaum Pond during 2020.

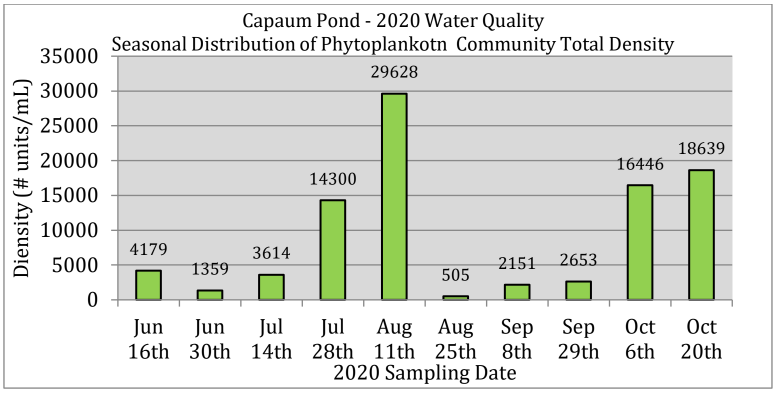


This is the same pattern exhibited by the phytoplankton community total density during 2020 (Figure 3-9).

The 2020 phytoplankton community richness in Capaum Pond was calculated to be 15.9 ± 5.5 taxa.

Density. Phytoplankton community density in Capaum Pond in the 10 samples collected from the pond during 2020 is summarized in Figure 3-9.

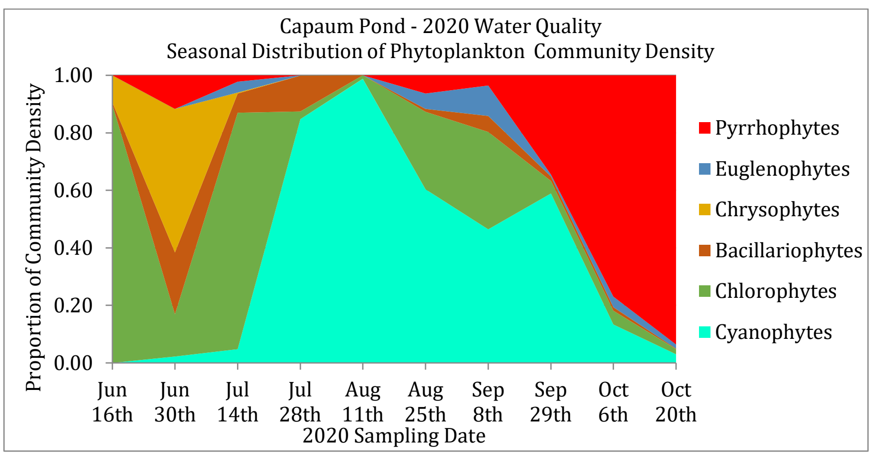
Figure 3-9. Summary of 2020 phytoplankton community density in Capaum Pond.



Community density ranged from 505 to 29,628 units (cells-colonies-fragments) per mL during the 2020 season and exhibited peaks during the July 28th to August 11th and the October 6th to October 20th sampling dates. Otherwise, 2020 density of the phytoplankton community in Capaum Pond was rather sparse.

The seasonal density composition of the 2020 phytoplankton community in Capaum Pond based upon major class is presented in Figure 3-10.

Figure 3-10. Density composition of the 2020 phytoplankton community in Capaum Pond.



Most of the Capaum Pond phytoplankton community dynamic exhibited during 2020 involved alterations of density dominance early in the season (June and early July) involving the Chlorophytes (green algae), Chrysophytes and Bacillariophytes (diatoms).

During July, August and September, the Cyanophytes were dominant, along with the Chlorophytes and increasing numbers of Pyrrhophytes.

Later in the season, from September 29th through October 20th, the Cyanophytes declined, and the Pyrrhophytes became the dominant forms in the water column. Pyrrhophytes include fire algae, primarily dinoflagellates, which are marine forms, often associated with 'red' tide.

Dominance. A ranking of 2020 phytoplankton dominance in Capaum Pond was conducted based upon the community density exhibited by various taxa that were identified during the sampling season. Taxa are considered dominant in the community if they comprise at least 5 percent or more of the total phytoplankton density. The results of this ranking of density within the 2020 phytoplankton community are presented in

Table 3-7. The data summarized in Table 3-7 demonstrate the significant changes that can occur during a 5-month period within the phytoplankton community with regard to the composition of density-dominant taxa, and particularly the rise-and-fall of major classes of phytoplankton within the community.

Table 3-7. Rank of 2020 phytoplankton density dominance in Capaum Pond.

Sampling Date	Genus (species when known) (Major Group)	Density Rank	% of Total Density
June 16th	*Mougeotia* sp. (Chlorophyta)	1	88.8
	Dinobryon sp. (Chrysophyta)	2	9.5
June 30th	*Mallomonas* sp. (Chrysophyta)	1	28.9
	Dinobryon sp. (Chrysophyta)	2	21.0
	Synedra sp. (Bacillariophyta)	2	21.0
	Cryptomonad sp. (Pyrrhophyta)	4	10.5
	Mougeotia sp. (Chlorophyta)	5	8.8
July 14th	*Mougeotia* sp. (Chlorophyta)	1	45.0
	Schroedaria sp. (Chlorophyta)	2	23.8
	Monoraphidium sp. (Chlorophyta)	3	9.7
July 28th	*Planktolyngbya limnetica* (Cyanophyta)	1	44.0
	Woronichinia sp. (Cyanophyta)	2	13.5
	Aulacoseria sp. (Bacillariophyta)	3	11.0
	Pseudanabaena sp. (Cyanophyta)	4	9.4
	Aphanizomenon flos aquae (Cyanophyta)	5	9.2
	Aphanizomenon gracile (Cyanophyta)	6	7.2
August 11th	*Limnothrix* sp. (Cyanophyte)	1	70.8
	Planktolyngbya limnetica (Cyanophyta)	2	12.2
	Dolichospermum flos-aquae (Cyanophyta)	3	6.2
	Pseudanabaena sp. (Cyanophyta)	4	5.2
August 25th	*Dolichospermum mucosum* (Cyanophyta)	1	27.1
	Cuspidothrix sp. (Cyanophyta)	2	16.2
	Schroedaria sp. (Chlorophyta)	3	13.1
	Microcystis sp. (Cyanophyta)	4	11.9
	Ceratium sp. (Pyrrhophyta)	5	5.3
	Trachelomonas sp. (Euglenophyta)	5	5.3
September 8th	*Microcystis wesenbergii* (Cyanophyta)	1	26.8
	Coelastrum sp. (Chlorophyta)	2	13.4
	Trachelomonas sp. (Euglenophyta)	3	10.6
	Planktolyngbya limnetica (Cyanophyta)	4	8.5
	Staurastrum sp. (Chlorophyta)	5	7.1
	Microcystis sp. (Cyanophyta)	6	5.6
September 29th	*Cryptomonad* sp. (Pyrrhophyta)	1	34.0
	Aphanizomenon flos aquae (Cyanophyta)	2	22.6
	Microcystis wesenbergii (Cyanophyta)	3	11.0
	Dolichospermum crassum (Cyanophyta)	4	9.1
	Dolichospermum sp. (Cyanophyta)	5	6.6
	Microcystis sp. (Cyanophyta)	5	6.6
October 6th	*Cryptomonad* sp. (Pyrrhophyta)	1	76.8
October 20th	*Cryptomonad* sp. (Pyrrhophyta)	1	93.6

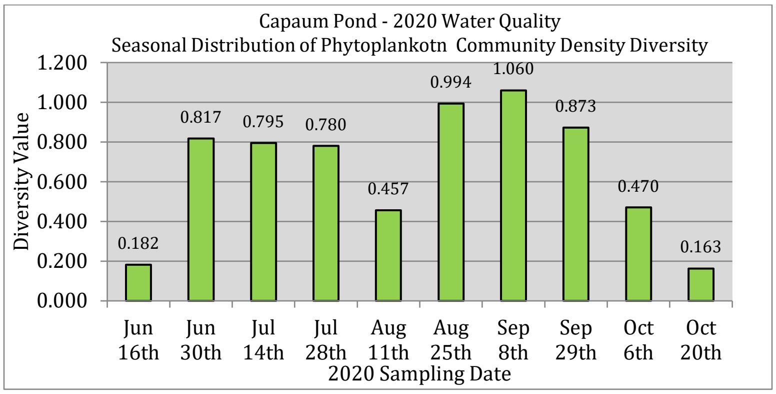
Many of the taxa listed in Table 3-7 above occurred on one or two occasions as density dominants during 2020, while several others such as *Planktolyngbya limnetica*, *Microcystis* sp. and *Dolichospermum* sp. occurred more frequently as dominants in the community.

Most notable in the table above is the rise of the Cyanophytes in community dominance from a minor component during June 16th (0%), June 30th (2%) and July 14th (5%) to the major component on July 28th (85%), August 11th (99%), August 25th (60%), September 8th (46%), September 29th (59%), followed by the rapid decline on October 6th (13%) and, finally, October 20th (3%). Coincident with the dynamics of the Cyanophytes from mid-summer through the end of the season is the absence of the Pyrrhophytes and then their rise to total dominance on the last two sampling dates of the 2020 season.

Diversity. Phytoplankton diversity in Capaum Pond during 2020 was measured using the Shannon-Wiener function[1] which calculates diversity, **[H]**, using number of taxa and the portion of individuals among the taxa on each sampling date. An increase in either factor will increase the diversity index value. Calculated values that approach, or exceed, 1.0 indicate maximum diversity in the distribution of the population.

Diversity calculated for the 2020 phytoplankton community in Capaum Pond using density is summarized in Figure 3-11.

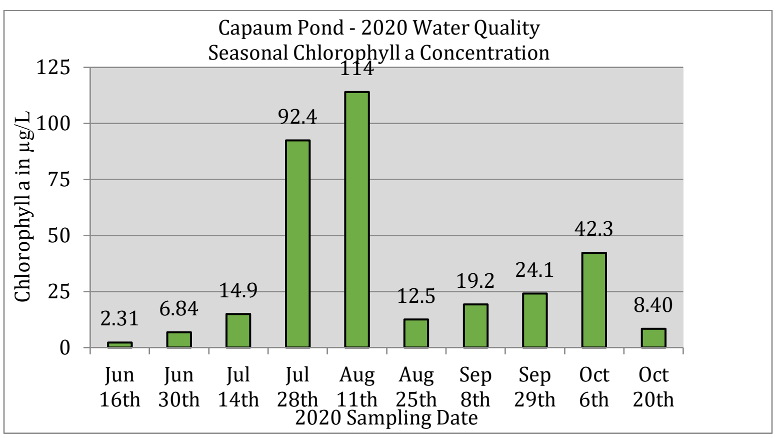
Figure 3-11. Seasonal distribution of 2020 phytoplankton community diversity based upon density.



Community diversity **[H]** was ~0.80 or higher on 6 of the 10 sampling dates during 2020. The lowest value (0.182) occurred on the first (June 16th) sampling date. There also was a drop in diversity to 0.457 on the August 11th sampling date, which was when the highest density occurred in the community (Figure 3-10), and almost the entire community was comprised of Cyanophytes. Furthermore, density diversity exhibited a steady decline from the highest value (1.060) on September 8th through the final and lowest value (0.163) on October 20th.

Chlorophyll *a*. The chlorophyll ***a*** concentrations measured during 2020 are summarized in Figure 3-12.

Figure 3-12. Summary of 2020 Capaum Pond chlorophyll *a* values.

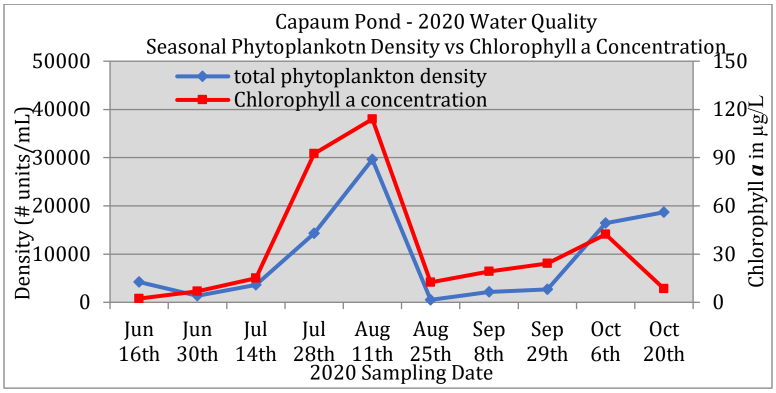


The chlorophyll ***a*** concentration exhibited a major peak and a minor peak during 2020. There was a steady increase from the minimum 2020 value of 2.31 µg ·L on June 16th to the maximum value of 114 on August 11th. Thereafter, the concentration decreased to 12.5 µg ·L on August 28th, then increased to the second seasonal peak at 42.3 µg ·L on October 6th.. The last measurement of the season was 8.40 µg ·L of chlorophyll ***a*** on October 20th. The average concentration during 2020 was 33.7 µg ·L of chlorophyll ***a***.

[1] $H = -\sum_{i=1}^{S} (p_i)\ (log_2)(p_i)$, in units of information per individual per unit volume or area, where p_i is the proportion of the total samples belonging to the ***i***th species and S is the number of species.

Figure 3-13 shows the relationship between phytoplankton density in Capaum Pond during 2020 and the seasonal chlorophyll ***a*** concentration.

Figure 3-13. Relationship between total phytoplankton density and chlorophyll a concentration in Capaum Pond, 2020.



3.1.5 Trophic Status

"Trophic" means nutrition or growth. The trophic state of ponds refers to biological production, plant and animal, which occurs in the pond and the level of production is determined by several factors but primarily phosphorus supply to the pond and by the volume and residence time of water in the pond. Different indicators are used to describe trophic state such as phosphorus, water clarity, chlorophyll ***a***, rooted plant growth and dissolved oxygen. The reader is referred to Chapter 1 for a more thorough explanation of trophic status and the process of calculating this important indicator of productivity.

There were sufficient water quality data collected from Capaum Pond during 2020 to calculate the Carlson Trophic State Index (TSI) using the three most common variables for evaluation (chlorophyll ***a***, total phosphorus, Secchi depth transparency). *Average* values for each variable for the 2020 sampling season were substituted into the appropriate equations (Chapter 1) used to calculate the TSI values for each variable.

The stepwise calculation and results of the analysis are as follows:

Chlorophyll *a*
2020 average chlorophyll ***a*** = 33.70 µg/L
Chlorophyll ***a*** TSI = 9.81*[ln (33.70)] + 30.6
TSI = (9.81)(3.52) + 30.6
TSI = 65.13

Total phosphorus
2020 average total phosphorus = 91.0 µg/L
Total phosphorus TSI = 14.42*[ln (91.0)] + 4.15
TSI = (14.42)(4.51) + 4.15
TSI = 69.18

Secchi depth
2020 average Secchi depth = 0.75 m
Secchi TSI = 60 – [14.41*[ln (0.75)]
TSI = 60 – (14.41)(-0.2932)
TSI = 64.21

The results of the TSI calculations can be interpreted by comparing the trophic index value with the parameters summarized in Table 3-8. Each water quality indicator (i.e., total phosphorus, Secchi depth and chlorophyll ***a***) measured in Capaum Pond resulted in a trophic index that was within the range of 50-70, which denotes a eutrophic condition of productivity.

Table 3-8. Relationships among Trophic Index, chlorophyll *a*, total phosphorus, Secchi depth and Trophic Class (after Carlson, 1996).

Trophic Index	Chlorophyll ($\mu g\ L^{-1}$)	TP ($\mu g\ L^{-1}$)	Secchi Depth (m)	Trophic Class
< 30 - 40	0.0 – 2.6	0.0 - 12	> 8 - 4	Oligotrophic
40 - 50	2.6 – 7.3	12 - 24	4 - 2	Mesotrophic
50 - 70	7.3 - 56	24 - 96	2 – 0.5	Eutrophic
70 – 100+	56 – 155+	96 – 384+	0.5 - <0.25	Hyper-eutrophic

Furthermore, the results from 2020 indicate an improvement in water quality when compared with the Trophic Index results calculated from Capaum Pond during 2019 (Table 3-9).

Table 3-9. Trophic Index results for Capaum Pond - 2015, 2018, 2019 and 2020.

Year	Chlorophyll	TP	Secchi Depth
2015	80.74 (HE)	78.8 (HE)	77.3 (HE)
2018	73.41 (HE)	77.5 (HE)	71.5 (HE)
2019	73.61 (HE)	70.6 (HE)	72.3 (HE)
2020	65.13 (E)	69.18 (E)	64.21 (E)

In fact, it would appear that overall water quality has improved slightly in Capaum Pond since 2015 when monitoring by the NLC first occurred (Table 3-9) and all of the calculations for the Trophic Index parameters were in the hyper-eutrophic range (Trophic Index > 70).

3.2 Summary

Capaum Pond can be characterized as a highly productive body of water that exhibits eutrophic to hyper-eutrophic conditions for the typical parameters used in the assessment of water quality during the growing season. Based upon the composition of the phytoplankton community documented during 2020, recreational use of this pond should be avoided because a variety of Cyanophyte genera occur in the pond that are potentially capable of producing cyanotoxins in the water column.

3.3 Literature Cited

Carlson, R.E., and J. Simpson. 1996. A Coordinator's Guide to Volunteer Lake Monitoring Methods. North American Lake Management Society. 96 pp.

Carlson, R.E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22(2): 361-369.

Nantucket Island Ponds and 2020 Water Quality

Chapter 4

Gibbs Pond

4.0 Introduction

This chapter presents a summary and discussion of the physical, chemical and biological data collected from Gibbs Pond by the NLC during 2020.

Gibbs Pond was sampled about every 2 weeks commencing on June 2^{nd} and ending on October 20^{st} for a total of 10 sampling excursions. The sampling excursion scheduled for October 6^{th} had to be canceled due to the occurrence of an intense harmful algal bloom (HAB) on the pond. Table 4-1 summarizes the 2020 sampling dates on Gibbs Pond.

Table 4-1. Summary of 2020 sampling dates at Gibbs Pond.

June	July	August	September	October
2^{nd}	14^{th}	11^{th}	8^{th}	20^{th}
16^{th}	28^{th}	25^{th}	29^{th}	
30^{th}				

The pond was sampled at about the center which was the deepest area of the water column. Following the collection of temperature and dissolved oxygen profile data on all sampling dates, integrate (***upper***) and grab (***lower***) samples were collected from the pond according to the data provided in Table 4-2.

Table 4-2. Summary of Gibbs Pond integrate and grab sample depths, 2020.

Sampling Date	integrate (*upper*) sample depth	grab (*lower*) sample depth
June 2^{nd}	0-2.4 meters	na
June 16^{th}	0-3.7 meters	na
June 30^{th}	0-2.4 meters	6.1 meters
July 14^{th}	0-1.8 meters	4.9 meters
July 28^{th}	0-1.8 meters	na
August 11^{th}	0-1.8 meters	na
August 25^{th}	0-1.8 meters	4.3 meters
September 8^{th}	0-1.8 meters	4.0 meters
September 29^{th}	0-1.8 meters	4.3 meters
October 20^{th}	0-1.8 meters	na

Raw water samples were collected from Gibbs Pond on 5 occasions for Eurofins Abraxis® test strip analysis when the pond was checked visually for the presence of HABs.

4.1 Results

4.1.1 Physical characteristics

General. Gibbs Pond (Figure 4-1) is located about 3 miles from the eastern end of Nantucket, just north of Milestone Road, and almost opposite the intersection with Tom Nevers Road.

Figure 4-1. Aerial view of Gibbs Pond (from *Google*™ earth).

The pond has a surface area of ~37 acres, an irregular r shape and a maximum depth of about 5.5 m. There is a single outflow, Phillips Run, which flows south into Tom Nevers Pond. The pond receives input from ground water, precipitation and surface runoff from the relatively small watershed.

Table 4-3 summarizes the physical data collected from Gibbs Pond during the 2020 sampling season.

Table 4-3. Summary of 2020 physical data collected from Gibbs Pond.

Gibbs Pond 2020 Physical Data			
Sampling Date	Total depth (m)	Secchi depth transparency (m)	Avg Water Column Temperature (°C)
June 2nd	5.6	0.64	18.1
June 16th	4.9	0.51	20.3
June 30th	6.4	0.41	22.5
July 14th	4.9	0.33	25.4
July 28th	5.2	0.25	26.6
August 11th	4.6	0.25	26.4
August 25th	4.3	0.33	24.3
September 8th	4.1	0.33	23.3
September 29th	4.9	0.46	19.1
October 20th	4.9	0.36	14.9

The maximum sampling depth of Gibbs Pond fluctuated during 2020 as a result of slightly different sampling locations and the fact that the pond is used to irrigate the adjacent cranberry bogs which would reduce overall water level.

Transparency. The 2020 Secchi depth transparency (SDT) at Gibbs Pond ranged from 0.25 to 0.64 m (Table 4-3). Almost all of the water color observations recorded on field sheets during 2020 were 'brown', indicating the presence of humic-tannin material from the adjacent cranberry bogs which impairs visibility.

Temperature. Temperature profile data were collected on all 10 sampling dates during 2020. The highest average temperature of the water column (26.6ºC) occurred on July 28th and then decreased through the remainder of the season (Table 4-3). The temperature versus depth profile data collected during 2020 at Gibbs Pond are summarized in graphs in Attachment #2 at the end of this report.

4.1.2 Chemical characteristics

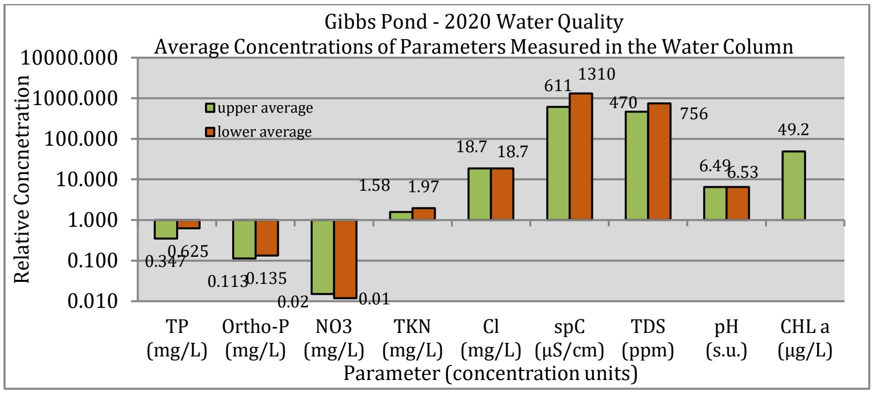
Table 4-4 summarizes the *average* values for the 2020 chemical characteristics measured at Gibbs Pond including dissolved oxygen, the nutrients phosphorus and nitrogen, and field measurements.

Table 4-4. Summary of 2020 chemical characteristics in *upper* region of Gibbs Pond.

		Capaum Pond 2020 Chemical Properties							
Sampling Date	Avg DO % saturation	TP (mg/L)	OP (mg/L)	TKN (mg/L)	NO_3-N (mg/L)	Cl (mg/L)	spC (µS/cm)	TDS (ppm)	pH (s.u.)
June 2nd	100.3	0.277	0.063	1.25	0.02	17.4	123	81	5.37
June 16th	110.2	0.288	0.074	0.95	0.01	18.0	142	93	7.04
June 30th	103.1	0.294	0.083	1.27	0.01	15.7		3738	4.67
July 14th	116.7	0.341	0.092	1.45	0.01	16.9	342	228	5.58
July 28th	106.8	0.421	0.131	2.08	0.01	18.6	108	70	6.06
August 11th	113.3	0.485	0.168	2.32	0.01	197	121	80	6.09
August 25th	106.0	0.404	0.165	1.36	0.01	18.5	117	76	7.24
September 8th	133.3	0.376	0.180	1.88	0.01	19.7	112	71	10.21
September 29th	114.1	0.308	0.117	1.89	0.05	21.5	272	180	6.89
October 20th	106.5	0.273	0.060	1.38	0.01	21.2	117	80	5.77
2020 average value	111.0	0.347	0.113	1.58	0.01	36.5	170	470	7.24
	all values shown are for the ***upper*** region of the water column highlighted cells = values reported are one-half the lower detection limit								

All samples summarized above were collected from the upper region of the water column. ***Lower*** region samples were collected from Gibbs Pond on 5 of the 10 sampling dates during 2020; however, those data are not summarized in Table 4-4 but are presented in Figure 4-2 (below) which summarizes the ***upper*** and ***lower*** average values for all 2020 chemical characteristics collected at Gibbs Pond. The ***y-axis*** in Figure 4-2 is formatted in logarithm scale to best display the wide range of 2020 *average* parameter values presented in the figure.

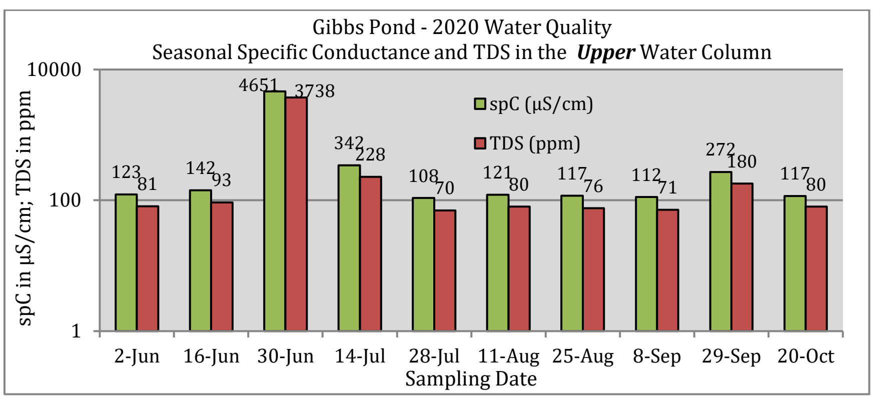
Figure 4-2. Summary of 2020 average concentrations of chemical parameters in Gibbs Pond.



The results for ***lower*** region samples collected at Gibbs Pond during 2020 also are presented in some of the following material in this chapter.

Specific conductance and Total Dissolved Solids (TDS). The distribution of specific conductance and TDS concentrations measured in the upper region of the water column in Gibbs Pond during the 2020 sampling season are summarized in Figure 4-3. Please note that the ***y-axis*** in Figure 4-3 is formatted in logarithm scale to best display the wide range of 2020 average concentrations.

Figure 4-3. Summary of 2020 specific conductance and TDS in *upper* samples from Gibbs Pond.



The concentrations of both parameters were relatively stable during the first two sampling excursions of 2020 and then increased 30-fold on the June 30th sampling date (Figure 4-3). Thereafter, the concentrations decreased through July 14th sampling date and then returned to stable values by July 28th and thereafter.

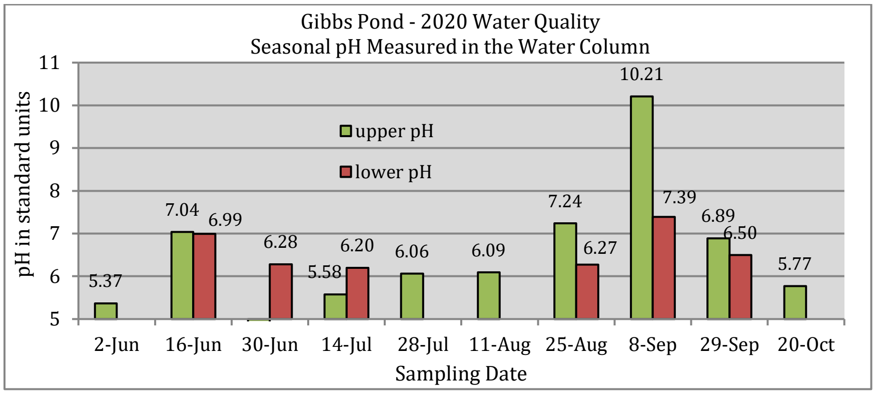
A similar increase in specific conductance and TDS was reported in Gibbs Pond during 2019, although the magnitude of the increase was not as great and the increase occurred later in the season

The situation described above with regard to the 30-fold increase in specific conductance and TDS remains as an anomaly because there are no other data collected from the pond that support this sudden increase in concentrations. Concentrations of both parameters in the ***lower*** region of the water column were close to values measured in the ***upper*** region during the remainder of the sampling season, so selective water withdrawals from the ***upper*** region and replacement with ***lower*** region water at higher concentrations is not a possible explanation here.

With the exception of the June 30th and September 29th sampling dates, all values of specific conductance and TDS measured during 2020 are considered within the normal range of values expected to occur in ponds that are fresh water. However, the concentrations of these analytes during the remainder of the sampling season are outside this range for fresh water and the pond appears to be too far from either Nantucket Sound (to the north) or the Atlantic Ocean (to the south) to explain the increases in specific conductance and TDS to high winds and salt spray during storm events.

pH. The pH data collected from the ***upper*** and ***lower*** regions of the Gibbs Pond water column during 2020 are presented in Figure 4-4.

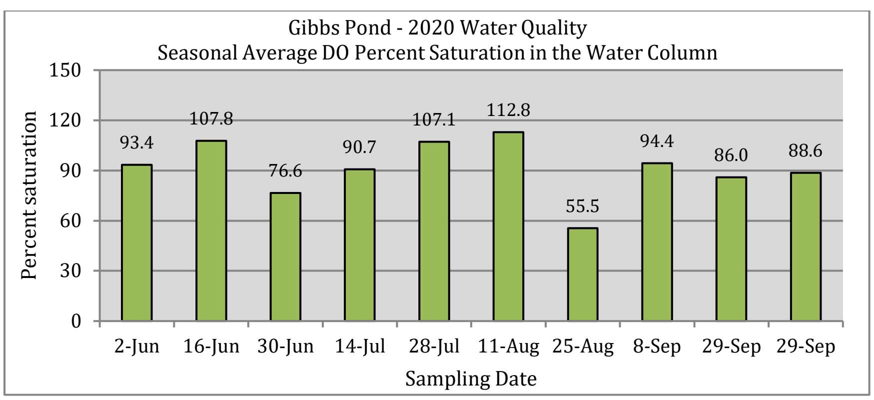
Figure 4-4. Summary of 2020 pH values measured in Gibbs Pond.



The ***upper*** region values ranged from a low value of 5.57 s.u. (June 2nd) to a high value of 10.21 s.u. (September 8th, and the *average* value in the ***upper*** region during 2020 was 7.24 s.u. (Table 4-4). The pH values <6.0 are likely due to the influx of water into the pond from the surrounding cranberry bogs which contain a lot of humic and tannic material.

Dissolved oxygen percent saturation. Dissolved oxygen is a chemical characteristic of water quality. The 2020 *average* percent saturation values for dissolved oxygen in the water column of Gibbs Pond are summarized in Figure 4-5.

Figure 4-5. Summary of 2020 dissolved oxygen percent saturation in Gibbs Pond.



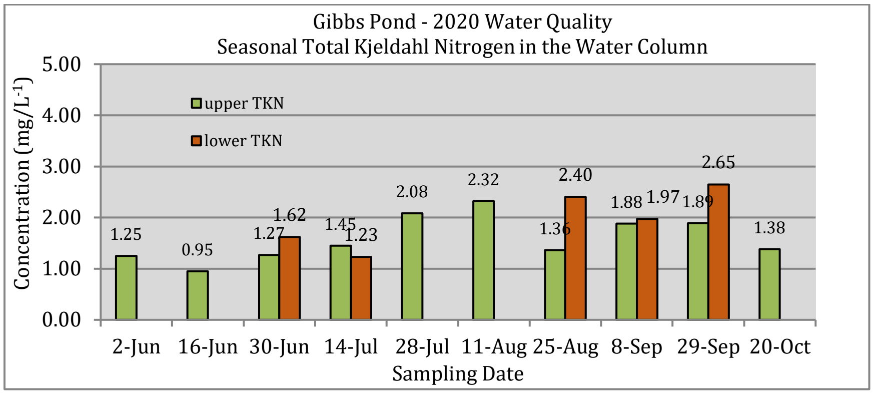
The *average* percent saturation in the water column was below 100 on 7 of the 10 sampling dates during 2020. The water column was supersaturated (>100%) on June 16th, July 28th and August 11th. The dissolved oxygen percent saturation data collected during 2020 at Gibbs Pond are summarized in profile graphs presented in Attachment #2 at the end of this report.

4.1.3 Plant Nutrients

Nitrogen. Nitrate-nitrogen was detected on June 2nd (0.02 mg N·L) and again on September 29th (0.05 mg N·L); otherwise, the concentrations of this nutrient were below detection on all other 2020 sampling dates (Table 4-4), which is not unusual because this form of nitrogen is readily available for uptake by phytoplankton in the water column and aquatic vegetation in the littoral zone of the pond.

Figure 4-6 presents the **total Kjeldahl nitrogen** (**TKN**) values measured in ***upper*** and ***lower*** region water samples collected from Gibbs Pond during 2020.

Figure 4-6. Summary of 2020 total Kjeldahl nitrogen concentrations measured in Gibbs Pond.

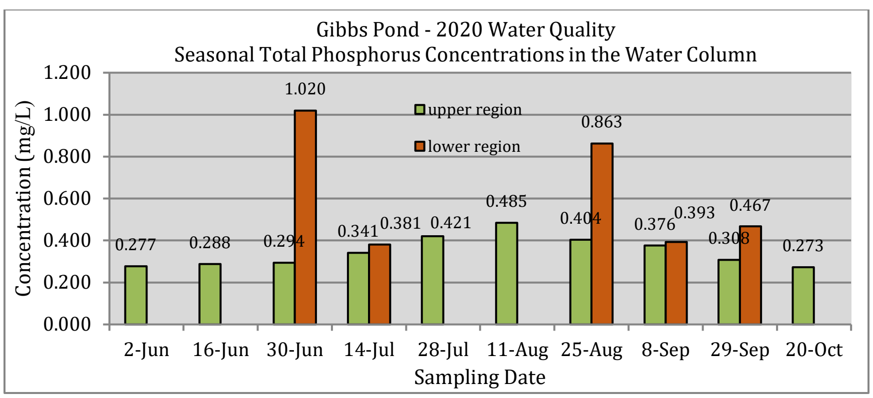


The **TKN** concentrations in the ***upper*** region of Gibbs Pond exhibited a slight bimodal pattern during 2020 and about doubled from late July through late September. Concentrations in the upper region ranged from 0.95 to 2.32 mg N·L, and averaged 1.58 mg N·L for the 2020 sampling season.

The substantially higher **TKN** concentrations measured in the ***lower*** region of the pond on June 30th (1.62 mg N·L), August 25th (2.40 mg N·L) and September 29th (2.65 mg N·L) highlight the partial stratification of the water column and the separation of ***upper*** and ***lower*** regions (Figure 4-6), which can occur in the pond at different periods of the growing season.

Phosphorus. The **total phosphorus** (**TP**) concentrations measured in the ***upper*** and ***lower*** regions of Gibbs Pond during 2020 are summarized shown in Figure 4-7.

Figure 4-7. Summary of 2020 total phosphorus concentrations measured in Gibbs Pond.

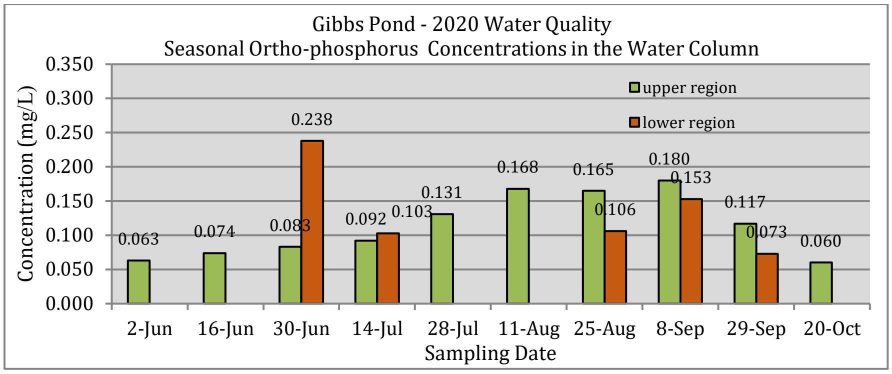


Upper region **TP** concentrations increased from 0.277 mg P·L on June 2nd to 0.485 mg P·L on August 11th and then decreased to the remaining 2020 sampling dates to a concentration of 0.273 mg P·L on October 20th; the *average* concentration in the upper region during the 2020 sampling season was 0.347 mg P·L (Table 4-4).

The higher TP concentrations measured in the ***lower*** region of the pond on June 30th (1.020 mg P·L), August 25th (0.863 mg P·L) and September 29th (0.467 mg P·L) are the same dates when higher concentrations of TKN were measured in the **lower** regions of the pond (see above), reinforcing that partial stratification occurred in the water column during these periods of the growing season.

Figure 4-8 summarizes the **ortho-phosphorus** (**OP**) concentrations measured in the ***upper*** and ***lower*** regions of Gibbs Pond during 2020. The **OP** measured in the ***upper*** region ranged from 0.063 mg P·L to 0.180 mg P·L during the sampling season and averaged 0.113 mg P·L during 2020 (Table 4-4). The concentrations measured in the ***upper*** region increased from 0.063 mg P·L on June 2nd to 0.180 mg P·L on September 8th and then decreased to 0.060 mg P·L by October 20th.

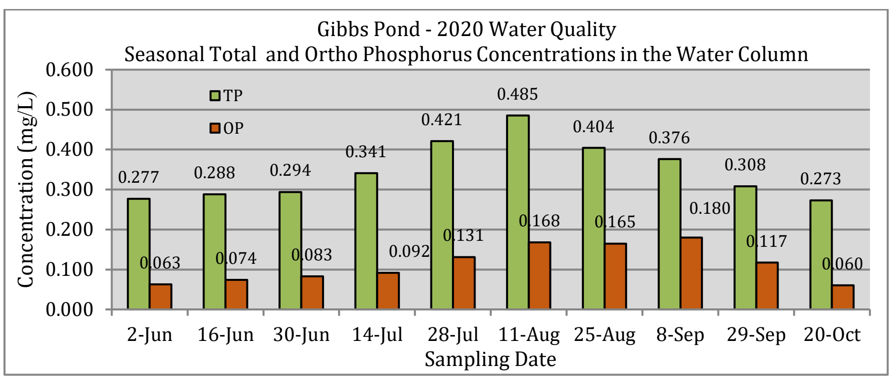
Figure 4-8. Summary of 2020 ortho-phosphorus concentrations measured in Gibbs Pond.



There was a 3-fold difference in **OP** concentrations between the ***upper*** and ***lower*** regions on June 30th (Figure 4-8) which suggest a partial stratification of the water column due to periods of calm (no wind) and an accumulation of this nutrient due to the settling of material from the ***upper*** region and the inability of any phytoplankton to photosynthesize in the ***lower*** region as a result of light extinction in the water column and poor SDT (Table 4-3).

Figure 4-9 summarizes the concentrations of **TP** and **OP** measured in the ***upper*** region of the Gibbs Pond water column during the 2020 sampling season. This figure is provided to visually present the relationship between **TP** and **OP** in the water column during the growing season.

Figure 4-9. Summary of 2020 ortho- and total phosphorus concentrations measured in *upper* region of Gibbs Pond.



Both forms of phosphorus exhibited an increase from June 2nd through August 11th and then declined through the October 20th sampling date. In general, the concentration of OP ranged from 22 to 41 percent of the TP concentration and averaged 32 percent of TP for the 2020 growing season.

The high concentrations of **OP** documented in Gibbs Pond during 2020 are unusual in any body of fresh water because this form of phosphorus is readily available for uptake by photosynthetic organisms present in the water column and the littoral zone. The fact that these high concentrations of OP continue to be measured in Gibbs Pond year after year emphasizes the depauperate nature of photosynthetic organisms present in the pond. Much of the plant material that occurs in the pond is affected by the very low transmission of light through the water column and high extinction rates due to interference from tannins and humic substances.

4.1.4 Phytoplankton

Description of the assemblage. Table 4-5 presents a summary of the Gibbs Pond phytoplankton community characteristics determined from 5 samples collected during 2020.

Table 4-5. Summary of 2020 Gibbs Pond phytoplankton community characteristics.

Capaum Pond Phytoplankton, 2020				
Sampling Date	Total Taxa Identified	Cell Density (cells-colonies-fragments/mL)	Density Diversity [H]	Chl ***a*** Concentration (µg/L)
June 16th	12	2431	0.607	20.4
July 14th	22	6496	0.859	48.4
August 11th	16	41981	0.589	69.7
September 8th	9	119451	0.337	76.2
September 29th	19	20067	0.473	72.9
2020 average	16	38085	0.573	57.52*
* additional chlorophyll a samples were collected and the average of all samples was 49.29 µg/L				

There were 36 different taxa identified in the 2020 phytoplankton samples collected from the pond and all six (6) major algal groups were represented (Table 4-6).

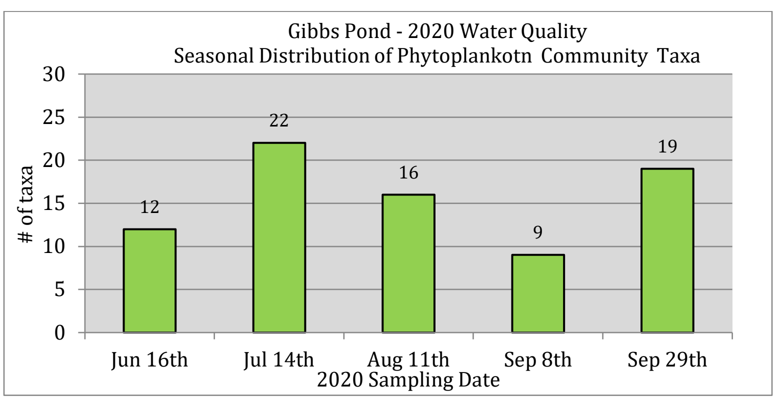
Table 4-6. Major groups, genera and species of 2020 phytoplankton identified in Gibbs Pond.

Cyanophyta	Chlorophyta	Chrysophyta (Bacillariophyceae)
Aphanizomenon flos-aquae	*Actinastrum* sp.	*Aulacoseira* sp.
Aphanizomenon gracile	*Arthrodesmus* sp.	*Cyclotella* sp.
Cuspidothrix sp.	*Closterium* sp.	*Navicula* sp.
Dolichospermum crassum	*Desmodesmus* sp.	*Nitzschia* sp.
Dolichospermum flos-aquae	*Dictyosphaerium* sp.	*Synedra* sp.
Dolichospermum smithii	*Monoraphidium* sp.	*Tabellaria* sp.
Limnothrix sp.	*Pediastrum* sp.	**Chrysophyta (Chrysophyceae)**
Merismopedia sp.	*Scenedesmus* sp.	*Mallomonas sp.*
Microcystis sp.	*Schroedaria* sp.	**Euglenophyta**
Microcystis aeruginosa	*Staurastrum* sp.	*Trachelomonas* sp.
Microcystsi wesenbergii	*Tetraedron* sp.	**Pyrrhophyta (Cryptophyceae)**
Planktolyngbya limnetica	*Tetrastrum* sp.	*Cryptomonad* sp.
Pseudanabaena sp.	**Chrysophyta (Bacillariophyceae)**	
Woronichinia sp.	*Asterionella* sp.	

The greatest representation of phytoplankton occurred within the Cyanophytes where at least 14 different taxa were identified including three (3) species of Dolichospermum and Microcystis, and two (2) species of *Aphamizomenon* (Table 3-6). The next greatest representation occurred within the Chlorophytes (green algae), where 12 different taxa were identified.

The number of phytoplankton taxa identified in the water column on each sampling date is summarized in Figure 4-10.

Figure 4-10. Seasonal distribution of phytoplankton community taxa identified in Gibbs Pond during 2020.

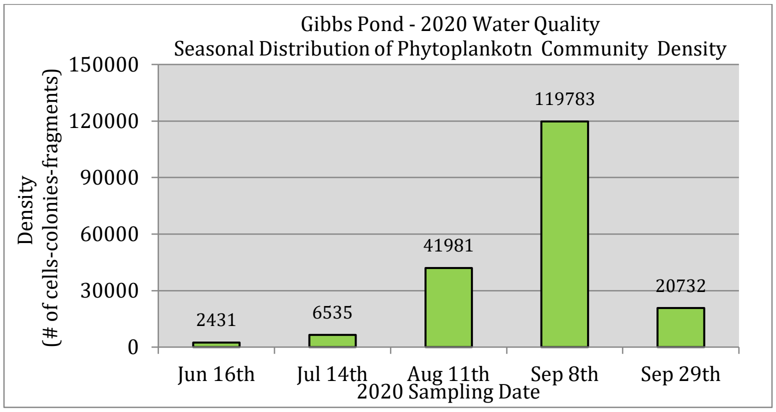


There was no distinct pattern with regard to the taxa observed in the water column during 2020. The 2020 phytoplankton community richness in Gibbs Pond based upon the 5 sampling excursions conducted was 15.6 ± 5.2 taxa.

The 2020 phytoplankton community characteristics in Gibbs Pond summarized above will be discussed in the following sections in this chapter.

Density. As summarized in Table 4-6 and shown in Figure 4-11, 2020 phytoplankton community density in Gibbs Pond ranged from a low of 2,431 units (cells-colonies-fragments)/mL on June 16th to 119,783 units/mL on September 8th, while the average density during 2020 was 38,292 units/mL.

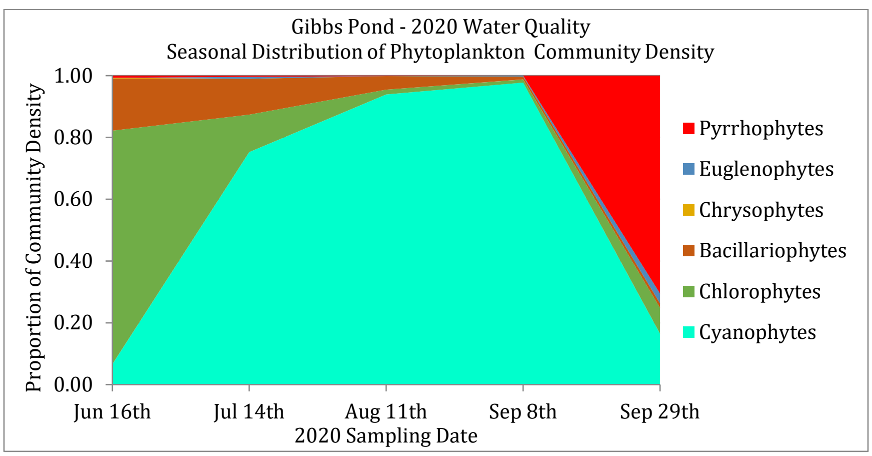
Figure 4-11. Summary of 2020 phytoplankton community density in Gibbs Pond.



Community density gradually increased from June 16th through September 8th and then decreased dramatically by September 29th, the last 2020 sampling date for water quality.

The seasonal density composition of the 2020 phytoplankton community in Gibbs Pond is shown graphically in Figure 4-12.

Figure 4-12. Density composition of the 2020 phytoplankton community in Gibbs Pond.



Based upon density, the Chlorophytes (green algae) and Bacillariophytes (diatoms) were prominent on the first sampling date (June 16th). By July 14th, the Cyanophytes comprised 75 percent of the total community density, and this representation increased to 94 percent on August 11th and to 98 percent by September 8th.

By September 29th, Pyrrhophytes (fire algae) comprised 70 percent of the total community density, with Cyanophytes, Chlorophytes and Euglenophytes comprising lesser amounts in that order. In many fresh-water ponds, diatoms are dominant early in the season as the water column temperature increases, then decline during mid-summer as other forms become more predominant in the community.

Dominance. A ranking of 2020 dominance of phytoplankton genera in Gibbs Pond is summarized in Table 4-7; genera are considered community dominants if they comprise at least 5 percent of the total community density or biomass.

Table 4-7. Rank of 2020 phytoplankton density dominance in Gibbs Pond.

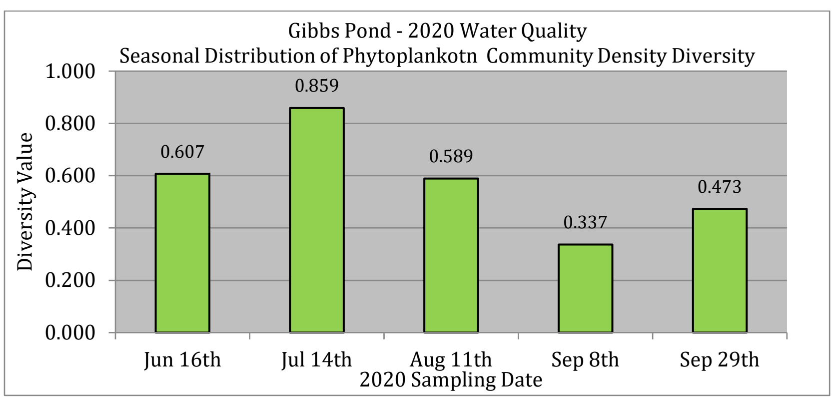
Sampling Date	Genus (and species where known)(Major Group)	Density Rank	% of Total Density
June 16th	*Closterium* sp. (Chlorophyte)	1	60.8
	Asterionella sp. (Bacillariophyte)	2	15.2
	Anthrodesmus sp. (Chlorophyte)	3	5.5
	Staurastrum sp. (Chlorophyte)	3	5.5
July 14th	*Woronichinia* sp. (Cyanophyte)	1	40.3
	Planktolyngbya limnetica (Cyanophyte)	2	19.8
	Aphanizomenon flos-aquae (Cyanophyte)	3	9.3
	Aulacoseria sp. (Bacillariophyte)	4	8.5
	Staurastrum sp. (Chlorophyte)	5	7.9
August 11th	*Planktolyngbya limnetica* (Cyanophyte)	1	54.5
	Aphanizomenon gracile (Cyanophyte)	2	26.2
	Pseudanabaena sp. (Cyanophyte)	3	6.4
September 8th	*Planktolyngbya limnetica* (Cyanophyte)	1	78.6
	Aphanizomenon gracile (Cyanophyte)	2	13.1
	Pseudanabaena sp. (Cyanophyte)	3	5.6
September 29th	*Cryptomonad* sp. (Pyrrhophyte)	1	72.9
	Planktolyngbya limnetica (Cyanophyte)	2	15.9
	Monoraphidium sp. (Chlorophyte)	3	5.8

The data summarized in Table 4-7 clearly demonstrate the phytoplankton community composition presented graphically in Figure 4-10. The Chlorophytes and Bacillariophytes comprised 87 percent of the community on June 16th. By July 14th, the Cyanophytes achieved total dominance with ~70 percent of the community composition, which continues through September 8th with *Planktolyngbya limnetica* and *Aphanizomenon gracile* being community dominants.

Diversity. Phytoplankton diversity in Gibbs Pond was measured using the Shannon-Wiener function[1] which calculates diversity, **[H]**, using number of taxa and the portion of individuals among the taxa on each sampling date. An increase in either factor will increase the value of the diversity index. Calculated values that approach 1.0 indicate conditions of maximum diversity in the distribution of the population.

Diversity in Gibbs Pond was calculated using only density because phytoplankton biomass was not analyzed during 2020. The seasonal distribution of density diversity is presented in Figure 4-13.

Figure 4-13. Summary of 2020 phytoplankton community density diversity in Gibbs Pond.

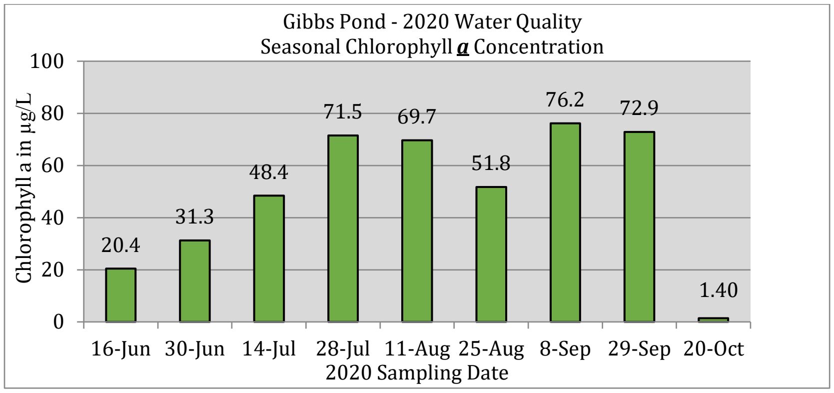


Community diversity averaged about 0.600 during the entire season and the community was most stable on July 14th when there were 5 dominant genera in the water column (Table 4-7). The September 8th sampling date was the least diverse of the 2020 collections, with 79 percent of the total community density residing in one Cyanophyte species, *Planktolyngbya limnetica*.

[1] $H = -\sum_{i=1}^{s} (p_i)(log_2)(p_i)$, in units of information per individual per unit volume or area, where p_i is the proportion of the total samples belonging to the ***i***th species and S is the number of species.

Chlorophyll *a*. Chlorophyll **a** samples were collected from Capaum Pond on 9 sampling dates and the results of measurements on those samples are presented in Figure 4-14.

Figure 4-14. Summary of 202 chlorophyll *a* concentrations measured in Gibbs Pond.



Chlorophyll ***a*** concentrations continually increased from 20.4 µg·L on the first sampling date and exhibited 2 peaks, one during late July and early August and the other during the month of September (Figure 4-14). The *average* of all samples collected during 2020 was 49.29 µg·L, which is considered a high value for a pond like Gibbs with low water column transparency caused by humic and tannic compounds in the system that affect clarity.

4.1.5 Trophic Status

Sufficient water quality data were collected from Gibbs Pond during 2020 to calculate the Carlson Trophic State Index (TSI) using chlorophyll ***a***, total phosphorus, and Secchi depth transparency. Average values were calculated for each variable for all 2020 sampling dates. The average values then were substituted into the Carlson equations to calculate the TSI values for each variable. The stepwise calculation and results of the analysis are as follows:

Chlorophyll *a*

2020 average chlorophyll *a* = 49.29 µg/L

Chlorophyll *a* TSI = 9.81*[ln (49.29)] + 30.6

TSI = (9.81)(3.90) + 30.6

TSI = 68.86

Secchi depth

2020 average Secchi depth = 0.39 m
Secchi TSI = 60 – [14.41*[ln (0.39)]
TSI = 60 – (14.41)(-0.95)
TSI = 73.69

Total phosphorus

2020 average total phosphorus = 347.0 µg/L
Total phosphorus TSI = 14.42*[ln (347)] + 4.15
TSI = (14.42)(5.85) + 4.15
TSI = 88.51

The calculated TSI values, when compared with the criteria presented in Table 4-8 below to evaluate the 2020 trophic status of Gibbs Pond, place all 3 of the 2020 water quality parameters within either the eutrophic (chlorophyll ***a***) or hyper-eutrophic (Secchi depth, total phosphorus) range, indicating very high seasonal productivity in Gibbs Pond.

Table 4-8. Relationships among Trophic Index (TI), chlorophyll *a*, total phosphorus, Secchi depth, and Trophic Class (after Carlson 1996).

Trophic State Index	Chlorophyll *a* (μg·L^{-1})	Total phosphorus (μg·L^{-1})	Secchi Depth (m)	Trophic Class
< 30 - 40	0.0 – 2.6	0.0 - 12	> 8 - 4	Oligotrophic
40 - 50	2.6 – 7.3	12 - 24	4 - 2	Mesotrophic
50 - 70	7.3 - 56	24 - 96	2 – 0.5	Eutrophic
70 – 100+	56 – 155+	96 – 384+	0.5 - <0.25	Hyper-eutrophic

Furthermore, if we compare the 2020 Trophic Index data with similar data from previous years (2016, 2017, 2019), and compare all of these data (Table 4-9), we find that

- the chlorophyll ***a*** Index has decreased slightly and moved from hyper-eutrophic to eutrophic,
- the TP Index is essentially unchanged and remains within the upper hyper-eutrophic range, and
- the Secchi depth Index has increased from the eutrophic to the hyper-eutrophic region

Table 4-9. Trophic State Indices for Gibbs Pond based upon 2016, 2017, 2019 and 2020 water quality.

Year	Chlorophyll	TP	Secchi Depth
2016	76.89 (HE)	88.5 (HE)	66.9 (E)
2017	71.54 (HE)	93.0 (HE)	74.9 (HE)
2019	68.12 (E)	89.6 (HE)	73.2 (HE)
2020	68.84 (E)	88.50 (HE)	73.71 (HE)

In spite of the relatively minor changes in Trophic Index described above, Gibbs Pond has demonstrated extreme productivity since monitoring began during 2015 and would have to undergo significant reductions in the values of all 3 Trophic State parameters for water quality to improve substantially.

4.2 Summary

Based upon the data collected during 2020 and several years previous, Gibbs Pond exhibits water quality similar to other Island ponds studied by the Nantucket Land Council. The pond has high productivity characterized as eutrophic to hyper-eutrophic based upon the numerical analysis of 3 separate water quality variables that were monitored. Many Island ponds likely are very similar in productivity to Gibbs Pond due to their extremely shallow nature and the highly enriched organic material contained in the sediments from aquatic vegetation that has decomposed and accumulated in that region over long periods of time. Nutrients such as nitrogen and phosphorus that are trapped in these bottom sediments are released into the water column at various times during the mid-summer growing season when mixing of the water column occurs due to wind of sufficient velocity blowing across the Island that generate water currents and circulation throughout the pond.

4.3 Literature Cited

Carlson, R.E. and J. Simpson. 1996. *A Coordinator's Guide to Volunteer Lake Monitoring Methods*. North American Lake Management Society. 96 pp.

Nantucket Island Ponds and 2020 Water Quality

Chapter 5

Cyanophytes, Cyanotoxins and Water Quality Concerns for Nantucket Island Ponds

5.0 Introduction

The major focus of 2020 water quality monitoring on Nantucket Island was a continuation of the 2019 effort with the detection of HABs and deployment of the Air Sampling Devices (ASDs) to gather further evidence regarding the aerosolization and dispersal of cyanotoxins (cyanophyte toxins). Based upon the 2019 results, Capaum Pond became the primary focus of the HABs and aerosolization of cyanotoxin research.

The full scope of this effort included (1) the regular collection of integrated phytoplankton samples from the water column to document and archive the community of Capaum Pond, (2) the routine weekly observation of the shoreline area of Capaum Pond for evidence of HABs, (3) the collection of a water sample for a Eurofins Abraxis® toxin strip test when a potential HAB was observed, (4) the analysis of raw water samples for a potentially toxigenic cyanobacteria screen, and based upon these results, (5) the analysis of detectable cyanotoxins present in the water column sample during conditions suspected to be HABs, and (6) deployment of the ASDs to document transport of aerosolized cyanotoxins and/or airborne pico-cyanobacteria from the pond to adjacent areas where local residents or recreational users could be exposed through contact (inhalation).

Given the importance of cyanophytes as a biological component in the Nantucket pond ecosystems and its status in the overall 2019-2020 research work-plans, it seemed appropriate to dedicate a chapter of this report to cyanophytes, cyanotoxins and the findings related to Nantucket Island ponds, specifically Capaum Pond. Basic information related to the 2020 phytoplankton community of Capaum Pond was presented in Chapter 3, which summarized all of the 2020 water quality data. The information presented in this chapter relates specifically to the 2020 cyanophyte and cyanotoxin data collected from Capaum Pond.

5.1 Background

As a major group within the phytoplankton, cyanophytes are ubiquitous, occurring in almost every habitat, and their presence in small numbers in the phytoplankton assemblage of aquatic ecosystems usually is part of a natural process of community succession during the growing season. When present in large numbers such as happens in algal 'bloom' conditions, however, cyanophytes can induce physical, chemical and biological changes in the aquatic environment in which they occur and eventually affect the ecosystem in a negative manner which, over a long period of time, may require some direct remedial action to reverse or overcome.

High concentrations ('blooms') of cyanophytes in the water column lowers transparency, reducing the depth of the photic zone (area of the water column where incident light is sufficient to allow photosynthesis to occur) and the volume of water (surface area and depth in the pond) that supports other photosynthetic organisms. Many forms of cyanophytes have internal gas vacuoles that enable them to regulate their depth in the water column to maximize photosynthesis, whereas many of the other forms of phytoplankton have no means of mobility and are subject to the influence of gravity and eventually settle to the bottom.

In addition, high concentrations of cyanophytes and other algae in the water column result in high rates of cell die-off due to very brief life cycles, thus creating biomass which settles to the bottom and causes oxygen depletion through decomposition of the dead plant material and other organic matter in the bottom sediments. De-oxygenation has a direct negative effect on aquatic organisms in the bottom region of lakes and ponds that depend on oxygen for survival, as well as the indirect effect of toxic gas release and nutrient mobilization into the water column.

In shallow water systems, exhibited by many Nantucket Island ponds, there are regular periods of wind-induced circulation where the ***lower*** region of the water column mixes with the ***upper*** region of the water column, which temporarily reduces overall oxygen saturation and distributes mobilized nutrients throughout the pond for uptake and metabolism by phytoplankton. The release of nutrients into the water column exacerbates the cycle by encouraging increased primary productivity by phytoplankton in an already over-productive and stressed system.

By the time a dense cyanophyte mat, resembling spilled blue-green paint, is seen floating on the surface of the pond, the cells already have affected the aquatic ecosystem in which they are located and, under certain conditions, can pose health and safety issues for recreational users of the water body. Algal cells floating on the surface and forming a blue-green scum already have died and lysed, releasing their cell contents into the surrounding environment.

In certain instances, the dead, lysed cells forming a scum on the pond surface are Cyanophytes that produce cyanotoxins and release these toxins (cyanotoxins) when ruptured. The cyanotoxins include neurotoxins (affect the nervous system), hepatotoxins (affect the liver) and dermatoxins (affect the skin). There are several pathways of exposure to cyanobacteria (Cyanophytes) and their toxins including ingestion of drinking water contaminated with cyanotoxins and through direct contact, inhalation and/or ingestion during recreational activities. A wide range of symptoms can occur in humans following acute recreational exposure to HABs and associated toxins including fever, headaches, muscle and joint pain, blisters, stomach cramps, diarrhea, vomiting, mouth ulcers, and allergic reactions.

The body of knowledge surrounding these Cyanophytes and their toxins has grown rapidly, particularly during the past few decades. As of 2008, when a major NATO document (Zaccaroi and Scaravelli, 2008) was released on algal toxins, 46 species of cyanophytes were identified that produce toxins. In fact, at the time, some researchers believed that it would be prudent to assume any cyanophyte population has toxic potential in the aquatic ecosystem in which it is located.

Another summary of cyanophytes and cyanotoxins published by the US Environmental Protection Agency (2014) provided a breakdown of the three (3) primary cyanotoxins (Microcystin-LR, Cylindrospermopsin, Anatoxin-a), the number of known analogues of each toxin, a summary of health effects, and the most common cyanophyte genera with the potential of producing toxin. The US EPA summary information is presented in Table 5-1.

Table 5-1. Summary of primary cyanotoxins, health effects and potential toxin-producing cyanophyte genera[1].

<table>
<tr><th>Cyanotoxin</th><th># Known Analogues</th><th>Primary Organ Affected</th><th>Health Effects</th><th>Most common cyanophyte genera producing toxin[2]</th></tr>
<tr><td>Microcystin-LR</td><td>80~90</td><td>Liver</td><td rowspan="2">Abdominal pain
Vomiting and diarrhea
Liver inflammation and hemorrhage
Acute pneumonia
Acute dermatitis
Kidney damage
Potential tumor growth promotion</td><td>Microcystis
*Dolichospermum
Planktothrix
Anabaenopsis
Aphanizomenon
**Woronichinia</td></tr>
<tr><td>Cylindrospermopsin</td><td>3</td><td>Liver</td><td>Cylindrospermopsis
Aphanizomenon
Dolichospermum
Lyngbya
Rhaphidiopsis
Umezakia</td></tr>
<tr><td>Anatoxin-a group</td><td>2-6</td><td>Nervous system</td><td>Tingling, burning, numbness, drowsiness, incoherent speech, salivation, respiratory paralysis leading to death</td><td>Dolichospermum
Planktothrix
Aphanizomenon
Cylindrospermopsis
Oscillatoria</td></tr>
<tr><td colspan="5">[1] table from US EPA 2014.</td></tr>
<tr><td colspan="5">[2] not all species of the genera listed produce toxin, listed genera not equally as important in producing toxins</td></tr>
<tr><td colspan="5">* previously the genus Anabaena; ** previously the genus Coelosphaerium</td></tr>
</table>

For some unknown reason, the US EPA cyanotoxin summary information failed to mention *Saxitoxin*, a potent neurotoxin and the substance known as *paralytic shellfish toxin*; used collectively, the term Saxitoxin also refers to the suite of more than 50 structurally related analogues (https://en.wikipedia.org/wiki/Saxitoxin). The cyanophyte genera identified so far that are known to produce this toxin include *Dolichospermum*, *Aphanizomenon*, and *Sphaerospermopsis*.

Following review of some scientific literature, it appears that considerable time and world-wide research have occurred since the US EPA cyanotoxin summary was compiled (2014) and a recent critical review by Plaas and Paerl (2020) have identified 21 cyanobacterial genera in which research has documented the potential production of cyanotoxins. These authors have presented an extensive review of the literature on the incorporation of cyanobacterial cells and cyanotoxins into spray aerosol in marine and freshwater systems.

5.2 Results

The results presented in this and the following sections relate to the segment of the 2020 work-plan dealing with cyanophytes, cyanotoxins and a summary of findings following the conclusion of the monitoring effort.

5.2.1 Eurofins Abraxis® Fresh Water Test Strips

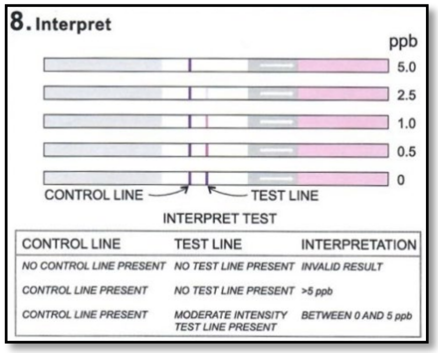
Routine weekly observations were conducted along the shoreline of Capaum Pond during 2020 to check for potential HABs in progress, determined by the presence of a surface scum resembling spilled blue-green paint (see Figure 5-1).

Figure 5-1. Capaum Pond shoreline exhibiting a potential HAB on October 6th 2020 (photo credit RJ Turcotte).

If observed conditions indicated a possible HAB in progress at a pond, then a water sample was collected and returned to the NLC office for (1) a Eurofins Abraxis® strip test for *Microcystins*, 0-5 ppb, Finished Drinking Water (PN 520017 [20 tests]), and a (2) Eurofins Abraxis® strip test for Anatoxin-a, 0-2.5 ppb, Source Drinking Water, (PN 300620 [5 tests]). According to the manufacturer's literature, if the sample contains toxin over the US EPA health advisory or WHO (World Health Organization) concentration limits (1.0 ng/mL), the tests will detect the toxin even if there are no visible algal cells in the sample. The only test kit departure of use instructions for Nantucket concerned the series of three (3) freeze-thaw cycles to lyse the cells because chloride concentrations in the ponds interferes with the lysing material normally used in conjunction with the test strips.

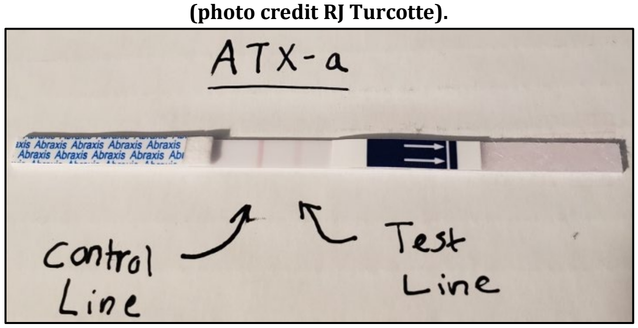
During 2020, a total of 11 different Eurofins Abraxis® strip tests for Microcystins/Nodularins and Anatoxin-a were performed on pond samples including 6 samples from Capaum Pond and 5 samples from Gibbs Pond. The interpretation of the algal toxin strip test for presence of toxins is somewhat counterintuitive because the test requires visual comparison of a 'control' line on the strip with a corresponding 'test' line on the strip and the intensity of the test line determines the relative concentration of toxin present, with a less intense 'test' line indicating higher concentration and a more intense 'test' line indicating less concentration. Figure 5-2 presents a section from the Eurofins Abraxis® visual instruction for conducting the *Microcystin* strip test.

Figure 5-2. Excerpt from Eurofins Abraxis® strip test for *Microcystin* showing determination of toxin concentration.



The higher concentrations of toxin are indicated by less intense 'test' lines compared with the 'control' line. Unfortunately, a progression of test line intensities was not always apparent when conducting the Eurofins Abraxis® strip test for Microcystin/Nodularis or Anatoxin-a. In most cases, the control line that developed on the strip was apparent and the test line that appeared was either very faint (Figure 5-3) or non-existent.

Figure 5-3. A Eurofins Abraxis® strip test for Anatoxin-a on Capaum Pond, August 4th 2020 (photo credit RJ Turcotte).



Strip test results such as the one shown above would warrant sending a raw water sample to GreenWater CyanoLab in Palatka, Florida for a Potentially Toxigenic (PTOX) Cyanobacteria Screen.

5.2.2 Potentially Toxigenic (PTOX) Cyanobacteria Screen.

During 2020, GreenWater CyanoLab performed a total of 11 separate PTOX tests on samples received from Nantucket ponds as summarized in Table 5-2.

Table 5-2. Summary of 2020 Nantucket pond samples submitted to GreenWater CyanoLab for PTOX testing.

2020 Date	Capaum	Gibbs
June 30th		X
July 14th		X
July 28th	X	
August 25th	X	
September 8th	X	X
September 29th	X	X
October 6th	X	X
November 2nd	X	

The results of the PTOX testing usually were reported back to the Program cooperators within 48-72 hours after the GreenWater CyanoLab received the live sample shipment. The results for each raw water sample received were reported as potentially toxin-producing genera (and the specific toxin produced) occurring in the sample. The results would include recommendations for subsequent cyanotoxin analysis.

Table 5-3 presents the cyanophyte genera identified in Capaum and Gibbs Ponds PTOX samples submitted to GreenWater CyanoLab during 2020 and the specific cyanotoxins that are potentially produced by each genus.

Table 5-3. A summary of cyanophyte genera identified in Nantucket Island ponds, 2020.

	Pond		Potential Toxin Produced			
Genus	Capaum	Gibbs	Microcystins	Saxitoxins	Anatoxin-a	Cylindrospermopsin
Aphanizomenon sp.	X			X	X	X
Cuspidothrix sp.	X			X	X	X
Dolichospermum sp.	X	X	X	X	X	X
Geiltlerinema sp.		X	X	X		
Microcystis sp.	X	X	X			
Phormidium sp.	X	X	X	X	X	
Planktothrix sp.	X		X	X	X	
Pseudanabaena sp.	X		X			

As summarized above, several genera of cyanophytes were identified by GreenWater CyanoLab in both ponds, including 7 genera in Capaum and 4 genera in Gibbs. The genera summarized above do not necessarily represent the entirety of cyanophytes in the water column of each pond because the raw water samples were collected from the pond surface if a HAB was suspected and genera suspended in the water column would not be included in those samples.

5.2.3 Nantucket Ponds - Cyanophytes and Cyanotoxins in 2020

The following material summarizes cyanophyte and related data collected from Capaum and Gibbs Ponds during the 2020 sampling season.

5.2.3.1 Capaum Pond

Cyanophytes. Cyanophytes were identified in 9 of 10 phytoplankton samples collected from Capaum Pond in 2020. A total of 12 genera and at least 16 different species were identified; these cyanophytes are summarized in Table 5-4.

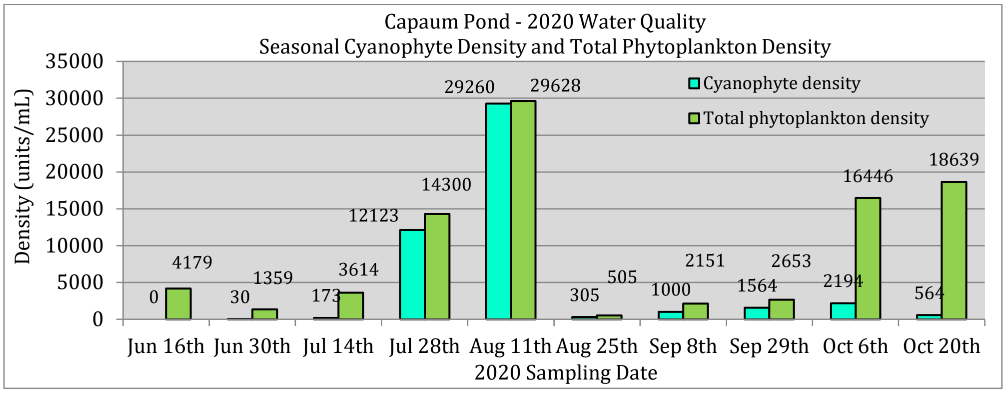
Table 5-4. Cyanophytes identified in Capaum Pond, 2020.

Cyanophyte genera (species when identified)
Anabaenopsis sp.
Aphanizomenon flos-aquae
Aphanizomenon gracile
Aphanocapsa sp.
Cuspidothrix sp.
Dolichospermum crassum
Dolichospermum flos-aquae
Dolichospermum mucosum
Dolichospermum sigmoideum
Limnothrix sp.
Microcystis sp.
Microcystis wesenbergii
Planktolyngbya limentica
Pseudanabaena sp.
Planktothrix sp.
Woronichinia sp.

All of the cyanophyte genera identified in the table above have been reported in the scientific literature to potentially produce cyanotoxins.

The Capaum Pond population density of the cyanophytes on 9 sampling dates during 2020 compared with the density of the total phytoplankton community is summarized in Figure 5-4, and includes the June 16th sampling date when there were no cyanophytes observed in the phytoplankton sample collected.

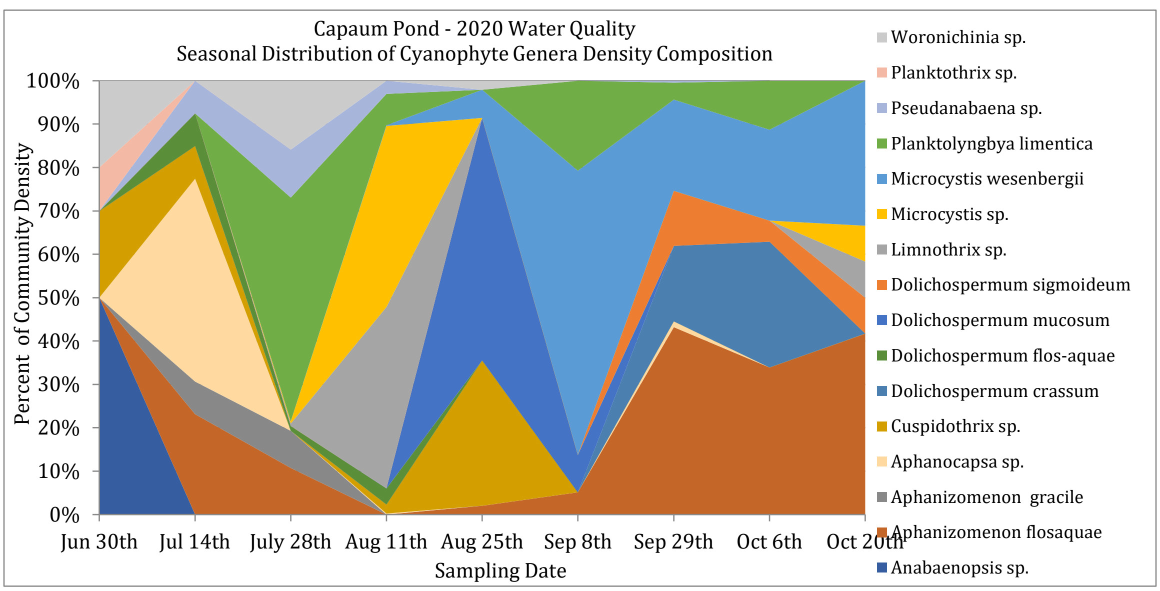
Figure 5-4. Capaum Pond – 2020 cyanophyte density and total phytoplankton density



When compared with the total phytoplankton community density in Capaum Pond during the early portion of the 2020 sampling season, the proportion of the cyanophytes in the total community ranged from 0 percent on June 16th to 85 percent on July 28th to 99 percent on August 11th. Thereafter, the cyanophytes varied from 60 percent to 3 percent of the total community density. The cyanophytes averaged about 37 percent of the total community density during the entire 2020 sampling period.

Figure 5-6 summarizes the density distribution of cyanophyte genera during the 9 sampling dates during 2020 when cyanophytes were observed in Capaum Pond.

Figure 5-6. Seasonal distribution of cyanophyte genera density in Capaum Pond, 2020.



There were continual fluctuations of specific cyanophyte genera exhibited among the 9 sampling dates with respect to density, with some genera demonstrating importance throughout the sampling season and other genera being present at various times but not as important in terms of total numbers (density). A few genera including *Aphanizomenon* and *Planktolyngbya* were observed throughout most of the 2020 sampling season, while other genera such as *Anabaenopsis*, *Aphanocapsa*, and the 4 different genera of *Dolichospermum* only occurred on 1 or 2 sampling dates.

It is a fact that major changes within the phytoplankton community can occur within a relatively brief period of time. This situation emphasizes the need to sample these island ponds with an appropriate frequency so that major changes in density are documented to the extent that patterns can be elucidated and described with a sufficient degree of accuracy during the period of the sampling season.

Cyanotoxins. During 2020, considerable emphasis was focused on (1) the detection of cyanotoxins in Capaum Pond and (2) whether aerosolization of picocyanobacteria containing toxins or toxins following release from cyanophyte cells is a mechanism of transport away from the pond that can be detected and potentially impact public health through inhalation of transported particles.

As a matter of field sampling consistency during 2020, a raw water sample generally was collected from Capaum Pond on each sampling date and returned to the NLC office where the freeze-thaw process inducing cell lysis occurred, which then was followed by Eurofins Abraxis® strip tests for detection of the cyanotoxins *microcystins* and *anatoxin-a*. Based upon the strip test results, water samples could be shipped overnight to GreenWater Laboratories in Palatka, Florida for a Potentially Toxigenic (PTOX) Cyanobacteria Screen and then follow-up for specific cyanotoxin analyses if warranted by the PTOX Cyanobacteria Screen results and recommended analyses.

On 9 occasions during 2020, raw water samples collected from Capaum Pond and tested with Eurofins Abraxis® strip tests warranted further analysis and were shipped overnight to GreenWater CyanoLab. The dates and cyanotoxin results from these raw water samples are summarized in Table 5-5.

Table 5-5. Summary of 2020 cyanobacteria toxin results from Capaum Pond.

	2020 CYANOTOXIN RESULTS		
	MCs/NODs	ANTX-A	
Date	ng/mL	ng/mL	Comments
July 28th	ND	ND	north shore collection
July 31st	2.73	ND	north shore collection
August 11th	ND	0.16	north shore collection
August 25th	183	0.38	north shore collection
September 8th	603	ND	north shore collection
September 26th	2410	ND	north shore collection
October 6th	1050	ND	north shore collection
October 20th	198	ND	north shore collection
November 3rd	2.71	ND	north shore collection
MCs/NODs – *Adda Microcystins/Nodularins*; ANTX-A – *Anatoxin-a*			

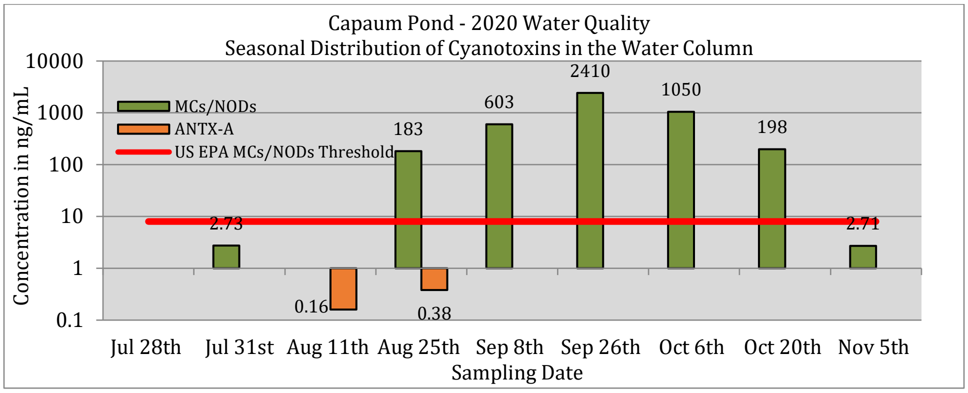
It should be noted that there were 5 occasions during 2020 when the levels of microcystins/nodularins detected by the Adda ELISA test procedures exceeded the current "US EPA Recommended Value for Recreational Criteria and Advisory", which currently is set at 8.0 ng/mL (ppb) total microcystins.

Microcystins, or *cyanoginosins*, are a class of toxins that are cyclic hepatapeptides produced through nonribosomal peptide synthases; Microcystin-LR is the most common of over 50 different microcystins that have been identified (https://en.wikipedia.org/wiki/Microcystin#). Microcystions are hepatotoxic and able to cause serious liver damage. Acute health effects of Microcystin-LR are abdominal pain, vomiting and nausea, diarrhea, headache, blistering around the mouth, and after inhalation, dry cough and pneumonia.

Anatoxin-a, also known as Very Fast Death Factor (VFDF), is a secondary, bucyclic amine alkaloid and cyanotoxin with acute neurotoxicity (https://en.wikipedia.org/wiki/Anatoxin-a). The toxin is produced by at least seven (7) different cyanobacteria genera and symptoms of anatoxin-a exposure include loss of coordination, muscular fasciculations, convulsions and death by respiratory paralysis. Its mode of action is through the nicotinic acetylcholine receptor (nAchR) where it mimics binding of the receptor's natural ligand.

The cyanotoxin results summarized in Table 5-5 also are presented in a column chart (Figure 5-7) to display the seasonal distribution in Capaum Pond during 2020.

Figure 5-7. Seasonal distribution of cyanotoxins measured in Capaum Pond, 2020.



Microcystins/nodularins were detected in 7 of the 9 samples collected during the 2020 season (Figure 7-8). Concentrations exhibited a bell-shaped curve and ranged from below detection (MRL = 0.75 ng/mL) on July 28th to 2,410 ng/mL reported on September 26th. Thereafter, the concentrations decreased to 2.71 ng/mL reported on November 5th.

Anatoxin-a was detected in only 2 of the 9 samples collected during 2020. The reported concentrations were 0.16 and 0.38 ng/mL on August 11th and August 25th, respectively.

Deployment of the Air Sampling Device(s). In addition to the collection of pond water for the analysis of specific cyanotoxins, there also was considerable effort at Capaum Pond during 2020 with deployment of the different prototypes of the Air Sampling Device (ASD) units along the pond shoreline, particularly when approaching storms were forecast with sufficient wind blowing across the Island to cause disturbance on the surface of the ponds. The different ASD prototypes were described in Chapter 2.

A total of 9 different ASD deployments occurred along the shoreline of Capaum Pond between July 28th and November 3rd 2020, with different combinations of ASD prototypes deployed on these occasions. Raw water samples were collected from the pond prior to each deployment and submitted to the GreenWater CyanoLab for cyanotoxin analysis. A summary of the 2020 ASD deployments is presented in Table 5-6.

Table 5-6. Summary of 2020 Air Sampling Device (ASD) deployments at Capaum Pond.

Deployment			Air Sampler Device Type			Elapsed time (decimal)	
#	Date	Location	Filter	Vortex	Impinger		Weather
1	Jul 28th	N	X	X		8.0	78F; sunny; wind SW @13 mph; gusts to 20 mph
2	Jul 31st	N	X	X		8.0	75F; partly cloudy; wind W @7mph; rain , light fog
3	Aug 11th	N	X	X		8.0	79F; partly cloudy; wind SSW @ 11 mph
4	Aug 25th	N	X	X		8.0	73F; clear; wind NW @ 23 mph
5	Sep 8th	N	X	X		8.0	75F; partly cloudy; wind ESE @ 6 mph
6	Sep 22nd	S	X		X	48.0	64F; cloudy; wind N @ 33 mph, gusts to 50 mph
7	Oct 6th	N	X		X	48.0	61F; overcast; wind S @1-0 mph, gusts to 30+
8	Oct 20th	N	X		X	48.0	63F; overcast; wind S @ 9 mph; some fog in area
9	Nov 3rd	N	X		X	48.0	56F; clear; wind S @ 11 mph, gusts to 20 mph

None of the filter and liquid samples retrieved from the ASD deployments and sent to GreenWater CyanoLab for analysis yielded positive results for cyanotoxins; all results came back “ND” (non-detectable). These results from the ASD deployments were in spite of measureable concentrations of either MCs/NODs or ANTX-A in the water column of the pond at the time of deployment as shown in Table 5-5.

Unfortunately, we do not understand the mechanism of aerosolization of cyanotoxins from ponds exhibiting HABs well enough to explain the lack of toxins captured either on filters or in liquid. It is likely that in the case of many of the deployments, there was insufficient wind speed blowing across the surface of the pond to set up wave activity and potential spray aerosol. Another possible factor might be the lack of fog conditions surrounding most of the 2020 deployments. The positive ANTX-A and MCs/NODs results captured on filters during the September 11th 2019 deployment at Capaum Pond occurred under when both sufficient wind speed and the presence of fog were documented as environmental conditions. The presence of fog could be very important and explain a potential mechanism that aids in the preservation of cyanotoxins in the atmosphere above the pond and the transport of aerosols away from the pond (Sutherland et al. 2021).

5.2.3.2 Gibbs Pond.

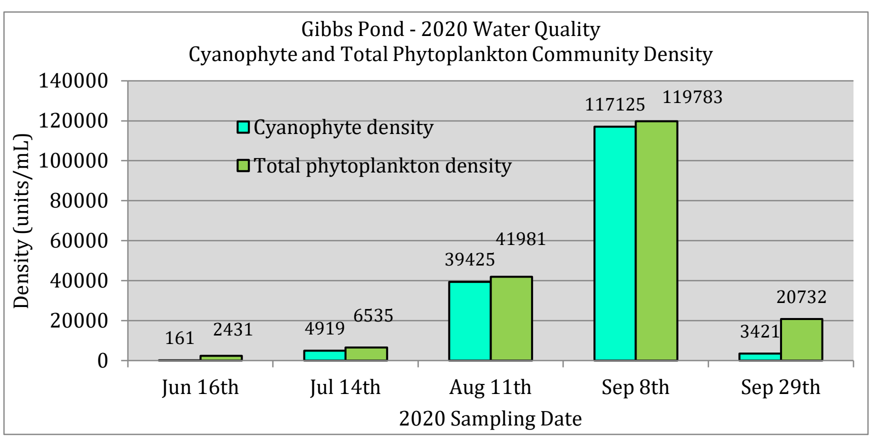
Cyanophytes. Cyanophytes were identified in all 5 phytoplankton samples collected at Gibbs Pond during 2020. As summarized in Table 5-7, a total of 9 genera and at least 12 species were identified. All of the genera listed above except *Merismopedia* have the potential to produce cyanotoxins.

Table 5-7. Cyanophytes identified in Gibbs Pond, 2020.

Cyanophyte genera (species where identified)
Aphanizomenon flos aquae
Aphanizomenon gracile
Cuspidothrix sp.
Dolichospermum crassum
Dolichospermum flos-aquae
Dolichospermum smithii
Limnothrix sp.
Merismopedia sp.
Microcystis wesenbergii
Planktolyngbya limentica
Pseudanabaena sp.
Woronichinia sp.

The cyanophyte population dynamics on the five (5) sampling dates with respect to density of the entire phytoplankton community in Gibbs Pond is presented in Figures 5-8.

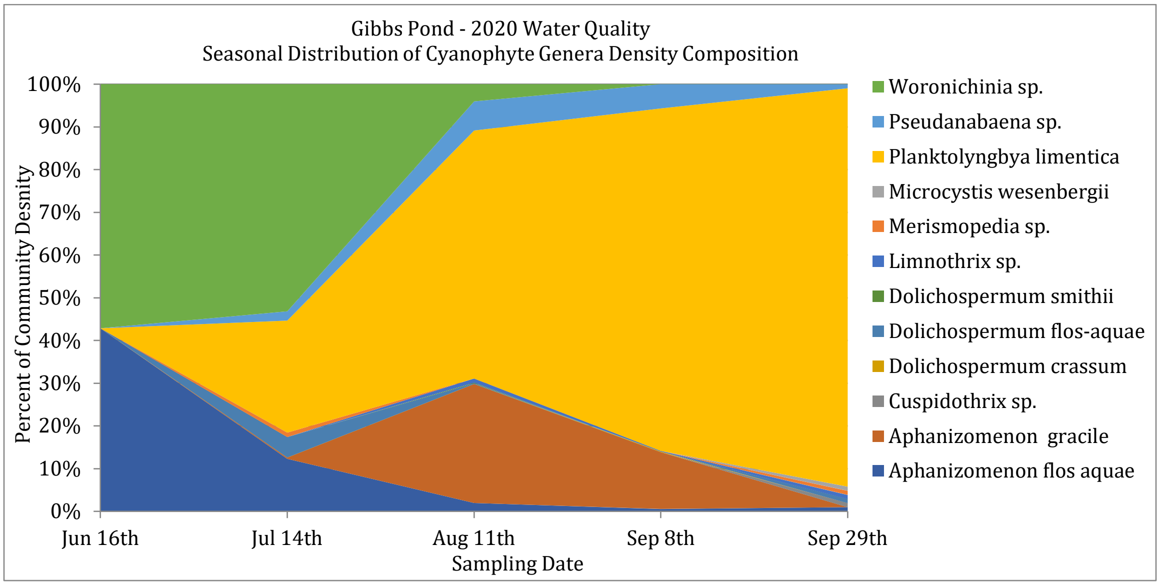
Figure 5-8. Gibbs Pond – 2020 cyanophyte and total phytoplankton density.



The proportion of cyanophytes occurring in the total phytoplankton community during 2020 was 7 percent on June 16th, 75 percent on July 14th, 94 percent on August 11th, 98 percent on September 8th, and 17 percent on September 29th.

Figure 5-9 summarizes the density distribution of the cyanophyte genera identified in Gibbs Pond during the 2020 sampling season.

Figure 5-9. Seasonal distribution of cyanophyte genera density in Gibbs Pond, 2020.



The dramatic seasonal fluctuations of different cyanophyte genera that were evident in Capaum Pond during 2020 (Figure 5-6) did not occur in Gibbs Pond. Instead, only a limited number of genera, including *Aphanizomenon flos-aquae*, *Aphanizomenon gracile*, *Planktolyngbya limnetica*, and *Woronichinia* sp., were major density components of the 2020 community while other genera, such as *Dolichospermum flos-aquae*, *Limnothrix* sp., *Microcystis wesenbergii*, and *Pseudanabaena* sp., occurred, but only at very minor density levels during the sampling season.

Cyanotoxins. There were 2 dates during 2020 when raw water samples collected from the pond, lysed and tested using the Eurofins Abraxis® strip test and shipped overnight to GreenWater Laboratories warranted further toxin analyses including September 29th and October 6th. The results from the toxin analyses are summarized in Table 5-8.

Table 5-8. Summary of 2020 cyanotoxin results from Gibbs Pond.

	2020 CYANOTOXIN RESULTS		
	MCs/NODs	ANTX-A	
Date	ng/mL	ng/mL	Comments
September 29th	35.3	ND	
October 6th	7290	ND	
MCs/NODs – *Adda Microcystins/Nodularins*; ANTX-A – *Anatoxin-a*			

Microcystins/nodularins were detected in both samples collected during the 2020 season. The concentrations measured were 35.3 ng/mL on September 29th and 7,290 ng/mL on October 6th. In both cases, the levels of microcystins/nodularins detected by the Adda ELISA test procedures exceeded the current "US EPA Recommended Value for Recreational Criteria and Advisory", which is 8.0 ng/mL (ppb) total microcystins. On September 29th, the exceedance was 4-fold; on October 6th, the exceedance was over 900-fold.

Deployment of the Air Sampling Devices (ASDs). There were no deployments of ASDs along the shoreline of Gibbs Pond during 2020 in spite of the detection of high concentrations of cyanotoxins late during the sampling season.

5.3 Summary

The major focus of the 2020 water quality monitoring on Nantucket Island was the detection of HABs at Capaum Pond and deployment of the different ASD prototypes along the pond shoreline to capture airborne cyanotoxins or picocyanobacteria containing cyanotoxins. There was a less focused effort to detect HABs at Gibbs Pond and no ASD deployment occurred there during 2020.

The full scope of the 2020 water quality monitoring effort at Capaum Pond included (1) the regular collection of integrated phytoplankton samples from the water column to archive and document the community of each pond, (2) routine weekly observation of the shoreline area of each pond for evidence of HABs, (3) the collection of a water sample for Eurofins Abraxis® toxin strip tests if potential HABs were observed, (4) the analysis of raw water samples for a potentially toxigenic (PTOX) cyanobacteria screen, and based upon these results, (5) the analysis of detectable cyanotoxins present in the water column during conditions suspected to be HABs, and then (6) the deployment of the prototype ASDs to document transport of aerosolized cyanotoxins and/or airborne pico-cyanobacteria away from the affected pond to adjacent areas where local residents or recreational users could be exposed through contact (inhalation).

Based upon the 2020 results described in this chapter, there should be no doubt that cyanophytes and cyanotoxins are a potential water quality and public health threat on Nantucket Island at least during the growing season of each year which is the time when the Island is most populated from tourism. Unfortunately, we still do not understand the exact mechanism whereby spores or particles of algal toxins and picocyanobacteria are released from the surface of ponds experiencing a HAB into the atmosphere for transport as aerosol particles. In contrast to the 2019 ASD results, there was no further evidence collected by the ASDs during 2020 that proved transport does occur away from the pond surfaces.

The presence of cyanophyte genera in a Nantucket pond that have the potential to produce cyanotoxins does not mean that toxins are being produced. That is why the present study used the Eurofins Abraxis® strip tests to evaluate the presence of cyanotoxins, followed by submission of water samples to GreenWater CyanoLab for analysis if warranted by the strip test results.

The NLC has been dedicated during the past decade with regard to water quality monitoring and, more recently, with specific efforts related to identifying HABs and cyanotoxins in Nantucket ponds. The data collected to date highlight the fact that Nantucket ponds contain dramatically different populations of cyanophytes and there is the potential for different cyanotoxins and concentrations of toxins among these ponds. Even differences within a particular pond can be dramatic as was exhibited by Capaum Pond during 2020 when *microcystins/nodularins* were the primary cyanotoxin produced in the water column. These 2020 results are in direct contrast to the results gathered during 2019 when *anatoxin-a* was the primary cyanotoxin present in the water column and *microcystins/nodularins* were present and of lesser importance. These differences within a pond during consecutive seasons further support the claim that certain Island ponds require regular water quality monitoring to document the potential presence of cyanotoxin-producing cyanophyte genera and the specific cyanotoxins being produced during any given growing season.

The interested reader is referred to the following US Environmental Protection Agency (US EPA) link for more information related to the federal standards for cyanobacteria and cyanotoxins in drinking water and recreational waters: **https://www.epa.gov/cyanohabs.**

The reference: **https://www.epa.gov/sites/production/files/2014-08/documents/cyanobacteria_factsheet.pdf**, was used earlier in this chapter to describe the various cyanobacteria genera and their potential to produce toxins.

There will be further discussion concerning cyanophytes, cyanotoxins and Nantucket Island ponds in the next chapter of this report.

5.4 Literature Cited

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https://en.wikipedia.org/wiki/Microcystin#)

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Sutherland, J.W., Turcotte, R.J., Molden, E., Moriarty, V., Kelly, M. Aubel, M. and A. Foss. 2021. The detection of airborne anatoxin-a (ATX) on glass fiber filters during a harmful algal bloom. Lake Reserv Manage. 36 (In press).

United States Environmental Protection Agency. 2014. Cyanobacteria and Cyanotoxins: Information on Drinking Water Systems. Office of Water; EPA-810F11001. 11 pp. + Frequently Asked Questions.

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Nantucket Island Ponds and 2020 Water Quality

Chapter 6

Background, 2020 Monitoring Program, Discussion, Summary, Conclusions and Recommendations

6.0 Introduction

This report has presented, in chapter format, the details of the 2020 Nantucket Island pond water quality program conducted by the Nantucket Land Council (NLC), IBM Research and the Rose Laboratory at Rensselaer Polytechnic Institute. This chapter provides (1) a summary of the 2020 water quality monitoring program, (2) a brief summary and discussion of the results, and (3) some basic conclusions and (4) recommendations for future considerations of pond monitoring and water quality management. Many of the Island ponds are used for contact recreation, and the above elements are offered so that reasonable and prudent decisions can be made by scientists, property owners, policy makers and administrators regarding public health and safety.

6.1 Background

The Nantucket Land Council (NLC) Inc. became involved in water quality monitoring of Island ponds during 2009 when Miacomet and Hummock Ponds were surveyed as part of a cooperative effort sponsored by the NLC and the University of Massachusetts (UMass) Field Station. Specific water quality studies were proposed and implemented at that time to fill a gap that was developing due to financial restrictions and the temporary pause of the on-going Town of Nantucket water quality monitoring program on select Island ponds. The 2009 cooperative monitoring effort on Miacomet and Hummock Ponds resulted in two (2) separate reports that described the results and water quality in great detail (Sutherland and Oktay 2010a, 2010b).

During the 12-year period since 2009, the NLC has sponsored the water quality survey of 12 different Island ponds; in some cases, such as Hummock Pond and Head of Hummock Pond, these ponds have been surveyed during multiple years. A most recent summary of the ponds surveyed and years the surveys were conducted is presented in Sutherland and Molden (2019).

6.2 2020 Water Quality Monitoring Program. Beginning on June 2nd 2020, the NLC conducted a total of 21 sampling excursions on Capaum and Gibbs Ponds. Pond sampling concluded on October 20th. Table 6-1 summarizes the 2020 sampling excursions to these ponds.

Table 6-1. Summary of 2020 sampling dates on Capaum and Gibbs Ponds.

Date	Capaum	Gibbs
June 2nd	X	X
June 16th	X	X
June 30th	X	X (2)
July 14th	X	X (2)
July 28th	X	X
August 11th	X	X
August 25th	X	X (2)
September 8th	X	X (2)
September 29th	X	X (2)
October 6th	X	X
October 20th	X	
# excursions	11	10
# chem samples	11	15
X (2) = pond sampled; samples collected from *upper* and *lower* regions of water column		

The field protocols for water quality sampling were described in Chapter 2 of this report and these protocols are followed strictly on each pond that is monitored.

6.3 Discussion

Water Quality Parameters. Many of the parameters (analytes) that are measured on a pond have certain value in assessing overall water quality, which should become clear when reading through the various pond chapters in this report and the sizeable assortment of previous reports that describe the water quality of ponds that have been monitored by the NLC during the previous decade.

Table 6-2 provides a summary of *maximum*, *minimum* and *average* values for the suite of analytes that were monitored in Capaum and Gibbs Ponds, including physical, chemical and biological data.

Table 6-2. A summary of *minimum*, *maximum* and *average* values for the suite of parameters monitored during 2020 at Capaum and Gibbs Ponds.

Nantucket Ponds	Secchi (m)	Chl ***a*** (µg/L)	DO (% sat)	NO3-N (mg/L)	TN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	TDS (mg/L)	spC (µS/cm)	pH (s.u.)
Capaum Pond										
minimum value	0.33	2.31	79.0	0.005	0.77	0.036	0.005	169	254	6.27
maximum value	1.55	114.0	146.5	0.02	3.06	0.214	0.023	522	790	9.77
average value	0.75	33.7	115.3	0.01	1.39	0.091	0.007	227	339	7.57
Gibbs Pond										
minimum value	0.25	1.4	55.5	0.005	0.95	0.273	0.060	70	108	4.67
maximum value	0.64	76.2	112.8	0.05	2.32	0.485	0.180	3738	4651	10.21
average value	0.39	49.3	91.3	0.02	1.59	0.347	0.113	470	611	6.49
Values highlighted are reported as one-half the lower detection limit.										

Ponds such as Capaum and Gibbs that were monitored during 2020 are very dynamic in nature and subject to great influence by both autochthonous (within the system) and allochthonous (outside the system) factors to the extent that a comparison of these waters at another time in the future could likely reveal much different results than the 2020 data summarized above and in previous chapters of this report.

Trophic State. In simplest terms, '*trophic state*' is the total weight of living biological material (biomass) in a water body at a specific time and location (Carlson and Simpson 1996), with the understanding that the time and location specific measurements can be grouped to achieve estimations of trophic state at the level of the individual lake or pond under investigation. Trophic state is the biological response to external driving factors such as nutrients, season of the year, and climate, as well as internal factors such as temperature, mixing of the water column, etc.

Using the information presented above for *trophic state*, the *trophic state index* developed by Carlson (1977) uses algal biomass as the basis for the water body classification. Three (3) variables, including chlorophyll ***a***, total phosphorus and Secchi depth transparency (SDT) are used, independently, to estimate algal biomass. Carlson's technique of classification is different than the earlier typological system developed by Naumann (1929) because the index reflects a continuum of states and not just a single state.

Total phosphorus and chlorophyll ***a*** data are the most objective criteria used to evaluate water quality in a pond because these values are measured by a laboratory using standard analytical techniques and the data can provide a relative comparison of water quality among ponds of similar size and/or geographic location.

SDT is a subjective measurement recorded by an individual and may differ from the transparency reading obtained by another individual even though both readings are collected at the same location and under the same conditions. In contrast to the analytical criteria used to assess water quality, SDT is the least expensive parameter to measure.

Table 6-3 provides a summary of 2020 Trophic Status Indices calculated for total phosphorus, chlorophyll ***a*** and SDT for Capaum and Gibbs Ponds, and compares these results with the results from 2019.

Table 6-3. A summary of Trophic Status Indices calculated for total phosphorus, chlorophyll *a* and Secchi depth transparency data collected at Capaum and Gibbs Ponds during 2019 and 2020.

		2019 and 2020 Trophic Status Indices and Trophic Status		
Pond	Year	Total phosphorus (TP)	Chlorophyll ***a*** (Chl ***a***)	Secchi Depth (SD)
Capaum	2019	70.6 (HE)	73.6 (HE)	72.3 (HE)
	2020	69.2 (E)	65.1 (E)	64.2 (E)
Gibbs	2019	89.5 (HE)	68.1 (E)	73.2 (HE)
	2020	88.5 (HE)	73.7 (HE)	73.7 (HE)
E = eutrophic status, HE = hyper-eutrophic status				

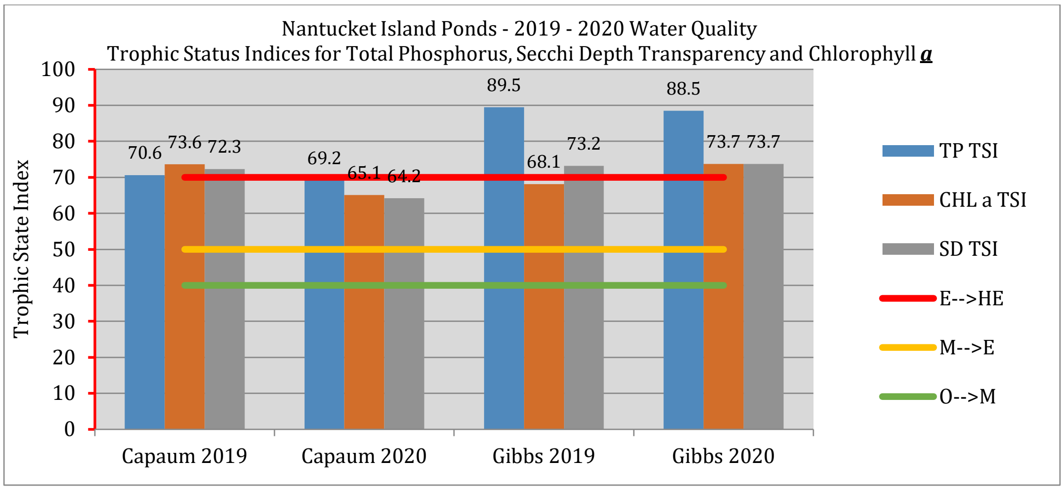
Trophic Status Indices that were calculated for Capaum and Gibbs Ponds from the equations for TP, chlorophyll ***a***, and SDT and summarized in Table 6-3 for each pond are cross referenced to the metrics summarized in Table 6-4 to properly interpret the trophic class that defines the productivity for each calculated index value.

Table 6-4. Relationships among Trophic Index, chlorophyll *a*, total phosphorus, Secchi depth and Trophic Class (after Carlson, 1996).

Trophic Index	Chlorophyll (µg L^{-1})	TP (µg L^{-1})	Secchi Depth (m)	Trophic Class
< 30 - 40	0.0 – 2.6	0.0 - 12	> 8 - 4	Oligotrophic
40 - 50	2.6 – 7.3	12 - 24	4 - 2	Mesotrophic
50 - 70	7.3 - 56	24 - 96	2 – 0.5	Eutrophic
70 – 100+	56 – 155+	96 – 384+	0.5 - <0.25	Hyper-eutrophic

The summary of Trophic Status Indices calculated for both ponds during 2019 and 2020 are summarized graphically in Figure 6-1.

Figure 6-1. Summary of Trophic Status Indices calculated for Capaum and Gibbs Ponds, 2019 and 2020.



Even two consecutive years of water quality data are not considered sufficient to characterize a lake or pond with respect to productivity; however, the current exercise was carried out in an effort to compare the ponds that were monitored during 2019 and 2020. Continued monitoring of these ponds over a longer period of time will provide a more robust water quality data-base for each pond and provide important information about changes in water quality and trends that might be occurring with regard to the various analytes that are essential in evaluating pond productivity.

For the interested reader, a summary of Trophic Status Indices developed for the Nantucket Island ponds monitored by the NLC during the previous 12 years is presented in Attachment #3 at the end of this report.

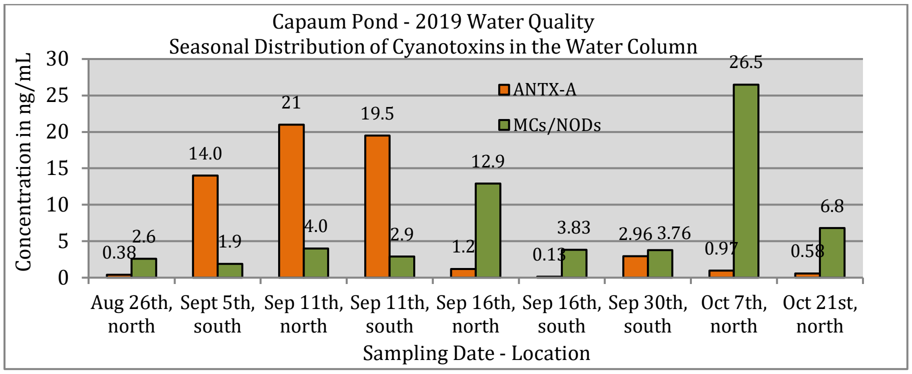
Cyanophytes, Cyanotoxins and Nantucket Island Ponds. Although there still is considerable research to be conducted in this area, the consequences of cyanophytes-cyanotoxins and their potential effects on water quality and public health on Nantucket Island are real and need to be addressed in the future so that year-round and seasonal residents are made aware of possible health-related situations and can act and/or respond accordingly.

The 2020 water quality results collected from Capaum Pond complete another installment in a multi-year Case Study, initiated during 2019, of the cyanophyte-cyanotoxin issue and provide considerable, additional evidence that the problem with cyanophytes-cyanotoxins on Nantucket Island must be addressed.

This particular body of water, approximately 18 acres in size, exhibited a single and extended HAB during 2019 which was detected on August 26th and continued through October 21st. During this 2-month period, there were 9 separate sampling excursions conducted for cyanotoxins and detectable levels of *anatoxin-a* and *microcystins/nodularins* were reported in each of the 9 samples.

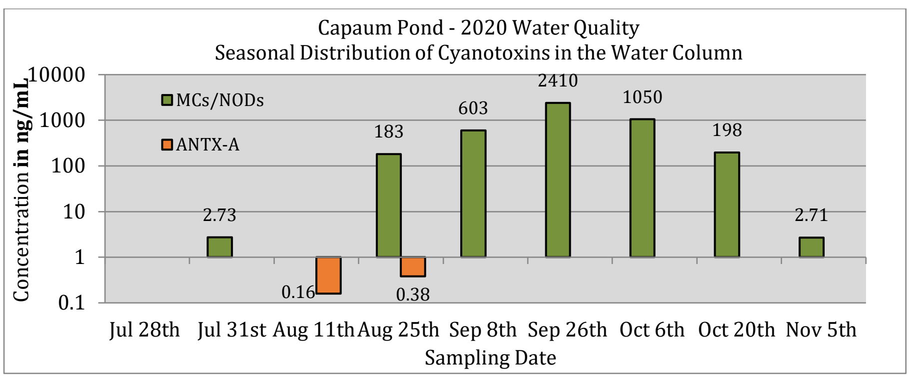
As summarized in Figure 6-2, *Anatoxin-a* dominated during the first part of the 2-month period, with concentrations ranging from 0.38 to 21.0 ng/mL, and averaging 13.7 ng/mL between August 26th and September 11th. *Microcystins/Nodularins* predominated during the second part of the 2-month period, ranging from 3.76 to 26.5 ng/mL, and averaging 10.8 ng/mL between September 16th and October 21st.

Figure 6-2. Seasonal distribution of cyanotoxins measured in Capaum Pond, 2019.



Now we fast forward to the 2020 sampling season on Capaum Pond. Once again, there was a single, extended HAB which first was detected on July 31st and continued through November 5th. During this 3+ month period, there were 8 separate sampling excursions to collect cyanotoxins. As summarized in Figure 6-3, detectable levels of anatoxin-a were reported in the August 11th and August 25th samples, while exceedingly high levels of microcystins/nodularins were reported in samples collected on August 25th through October 20th.

Figure 6-3. Seasonal distribution of cyanotoxins measured in Capaum Pond, 2020.



The data collected from Capaum Pond during 2019 and 2020 emphasize how dramatically consistent this pond, or any body of water, can be from one year to the next with regard to the occurrence and timing of HABs. On the other hand, the 2019 and 2020 data from Capaum Pond also highlight how different any pond can be in terms of (1) the potential genera producing cyanotoxins and (2) the particular cyanotoxin posing health risks to users of the water body and residents living adjacent to the pond.

The following guidelines for exposure to algal toxins were adopted by the World Health Organization (WHO) several decades ago (1999) and there is no evidence of any update since that time despite the world-wide increase in HAB reports and research efforts associated with HABs:

- 0.0-0.2 ng/L (little to no risk from Blue-green algal toxins: *Minimal Risk*)
- 0.2-1.0 ng/L (toxin detected but below WHO drinking water guidelines: *Low Risk*)
- 1.0-10.0 ng/L (toxin levels above WHO drinking water guidelines but below WHO limits for recreational use: *Moderate Risk*)
- 10-20 ng/L (toxin levels significant and approach WHO limits for recreational contact: *High Risk*)
- >20 ng/L (*toxin levels exceed WHO guidelines for recreational contact; users should avoid contact and be extremely careful to wash off pets*)

Using these WHO guidelines to interpret the 2019 and 2020 cyanotoxin results from Capaum Pond (Figures 6-2 and 6-3) during mid-summer and early fall clearly highlight the existence of major blocks of time when any contact with water in the pond provided *Moderate-to-High Risk* and other periods when all contact with pond water should be avoided due to extremely high cyanotoxin concentrations.

6.4 Summary

2020 was a very productive year in terms of water quality and HABs sampling but somewhat disappointing with respect to aerosol collection of cyanotoxins adjacent to Capaum Pond. Beginning on June 2nd, the Nantucket Land Council conducted a total of 21 sampling excursions on Capaum and Gibbs Ponds. Most water quality sampling concluded on October 20th; however, raw water samples for the analysis of cyanotoxins were collected on November 5th. There were 9 separate deployments of Air Sampling Devices (ASDs) during 2020; each deployment included the glass fiber filter prototype deployed during 2019 and a new liquid-vortex prototype designed to trap airborne particles in solution to enhance collection efficacy and retard particle degradation.

Highlights of the 2020 sampling season compiled from field sampling sheets, related notes and laboratory results are as follows:

- 26 chemistry samples were submitted to the Phoenix Environmental Laboratories, Inc. for analysis; 21 samples were collected from the ***upper*** region of both ponds using the integrated hose technique and 5 samples were collected from the ***lower*** region of Gibbs Pond using a van Dorn bottle,
- 16 phytoplankton samples were collected using the integrated hose technique and submitted to Barry Rosen for identification and enumeration,
- 11 pond surface water samples were collected for Eurofins Abraxis® strip tests and processed back in the NLC office following a series of 3 freeze-thaw procedures to lyse the algal cells in the sample,
- 6 pond surface water samples were submitted to GreenWater CyanoLab in Palatka Florida for a Potentially Toxigenic (PTOX) Cyanobacteria Screen for suspected incidents of suspicious blooms occurring on Capaum and Gibbs Ponds,
- 27 samples were submitted to GreenWater CyanoLab for toxin analysis including 11 pond surface water samples, 8 filters collected post-ASD deployment, 8 liquid samples collected post ASD vortex and impinger sampler deployment,
- 9 of the 11 pond surface water samples submitted to GreenWater CyanoLab exhibited positive results for algal toxins; 1 of the 8 filters submitted for analysis exhibited positive results for *Adda Microcystins/Nodularins,*
- 8 of the 9 surface water samples collected at Capaum Pond and submitted for toxin analysis exhibited positive results beginning on July 31st and continuing through November 5th when the last sample was collected; 7 of the 9 surface water samples collected at Capaum Pond exhibited positive results for *Adda Microcystins/Nodularins*; 2 of the 9 samples exhibited positive results for *Anatoxin-a*,
- Both surface water samples collected at Gibbs Pond and submitted for toxin analysis exhibited positive results for *Adda Microcystins/Nodularins* with concentrations of 35.3 ng/mL on September 29th and 7,290 ng/mL on October 6th.

The 2020 cyanotoxin results received from GreenWater CyanoLab for the Nantucket Island ponds that were monitored were presented previously in Chapter 8 of this report.

6.5 Conclusions

The following conclusions are presented after careful consideration of the 2020 water quality data collected from Capaum Pond and Gibbs Pond.

(1) Both ponds exhibited high levels of trophy (productivity, nutrient enrichment) during 2020 regardless of which index (total phosphorus, chlorophyll ***a***, SDT) was used for the evaluation.

(2) Determination of pond productivity using only 2 years of water quality data is not sufficient to characterize a pond because subtle changes from year-to-year can dramatically influence the status of pond water quality within the trophic gradient. Thus, a longer term record in required.

(3) Ponds such as Capaum and Gibbs are very dynamic in nature and subject to great influence by both autochthonous (within the system) and allochthonous (outside the system) factors to the extent that a comparison of these waters in the future could likely reveal different results than the 2019 and 2020 results summarized above.

(4) Nantucket Island ponds are capable of experiencing harmful algal blooms (HABs) at various times during the growing season and as a result due diligence is required on the local level to monitor conditions and, if necessary, post advisories to make recreational users of the ponds aware of potential public health concerns due to exposure to dangerous cyanotoxins in the water and adjacent air surrounding the ponds.

6.6 Recommendations

Environmental stewardship of Nantucket Island ponds falls under various jurisdictions including the Town of Nantucket, the Nantucket Conservation Foundation, the Nantucket Island Land Bank, and the Linda Loring Foundation, with other organizations such as the Nantucket Land Council advocating for the planning, protection and preservation of Island resources which include the ponds and associated water quality. The following recommendations are presented after careful consideration of the 2019 and 2020 water quality data collected from Capaum and Gibbs Ponds and previous water quality data collected by Sutherland and Molden (see 2019 report) during the past decade:

(1) Certain Nantucket Island ponds require attention directed toward several water quality issues that have been manifested for most of the past decade, including considerable nutrient enrichment and extended blooms of cyanobacteria that potentially produce toxins and pose a public health threat. All of the ponds investigated during 2019 and 2020 (Capaum, Gibbs, Head of Hummock, Miacomet) have been subject to previous water quality investigations by the Nantucket Land Council and should receive continued monitoring in the future.

(2) A list of Island ponds should be identified and monitored on a weekly basis for evidence of HABs along the pond shoreline during the 2021 growing season between June 1st and October 15th. This effort was initiated and coordinated during 2020 by the Town of Nantucket and involved other organizations including the Nantucket Conservation Foundation, the Nantucket Island Land Bank and the Nantucket Land Council. The format and results of the 2020 program are summarized and presented in Attachment #4 at the end of this report. The 2020 program should be evaluated so that improvements can be implemented moving forward with the 2021 program.

(3) The Nantucket ponds that should be monitored regularly by the Town program for HABs during the 2021 growing season include the list presented in Attachment #4 with special emphasis on those ponds that exhibited multiple observations of HABs during 2020 including, but not limited to, Hummock, Miacomet, and Clark's Cove.

(4) The Nantucket Land Council should continue to monitor the water quality and presence of HABs on Capaum and Gibbs Ponds on a regular basis during 2021..

(5) As more water quality data become available for Nantucket Island ponds, it would be prudent to start prioritizing those ponds with poor water quality and to discuss the possibility of whether some form of long-term management could be implemented to improve water quality and reduce the potential impact of HABs on local residents and pond users. It is important to remember, however, that water quality is the result of both autochthonous (internal) and allochthonous (external) influences. Water quality investigations similar to those conducted on Capaum and Gibbs Ponds during 2019 and 2020 are able to define the extent of the water quality problems, but are not able to determine the influence or extent of external factors. It is critical, therefore, to explore and understand the overall extent of external influence before selecting a plan of remediation because large amounts of money and effort could be wasted if the negative external influence is not elucidated and remediated.

(6) With respect to Capaum Pond, it is important to understand the potential for external influence on water quality from residential properties surrounding the pond and whether subsurface inputs from either fertilizer application or septic system drainage are adding nutrients to the pond. Installation of shallow well points and regular sampling of these wells would be worthy of investigation.

(7) With respect to Capaum Pond, the authors of this report are aware that the Nantucket Conservation Foundation retained SWCA Environmental Consultants to (1) investigate and document certain characteristics of Capaum Pond during 2020 which were presented in a report, and (2) use the information collected to propose various remediation activities that could be implemented in 2021 to improve the water quality of the pond and perhaps reduce the potential for harmful algal blooms (HABs). While it is not our intention to advocate or discourage any particular management strategy proposed by SWCA, we are concerned about the recommendation of a pond-wide aeration option which would, in our opinion, greatly enhance the re-suspension of cyanophyte forms from the bottom sediments and also increase the potential for cyanotoxins to be released from the pond surface as aerosols via bursting of bubbles during any HABs that could potentially occur during 2021.

(8) With respect to Gibbs Pond, we currently understand very little regarding the dynamics of the pond as it is used for irrigation of the surrounding cranberry bogs. In particular, records of the frequency and relative amounts of water withdrawal would be important information to gather, as well as whether water removal always occurs from a certain depth or whether the depth of removal can be controlled. We also have little understanding of whether the local bogs are fertilized in any manner to increase productivity of the annual cranberry harvest.

6.7 Literature Cited

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Nantucket Island Ponds and 2020 Water Quality

Attachment #1

Narrative and Schematic of 2020 Sensor Deployment at Capaum Pond

Capaum Pond sensor deployments -- 2020, Nantucket, MA

We envisioned deploying a suite of sensors near the middle of Capaum Pond from approximately June through November of 2020.

The sensors include three deployment modes (see Figure 1) including:

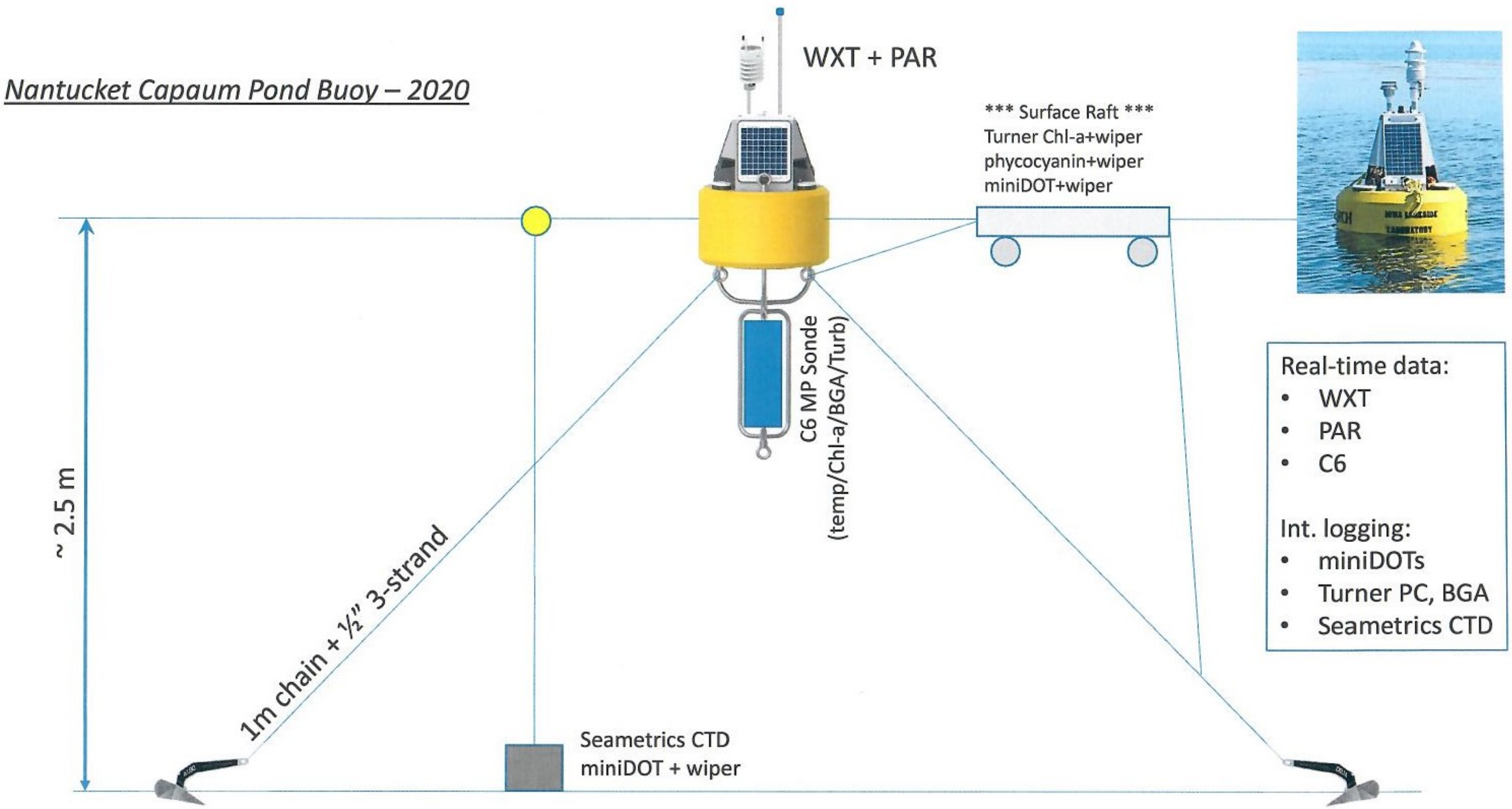
1. A 24" diameter data buoy equipped with a weather station, PAR (light) sensor, and a fluorescence-based water quality sonde. Periodic samplings of the data from these sensors will be available near real-time on a web-based portal. All recorded data will be retrieved upon sensor recovery at the end of the season. The buoy will be moored to the pond bed with one small (9 lb) plow anchor, 1 m of chain, and 1/2" 3-strand nylon line comprising each side of a 2-point mooring.

   The purpose of this deployment is to monitor near-surface weather conditions, light conditions, and water quality conditions throughout the season. Ideally, we hope to characterize weather and pond conditions before, during, and after cyanobacterial blooms. Near real-time data availability will inform us of system operability and provide periodic data for in-season analyses, especially as might be useful in conjunction with results from periodic physical sampling and associated lab analyses.

2. A small floating raft, approximately 24"x24" equipped with internally-logging Chl-a, Phycocyanin, and surface temperature sensors. As cyanobacterial blooms are often associated with marked changes near the water's surface (e.g., the aggregation of cyanobacterial colonies and/or visible surface scum), we believe that it will be important to monitor this region of the ecosystem for changes that the water quality sensors in the data buoy may be too deep to capture. Data from these sensors will be retrieved at the end of the deployment.

3. Pond-bed-deployed, internally-logging CTD (conductivity, temperature, depth) and DO (dissolved oxygen) sensors, mounted on a cinder block weight tethered to a surface float for retrieval. Data from these sensors will be retrieved at the end of the deployment.

   Understanding potential inflow of groundwater from (possibly wind-induced) hydrostatic pressure, and the potential of saline incursion into the system may help inform of conditions of internal nutrient loading and possibly even toxin generation and dynamics. High-frequency dissolved oxygen monitoring may help inform of potential anoxia-induced phosphorus release from the sediment that less frequent measurements may miss.


Nantucket Capaum Pond Buoy – 2020
WXT + PAR
*** Surface Raft ***
Turner Chl-a+wiper
phycocyanin+wiper
miniDOT+wiper
C6 MP Sonde
(temp/Chl-a/BGA/Turb)
~ 2.5 m
1m chain + ½" 3-strand
Seametrics CTD
miniDOT + wiper
Real-time data:
• WXT
• PAR
• C6
Int. logging:
• miniDOTs
• Turner PC, BGA
• Seametrics CTD

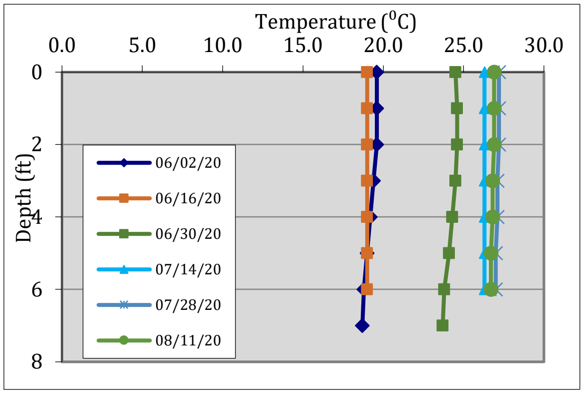
Nantucket Island Ponds and 2020 Water Quality

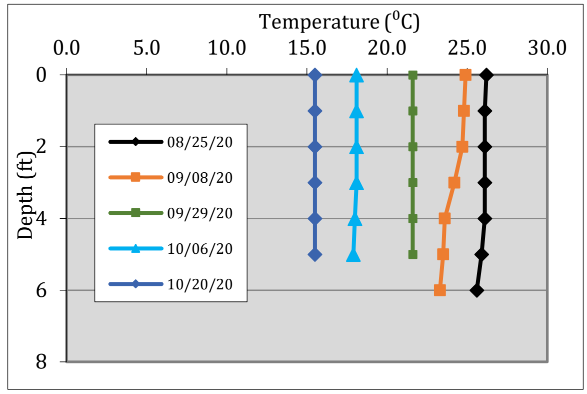
Attachment #2

2020 Pond Temperature and Dissolved Oxygen Percent Saturation Profiles

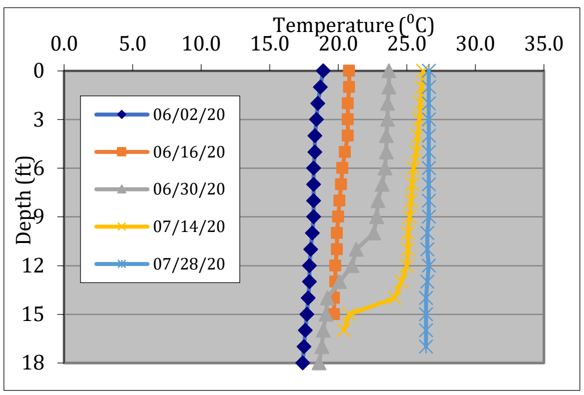
2020 Temperature Profile Data

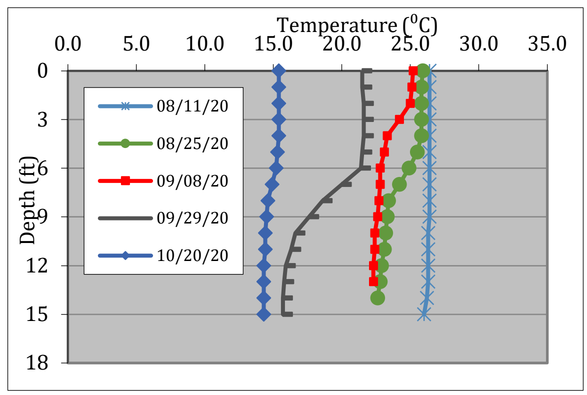
Capaum Pond





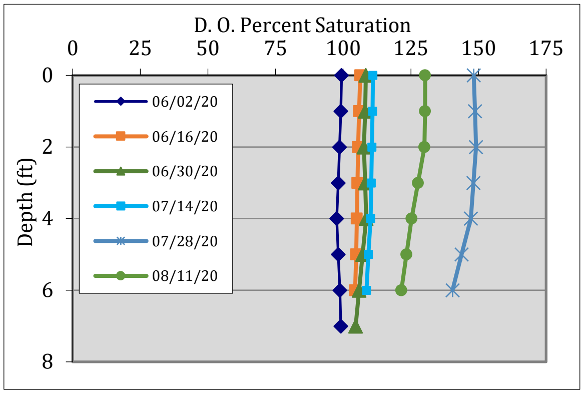
Gibbs Pond

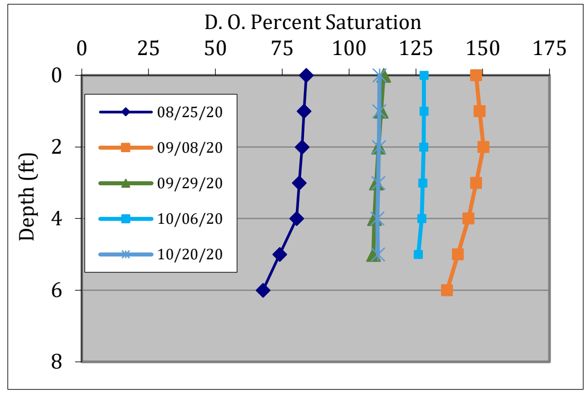




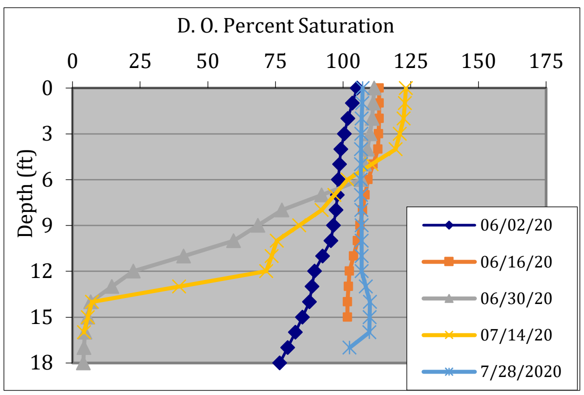
2020 Dissolved Oxygen Percent Saturation Profile Data

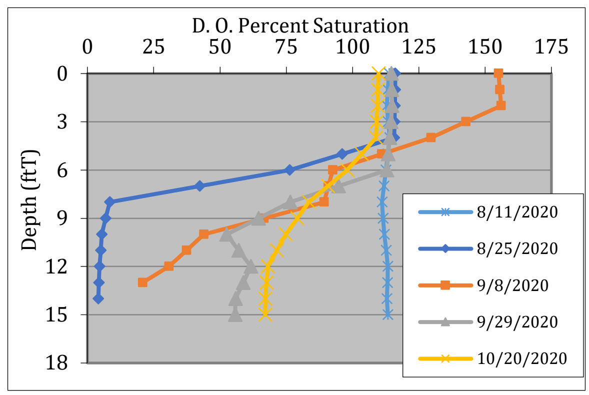
Capaum Pond





Gibbs Pond





Nantucket Island Ponds and 2020 Water Quality

Attachment #3

Summary of Nantucket Island Pond Trophic Status Indices since 2009

A summary of Trophic Status Indices calculated for total phosphorus, chlorophyll ***a*** and Secchi depth transparency for all 12 Nantucket Island ponds since 2009, when sufficient data were available to perform the calculations.

		Year of Water Quality Survey											
Pond	**Parameter**	**2009**	**2010**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	
	CHL	E							M				
Miacomet	SDT	E							E				
	TP	E							E				
	CHL	E		E									
Hummock	SDT	E		E									
	TP	E		E									
	CHL	E	HE	E	E				E				
Head of Hummock	SDT	E	E	E	E				E				
	TP	HE	HE	HE	HE				HE				
	CHL					M		E	O				
Maxcy	SDT					NA		NA	NA				
	TP					M		M	M				
	CHL					M		E	E				
Tom Nevers	SDT					HE		HE	HE				
	TP					E		HE	HE				
	CHL					E		E	E				
Washing	SDT					E		M	E				
	TP					E		E	E				
	CHL						HE			HE	HE	E	
Capaum	SDT						HE			HE	HE	E	
	TP						HE			HE	HE	E	
	CHL						E						
Pest House	SDT						NA						
	TP						E						
	CHL							HE	HE		E	HE	
Gibbs	SDT							E	HE		HE	HE	
	TP							HE	HE		HE	HE	
	CHL							E					
Little Weeweeder	SDT							E					
	TP							M					
	CHL							M					
North Head Long	SDT							E					
	TP							E					
	CHL								E				
Long	SDT								E				
	TP								HE				

CHL = chlorophyll ***a***; SDT = Secchi depth transparency; TP = total phosphorus
E = eutrophic status, HE = hyper-eutrophic status, M = mesotrophic status, na = insufficient data for calculation

Nantucket Island Ponds and 2020 Water Quality

Attachment #4

Summary of Town of Nantucket 2020 Island Pond Harmful Algal Bloom Monitoring

	Pond Name								
	Hummock	Long	Miacomet	Sesachacha	Capaum	Gibbs	Clark's Cove	Maxcy	Washing
Date of Observation	HAB occurring at time of observation (Y/N)								
6/3/2020	N	N	N	N	N	N	N	N	
6/9/2020	N	N	N	N	N	N	N	N	
6/16/2020	N	N	Y	N	N	N	N	N	
6/23/2020	N	N	Y	N	N	Y	N	N	
6/30/2020	N	N	N	N	Y	Y	N	N	
7/5/2020							Y		
7/7/2020	Y(head)	N	N	N			N	N	
7/21/2020	N	N	N	N	N	N	N	N	
7/27/2020	Y	N	N	N	N	N	N	N	
8/3/2020		N	N	N	Y	N		N	N
8/5/2020	Y						N		
8/11/2020	N	N	N	N	N	N	N	N	N
8/18/2020	N	N	N	N	N	N	N	N	N
8/25/2020	Y	N	N	N	Y	N	N	N	N
9/1/2020	N	N	N	N	Y	N	N	N	N
9/8/2020	Y	N	Y	Y	Y	Y	Y	Y	N
9/15/2020	Y	N	Y	N	Y	N	Y	N	N
9/22/2020	N	N	N	N	Y	N	N	N	N
9/29/2020	N	N	N	N	Y	Y	N	N	N
10/6/2020	N	Y	N	N	Y	Y	N	N	N
10/13/2020		N	N		N	N		N	N
10/21/2020	Y	N	N	N	Y	N	Y	N	N
10/28/2020	N	N	N	N	Y	Y	N	N	N
total observations	20	21	21	20	20	20	21	21	13
total HABs observed	6	1	4	1	11	6	4	1	0