Nantucket Island Ponds and 2018 Water Quality

Capaum Pond

A Summary of Physical, Chemical and Biological Monitoring

Prepared by:

James W. Sutherland, Ph.D.
NYS Department of Environmental Conservation (retired)
166 Main Street
Greenwich, NY 12834

Prepared for:

Nantucket Land Council, Inc.
6 Ash Lane
Nantucket, MA 02554

July 2019

DISCLAIMER

This report has been reviewed by the Nantucket Land Council, Inc. and approved for distribution. This approval, however, does not signify that the contents necessarily reflect the views and policies of the organization, nor does mention of trade names or commercial products constitute an endorsement of recommendation for use.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

Funding for this work was provided by the Nantucket Land Council (NLC), Inc. This was the tenth consecutive year that the NLC has sponsored water quality research on Nantucket Island ponds. By funding these projects, the NLC continues to demonstrate its vision focused on environmental stewardship of the unprotected water resources of Nantucket Island and its desire to advocate for the protection of important features of the Nantucket landscape that are constantly threatened by man's encroachment and influence.

The authors would like to thank the Nantucket Conservation Foundation for providing permission to access Tom Nevers Pond and Gibbs Pond for sampling during 2017.

The principal author would like to personally thank the following individuals whose assistance was instrumental in completing the field work, data analysis and report writing phases of this project: Cormac Collier for his continued dedication toward the environment and important water quality issues, and Emily Molden who is particularly reliable with critical field sampling of the ponds, often under less than ideal weather conditions.

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.

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 of nitrogen in a water body 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.

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 - Phytoplankton

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 lakes 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:

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

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.

1.7 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.

Hutchinson, G.E. 1967. A Treatise on Limnology. Volume II. Introduction to Lake Biology and the Limnoplankton. John Wiley, New York and London. 1115 pp.

Hutchinson, G.E. 1957. *A* Treatise on Limnology. Volume I. Geology, Physics and Chemistry. John Wiley, New York and London. 1015 pp.

Sutherland, J. W., J. A. Bloomfield and J. M. Swart. 1983. Final Report: Lake George Urban Runoff Study, US EPA Nationwide Urban Runoff Program. New York State Department of Environmental Conservation Technical Report, Albany, New York. 84 pp. + appendices.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Co., Philadelphia, Pa. 743 pp.

Nantucket Island Ponds and Their Water 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 20°C 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	
	total phosphorus
	nitrogen series (total 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, cyanophyte toxins

2.2 Methodology

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

Routine 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 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 would 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 Secchi depth transparency 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 (*epilimnion*) is sampled using the integrated hose technique; the lower zone of different temperature or oxygen concentration 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 epilimnetic 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 levels 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 were placed in a Styrofoam cooler with gel packs and shipped via FedEx (2nd day delivery) to a contract laboratory that is certified to process and analyze the nutrient chemistry analytes and chlorophyll ***a***. A Chain of Custody form (shown in Attachment 1) accompanied the samples to the analytical lab.

Depending upon conditions observed at each pond, a subsample of raw pond water collected from the epilimnion is tested for the presence of algal toxins (microcystins) using an Abraxis, LLC Algal Toxin Strip Test for Recreational Water. The test was 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 Laboratories in Palatka, Florida on certain occasions for the analysis of microcystins even though the Strip Test may indicate toxin concentrations of 0 ppb or 0-1 ppb for each sample. 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 Sample Collection. 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,	Vertical profiles at 2-foot intervals (except Secchi) at deep site	Standard Secchi protocol; YSI dissolved oxygen-temperature meter;
Chemical Characteristics (pH, conductivity, NO_3, NH_4, TN, TP)	Integrated epilimnetic sample; hypolimnetic grab sample at least 1 ft above bottom sediment	Ion Chromatograph, Atomic Absorption, Autoanalyzer, Spectrophotometer, pH meter
Biological Characteristics - Phytoplankton	Integrated photic zone sample	chlorophyll a, species identification and enumeration, biomass
Biological Characteristics - Phytoplankton	Integrated photic zone sample	microcystin analysis (if warranted)

The analytical procedures for water chemistry generally are determined by the specific analytical laboratory that receives samples for analysis and are not listed here since no facility has been recommended.

Phytoplankton identification-enumeration. The protocol used for the microscopic examination of phytoplankton for identification and enumeration is detailed below.

Counting method. At least 200 mL of preserved sample is required for this analysis. An inverted microscope is used for phytoplankton counts. The objectives of the inverted microscope are located below a movable stage and the light source comes from above, permitting viewing of organisms that have settled to the bottom of a chamber. A sample is prepared by filling duplicate cylindrical 50 mL Ütermohl settling chambers, which have a thin, clear glass bottom. The samples settle for an appropriate period (1 hour settling time/ mm of column depth, about 3 days). Sedimentation is the preferred method of concentration since it is nondestructive and non-selective. After the settling period, the chamber tower is gently removed with a cover slip, removing all but 1 mL of sample in a small well at the chamber bottom.

The sample is scanned using low magnification to determine the taxa present, and then analyzed at 1000x using oil immersion to accurately count cells below 10-20 µm in size which may be present. For biomass estimates, it also is necessary to have high magnification to measure width, length and depth of a cell. Non-overlapping random fields are examined until at least 100 units of the dominant taxa are counted. The entire chamber floor usually is counted to get a precision level of a least 95%. Results are recorded as number of cells per taxa present, with approximations being used for multicellular (colonial) taxa. Dead cells or empty diatom frustules are not counted.

Conversion to density (cells mL^{-1}). The microscope is calibrated at each magnification using an ocular micrometer placed in the eyepiece of the microscope and a stage micrometer. The number of cells counted for each taxon is determined using the following equation:

$$\#\ of\ cells/mL = \frac{C\ x\ A_s}{V\ x\ A_f x\ F}$$

where, C = number of cells counted (average of two settling chambers)
A_s = area of settling chamber bottom, (mm^2)
V = volume of sample settled (50 mL)
A_f = area of field (determined by the microscope calibration), (mm)
F = number of fields counted

Conversion to biovolume ($mg^3\ mL^{-1}$) - biomass ($mg\ m^{-3}$). Phytoplankton data derived on a volume-per-volume basis are more useful than numbers per milliliter (density) since algal cell sizes can differ in various bodies of water or within the same body of water at different times of the year. Average measurements were made from approximately 20 individuals of each taxon for each sampling period. The simplest geometric configuration that best fits the shape of the cell being measured (i.e., sphere, cone, cylinder) is used, and calculations made with corresponding formulas for that shape. The total biomass (um^3mL^{-1}) of any species is calculated by multiplying the average cell volume in cubic micrometers by the number of cells per milliliter. Results are recorded as biomass (mg/m^{-3}) by dividing total biovolume (mg^3/mL^{-1}) by 1,000.

Cyanophyte toxin analysis. At GreenWater Laboratories, samples received for analysis of *microcystin* (MC) are ultra-sonicated to lyse cells and release the toxins. In some cases, a duplicate sample (Lab Fortified Matrix, LFM) was spiked at 1.0 µg/L MCLR, which provided quantitative capability and additional qualitative confirmation. A *microcystin* enzyme linked immunosorbent assay (ELISHA) is utilized for the quantitative and sensitive congener-independent detection of MCs.

2.4 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.

2.5 Literature Cited

Nantucket Island Ponds and Their Water Quality

Chapter 3

Capaum Pond – 2015 and 2018

3.0 Introduction

This chapter provides a summary and discussion of the physical, chemical and biological data collected from Capaum Pond by the Nantucket Land Council, Inc. during August and September 2015 and again during August 2018.

3.1 Results

Capaum Pond was sampled twice during 2015, on July 21st and on September 8th; the pond also was sampled on August 15th 2018. The maximum water depth in the pond was 5.5 feet (66 inches) on July 21st at the sampling location in the approximate center of the pond; the sampling depth on September 8th was 4.8 feet (58 inches). On August 15th 2018, the maximum water depth was 6.3 feet (75 inches).

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 shown in Table 3-1 below.

Table 3-1. Summary of Capaum Pond integrate and grab sample depths, 2015 and 2018.

Sampling Date	integrate (*upper*) depth	grab (*lower*) depth
July 21st 2015	0-4 feet	5 feet
September 8th 2015	0-3 feet	4 feet
August 15th 2018	0-4 feet	6 feet

On July 21st 2015, a raw water sample was collected for algal toxins and submitted for analysis because observations suggested that an algal bloom was in progress; there also was a follow-up sample collected and submitted for toxins on July 28th 2015. The results from these two samples prompted subsequent collections of raw water samples for toxin analysis on August 4th and August 13th 2015. The results from these algal toxin samples are presented later in this chapter. Other observations recorded while sampling the pond during August 2015 included an absence of any visible submerged attached aquatic vegetation and the bottom was a dark organic material.

Observations recorded on the field sheet during the August 15th 2018 sampling of the pond included a notation that an algal bloom was in progress at the time of sampling. However, no raw water sample was collected for toxin analysis at that time.

3.1.1 Physical characteristics

General. Capaum Pond has an irregular shape with its long axis oriented north-south (Figure 3.1). The pond is located along the north shore toward the western end of Nantucket Island, ~2,000 feet 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 by a high sand berm running parallel to the shoreline.

Temperature. Temperature profile data were collected on the 2015 and 2018 sampling excursions. Due to the pond's shallow depth, there was only 2-3 degrees of temperature fluctuation from surface to bottom on both sampling dates. The average temperature was 25.4ºC on July 21st and 25.6ºC on September 8th. There was no temperature gradient in the water column on August 15th 2018; the surface emperature was 26.7ºC and the temperature at the bottom (6 feet) was 26.1ºC.

Transparency. The Secchi depth transparency measured at Capaum Pond was about 1 foot on both 2018 sampling dates, indicating very low light penetration from the pond surface down through the water column. The Secchi depth was recorded as 14 inches on July 21st and 10 inches on September 8th. Water color on both sampling dates was listed as 'cloudy green' which usually is indicative of an algal

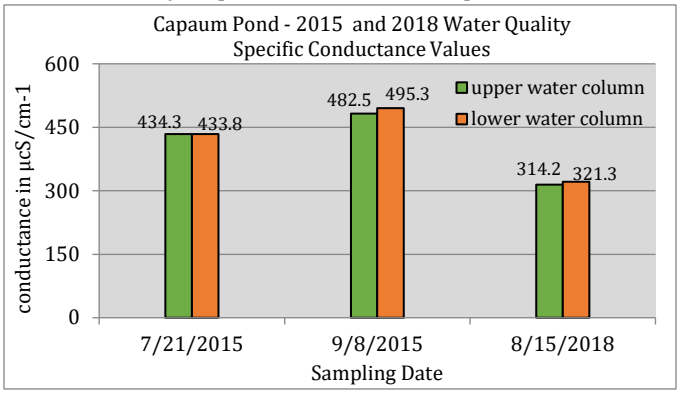
bloom in progress. On August 15th 2018, the Secchi depth transparency was 18 inches and the water color was recorded as 'cloudy green'.

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

3.1.2 Chemical characteristics

Specific conductance. Figure 3.2 summarizes the conductivity values measured in the *upper* and *lower* regions of the pond during July and September 2015 and August 2018. The individual values measured on July 21st 2015 were 434.3 and 433.8 µS·cm^{-1} in the upper and lower regions, respectively; on September 8th 2015, the *upper* and *lower* values were 482.5 and 495.3 µS·cm^{-1}, respectively; on August 15th 2018, the upper and lower values were 314.2 and 321.3 µS·cm^{-1}, respectively.

Figure 3-2. Summary of specific conductance in Capaum Pond, 2015 and 2018.

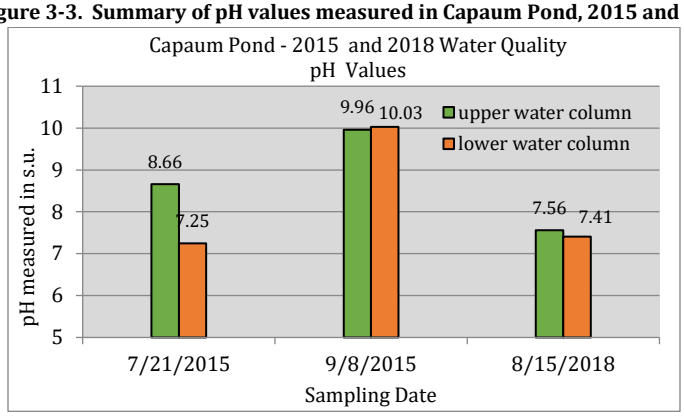


The similarity of the *upper* and *lower* conductance values on the 2015 and 2018 sampling dates reflects the shallow nature of Capaum Pond and the fact that the water column probably mixes from the surface to the bottom when any substantial wind (> 10 mph) blows across the Island, which keeps the upper and lower values fairly consistent.

The relative conductance values measured in Capaum are considered high within the range of specific conductance 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.

pH. The pH measured in the *upper* and *lower* regions of Capaum Pond on the July and September 2015 sampling dates and the August 2018 sampling date are summarized in Figure 3.3.

Figure 3-3. Summary of pH values measured in Capaum Pond, 2015 and 2018.

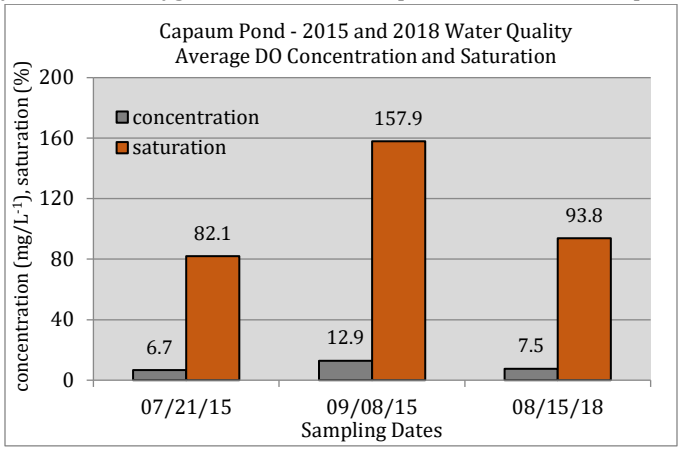


The values recorded on July 21st were 8.66 and 7.25 in the *upper* and *lower* regions, respectively, and suggest a distinct separation of these regions in the water column because a difference of 1 pH unit is equivalent to a 10-fold difference in pH. The significantly higher pH values recorded on September 8th, 9.96 in the *upper* region and 10.03 in the *lower* region reflect a considerable imbalance between pond respiration and photosynthesis which can result when intense algal blooms occur during the growing season. There will be more discussion related to this topic in the chapter section on phytoplankton.

The pH values recorded on August 15th 2018 were 7.56 s.u. in the *upper* region and 7.41 s.u. recorded in the *lower* region which are normal values and give no indication of bloom activity in the pond or separation of the upper and lower regions based upon pond stratification.

Dissolved oxygen concentration-percent saturation. The oxygen concentration and saturation patterns in Capaum Pond during July and September 2015 are shown in Figure 3.4.

Figure 3-4. Summary of dissolved oxygen concentration and percent saturation in Capaum Pond, 2015 and 2018.



The values presented in Figure 3.4 are average values for the individual profile readings taken from the surface down to 5 feet on July 21st 2015, down to 4 feet on September 8th 2015, and down to 6 feet on August 15th 2018.

There was considerable variation in the concentration (Δ=8.44 mg/L^{-1}) and saturation values (Δ=106.3%) measured from the surface to the bottom during the July 2015 sampling, and considerably

less variation measured during the September sampling date (concentration Δ=1.98 mg/L^{-1} and saturation Δ=26.4%). The July dissolved oxygen measurements were typical of a pond with warm water temperatures and moderate productivity. In contrast, the September values for concentration and saturation were elevated, i.e., supersaturated, and indicative of high productivity occurring in the pond, likely from an algal bloom at the time of sample collection.

The August 15th 2018 concentration and saturation values measured from surface to bottom showed some variation (concentration Δ=1.44 mg/L^{-1} and saturation Δ=19.0%) and suggest that a gradient was beginning to form between the upper and lower regions of the water column as a result of relative calm periods with no high wind blowing across the Island.

3.1.3 Plant Nutrients

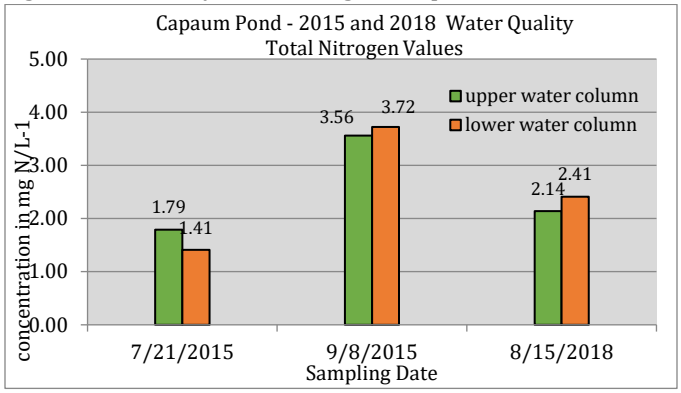
Nitrogen. There was no detectable nitrate-nitrogen measured in te 2015 and 2018 water samples collected from the *upper* and *lower* regions of Capaum Pond. This phenomenon is not unusual in ponds during the growing season because this form of nitrogen is readily taken up by phytoplankton occurring in the water column for growth and metabolism when it is available.

The same condition (levels below detection) was observed for **ammonia-nitrogen** in the *upper* region of the pond during both July and September 2015, and in the *lower* region of the pond during September 2015. The only elevated level of **ammonia-nitrogen** occurred in the *lower* region on September 8th and the value was reported as 0.260 mg N·L^{-1}. Very low levels of ammonia-nitrogen were measured in the *upper* and *lower* regions of the pond on August 15th 2018 (0.010 and 0.020 mg N·L^{-1}, respectively).

Based upon the low concentrations of **nitrate-nitrogen** and **ammonia-nitrogen** measured in Capaum Pond in 2015 and 2018, 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 during periods of high wind).

The **total nitrogen** (TN) measured in Capaum Pond during July and September 2015 and again during August 2018 is presented graphically in Figure 3.5.

Figure 3-5. Summary of total nitrogen in Capaum Pond, 2015 and 2018.

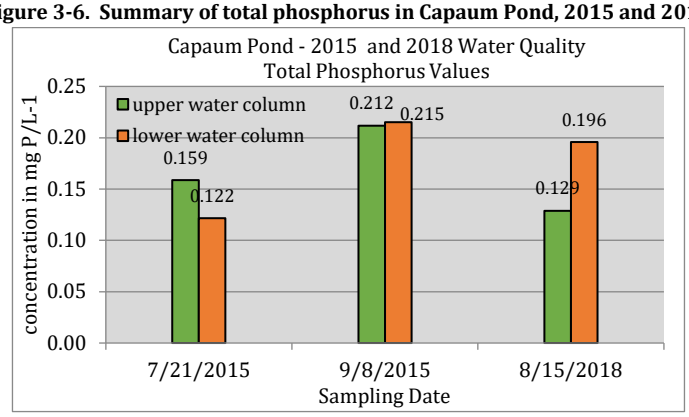


There was no significant difference between the *upper* and *lower* concentrations measured on any of the sampling dates; however, there essentially was a doubling in the average TN concentration in the pond between the July 2015 (average = 1.60 mg N·L^{-1}) and September 2015 (3.64 mg N·L^{-1}) sampling dates. The average concentration measured during 2018 (2.28 mg N·L^{-1}) was about one-half of the high and low concentrations measured during 2015.

The elevated TN concentrations measured in Capaum Pond during 2015 and 2018 are indicative of phytoplankton blooms occurring in the water column at the time that water sampling was conducted.

Phosphorus. The **total phosphorus** (**TP**) concentrations measured in Capaum Pond during July and September 2015 and during August 2018 are shown in Figure 3.6.

Figure 3-6. Summary of total phosphorus in Capaum Pond, 2015 and 2018.



As shown in the above figure, there were very minor differences between concentrations measured the *upper* and *lower* regions of the pond on each sampling date.

The average concentration in the water column measured on July 21st 2015 was 0.141 mg $P \cdot L^{-1}$, and this average increased by the September 8th 2015 sampling date to 213.5 mg $P \cdot L^{-1}$; on August 15th 2018, the average concnetration of TP measured in the pond was 0.162 mg $P \cdot L^{-1}$. These levels of phosphorus are considered high and reflect the moderate-to-high density of phytoplankton in the water column on both 2015 sampling dates and the 2018 sampling date.

3.1.4 Phytoplankton

Description of the assemblage. There were 30 different taxa identified in the August 15th 2018 phytoplankton sample collected from Capaum Pond and all six (6) major algal groups were represented (Table 3.1).

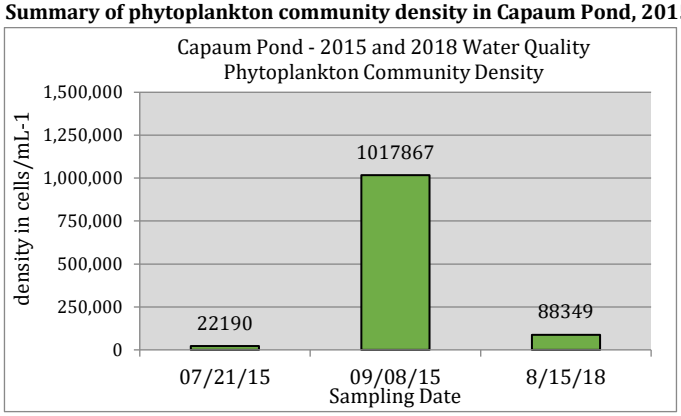
Table 3-2. Summary of Capaum Pond phytoplankton assemblage, 2018.

Cyanophyta	**Chlorophyta**	**Chrysophyta (Bacillariophyceae)**
Aphanizomenon flos aquae	*Monoraphidium contortum*	*Cyclotella* sp.
Ahanocapsa elachista	*Pediastrum duplex*	*Navicula* spp.
Merismopedia glauca	*Pyramimonas tetrarhyncus*	*Surirella* sp.
Microcystis aeruginosa	*Scenedesmus bijuga*	*Synedra acus*
Woronichinia naegeliana	*S. quadricauda*	**Chrysophyta (Chrysophyceae)**
Chlorophyta	*Selenastrum capricornutum*	*Ochromonas sp.*
Actinastrum Hantzschii	*S. minutum*	**Euglenophyta**
Ankistrodesmus falcatus	*Staurastrum natator var. crassum*	*Peranema* sp.
Closteriopsis longissima	***Chrysophyta (Bacillariophyceae)***	*Trachelomonas* sp.
Closterium acutum	*Achnanthes sp.*	**Pyrrhophyta (Cryptophyceae)**
Cosmarium sp.	*Aulacoseria granulata*	*Ceratium hirundinella*
Langerheimia quadriseta	*Cocconeis* sp.	

The greatest representation of phytoplankton taxa occurred within the Chlorophytes (green algae), where 14 different taxa were identified. The next most abundant groups were the Bacillariophytes (7 taxa) and Cyanophytes (5 taxa).

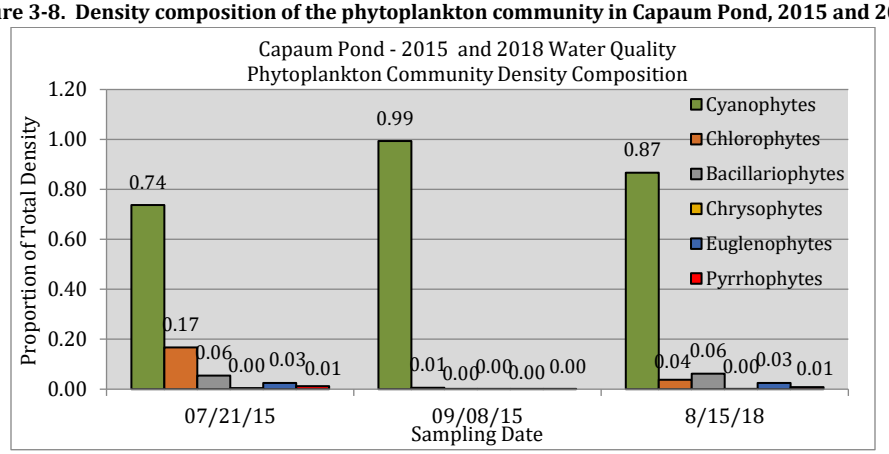
Density. Phytoplankton community density was 22,190 cells·mL^{-1} on July 21st 2015 and 1,017,867 cells·mL^{-1} on September 8th 2015, about a 50-fold increase in density between the two sampling dates (Figure 3.7). The community density on August 15th 2018 was 88,349 cells·mL^{-1}.

Figure 3-7. Summary of phytoplankton community density in Capaum Pond, 2015 and 2018.



The density composition of the phytoplankton community was rather similar during 2015 and 2018 with regard to the major groups and their importance (Figure 3.8). Cyanophytes were the most prominent group on all three sampling dates, comprising 99 percent of the community on September 8th 2015, 74 percent of July 21st 2015, and 87 percent on August 15th 2018 (Figure 3.8). The Chlorophytes, Bacillariophytes, and Euglenophytes were present in the July 21st 2015 and August 15th 2018 community, but far less important that the Cyanophytes in terms of community density.

Figure 3-8. Density composition of the phytoplankton community in Capaum Pond, 2015 and 2018.



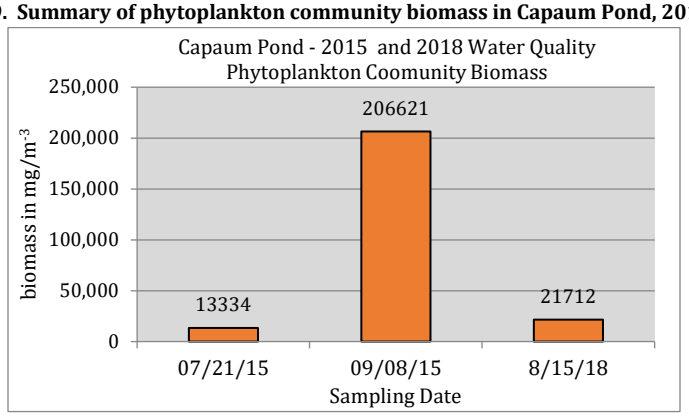
Given the shallow depth of Capaum Pond and the greatly reduced water clarity on every sampling date, the phytoplankton cell density measured on all July 21st 2015 (22,190 cells·mL^{-1}) and August 15th 2018 (88,349 cells·mL^{-1}) represent low level 'algal blooms' in progress, while the density measured on September 8th 2015 (1,017,867 cells·mL^{-1}) represents an explosion in population growth and a serious algal bloom in progress.

Biomass. Cell biovolume also was used to evaluate phytoplankton taxon productivity, since cell counts and conversion into density does not account for the significant size difference among the various phytoplankton taxa that occur in the pond. The misleading nature of density as a reliable cell descriptor is evident when reviewing biovolume values and noting the substantial difference between the size of, for example, the green algae *Monoraphidium contortum* cells (30.9 mg·m^{-3}) and *Closterium* sp. cells (4000.0 mg·m^{-3}). The difference in relative biovolume (the size of individual cells) explains how small numbers of

cells with a large biovolume can make a particular taxon a dominant member in the phytoplankton community.

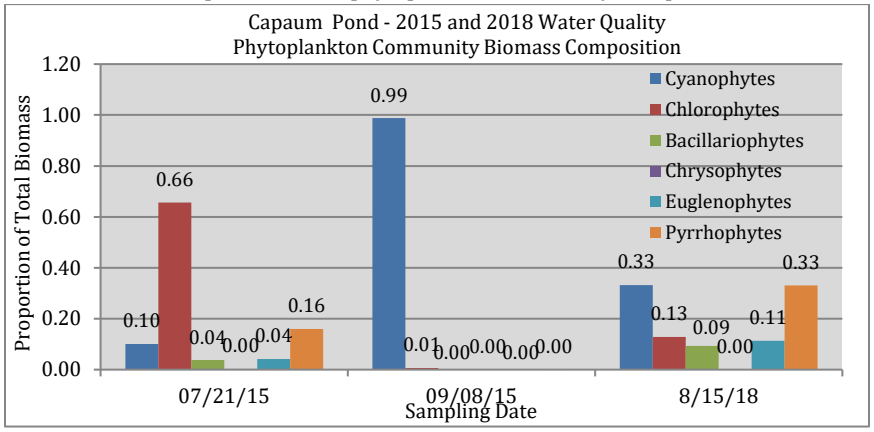
The phytoplankton community biomass measured on July 21st 2015, September 9th 2015 and August 15th 2018 is summarized in Figure 3.9.

Figure 3-9. Summary of phytoplankton community biomass in Capaum Pond, 2015 and 2018.



With regard to biovolume, the phytoplankton community exhibits much different composition characteristics on two of three sampling dates when compared with density composition (Figure 3.10).

Figure 3-10. Biomass composition of the phytoplankton community in Capaum Pond, 2015 and 2018.



Chlorophytes (66 percent), not Cyanophytes (10 percent), were the primary component of the July 21st 2015 community, while Cyanophytes (33 percent) and Pyrrhophytes (33 percent) shared equal importance in the biomass composition of the August 15th community (Figure 3.10). The Pyrrhophytes also were important in the July 21st 2015 community (16 percent); this group includes fire algae, primarily dinoflagellates, that are marine forms, often associated with 'red' tide.

Dominance. A ranking of phytoplankton taxa dominance in Capaum Pond is summarized in Table 3.2 for the 2015 and 2018 sampling dates. Taxa are considered dominant in the community if they comprise at least 5 percent of the total biomass.

There were 5 dominant taxa in the phytoplankton community on July 21st 2015 and only one dominant taxon on September 8th 2015 (Table 3.2). As discussed above, green algae comprised the major portion of the phytoplankton community biomass during July while essentially all of the community biomass on September 8th was the Cyanophyte, *Aphanizomenon flos aquae* (97 percent). On August 15th 2018, there

were four (4) dominant taxa in the Capaum Pond phytoplankton community with Cyanophytes and Pyrrhophytes contributing to the greater proportion of biomass (33 percent each).

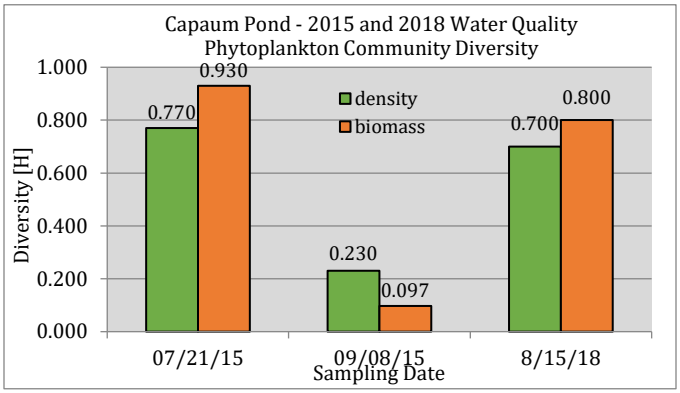
Table 3-3. Rank of phytoplankton dominanace, using biomass, in Capaum Pond, 2015 and 2018.

Sampling Date	Taxon (Major Group)	Biomass Rank	% of Total Biomass
7/21/15	*Staurastrum natator* var. *crassum* (Chlorophyte)	1	40
	Ceratium hirundinella (Pyrrhophyte)	2	15
	Pediastrum duplex (Chlorophyte)	3	9
	Anabaena flos aquae (Cyanophyte)	4	8
	Cosmarium spp. (Chlorophyte)	5	6
9/8/15	*Aphanizomenon flos aquae* (Cyanophyte)	1	97
8/15/18	*Aphanizomenon flos aquae* (Cyanophyte)	1	33
	Ceratium hirundinella (Pyrrhophyte)	2	33
	Trachelomonas sp. (Euglenophyta)	3	11
	Cyclotella sp. (Baccillariophyte)	4	5

Diversity. Phytoplankton diversity in Capaum 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 was calculated for the 2015 and 2018 phytoplankton communities in Capaum Pond using both density and biovolume for the sampling dates; the results of these analyses are shown in Figure 3.11.

Figure 3-11. Phytoplankotn community density and biomass diversity in Capaum Pond, 2015 and 2018.



Both versions of the diversity calculation shown in Figure 3.11 emphasize the dramatic change that occurred in the phytoplankton between July and August 2015 when the fairly diverse community changed to a community dominated by a single Cyanophyte species (*Aphanizomenon flos aquae*). In August 2018, the phytoplankton community diversity was similar to the density and biomass values that were measured during July 2015 (Figure 3.11), indicating that the community diversity was distributed among several species instead of concentrated in one or just a few species.

Cyanophytes. As a major phytoplankton group, Cyanophytes were identified in the July and September 2015 samples and the August 2018 samples collected at Capaum Pond. There were 3 different species identified on July 21st 2015, 6 species identified on September 8th 2015, and 5 species identified on August 15th 2018.

[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.

As shown in Table 3.3, a total of 9 different Cyanophyte species have been identified in Capaum Pond during the two years of water quality sampling.

Table 3-4. Cyanophyte species identified in Capaum Pond, 2015 and 2018.

Cyanophyte species	
Anabaena circinalis	*Gomphosphaeria lacustris compacta*
A. flos aquae	*Merismopedia glauca*
Aphanizomenon flos aquae	*Microcystis aeruginosa*
Aphanocapsa elachista	*Woronichinia naegeliana*
Chroococcus dispersus	

All of the Cyanophyte species identified in the table above have been shown to produce algal toxins except *Aphanocapsa elachista*, *Chroococcus dispersus* and *Gomphosphaeria lacustris compacta.*

Cyanophyte toxins. Four (4) raw water samples were collected from Capaum Pond during 2015 and shipped to GreenWater Laboratories to be analyzed for algal toxins. Water quality conditions observed at the pond on July 21st indicated that a bloom was in progress and prompted the collection of the first sample for algal toxins. Results from the analysis of this first sample encouraged the subsequent collections. Table 3.4 presents a summary of the results received from the toxin analyses.

Table 3-5. Results of Cyanophyte toxin analysis in Capaum Pond, 2015.

	Levels of Toxin (in µg/L)				
2015 Sampling Date	**Microcystins**	**Anatoxin-a**	**Cylindrospermopsin**	**Saxitoxin**	**Status**
July 21st	1.76				Moderate
July 28th	1.29*	ND	ND	0.11**	*Moderate, **Minimal
August 4th	0.87*	ND	ND	0.10**	*Low, **Minimal
August 13th	1.41*	ND	ND	0.08**	*Moderate, **Low
Level of detection (µg/L)	0.15	0.05	0.10	0.05	
ND = not detected above the LOD/LOQ					
Guidelines for interpretation of results. For samples which are *non-detects* – the highest possible risk category is listed.					
0.0-0.2 µg/L (little to no risk from blue-green algal toxins: Minimal Risk)					
0.2-1.0 µg/L (toxin detected but below World Health Organization (WHO) drinking water guidelines: Low Risk)					
1.0-10.0 µg/L (toxin levels above the WHO drinking water guidelines but generally below WHO limits for recreational use: Moderate Risk)					
10-20 µg/L (toxin levels are significant and approach WHO limits for recreational contact: High Risk)					
>20 µg/L (toxin levels exceed WHO guidelines for recreational contact. Users should avoid contact and be extremely careful to wash off pets)					

Microcystin (MC) was detected in samples submitted from July 21st and July 28th. The dominant genera identified in the July 28th sample prompted GreenWater Laboratory to recommend additional analyses be performed on the sample for anatoxin-a, cylindrospermopsin, and saxitoxin.

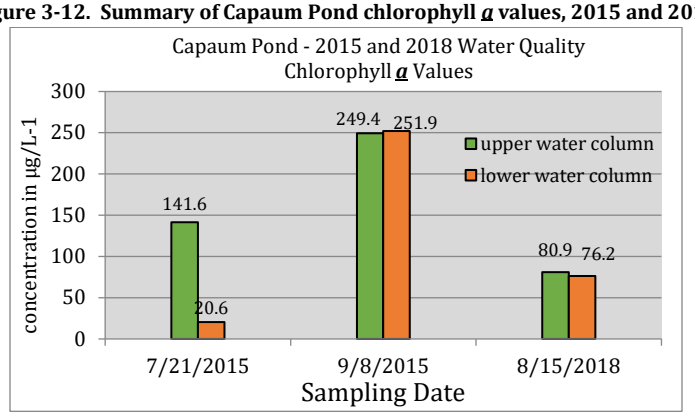
The presence of saxitoxin in the July 28th sample motivated the collection of the subsequent samples that were submitted for toxin analysis (see Table 3.4).

Although a potential algal bloom was observed when Capaum Pond was sampled on August 15th 2018, no sample was collected and submitted to GreenWater Laboratory for toxin analysis.

Based upon the collective toxin analyses performed in 2015, (1) contact recreation in Capaum Pond should be discouraged, (2) the pond should be monitored on a regular basis with raw water samples collected and submitted for toxin analysis when observations indicate that algal blooms are occurring, and (3) based upon the Cyanophyte species identified in the pond and the cell density counts associated with those species, the pond probably should be posted to advise visitors to the area of the potential adverse health effects of contact recreation. The Massachusetts Department of Public Health (MDPH) has issued guidelines Cyanobacteria in freshwater recreational water bodies in Massachusetts; a copy of these guidelines are included in Attachment #1 of this report.

Chlorophyll *a*. The chlorophyll ***a*** concentrations measured in Capaum Pond during 2015 and 2018 are shown in Figure 3.12.

Figure 3-12. Summary of Capaum Pond chlorophyll *a* values, 2015 and 2018.



There was a distinct separation of *upper* and *lower* regions of the pond on July 21st 2015 with respect to chlorophyll ***a*** as shown by the difference in the relative values, i.e., 141.6 µg·L^{-1} versus 20.6 µg·L^{-1}, respectively. The low chlorophyll reading in the *lower* region suggests that most of the phytoplankton community is located in the *upper* region where the light penetration is more suitable for photosynthesis.

The most interesting observation related to the mid-summer chlorophyll ***a*** in the pond was the pronounced increase in concentration by September 8th 2015, when an average of 250 µg·L^{-1} was measured in the water column, almost twice the concentration in late July.

These data support other pond measurements that the September phytoplankton density had increased to over 1 million cells per mL and that an intense bloom was occurring in the pond. Let us not lose sight of the proper perspective here, however; all of the chlorophyll ***a*** values measured in Capaum Pond during 2015 and 2018 were very high and indicate very pronounced activity of phytoplankton in the pond, likely bloom conditions.

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, 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 lake and pond productivity.

There were sufficient water quality data collected from Capaum Pond during 2018 to calculate the Carlson Trophic State Index (TSI) using the three most common variables for evaluation (chlorophyll ***a***, total phosphorus, Secchi depth transparency). Values for each variable for the August 15th sampling date were substituted into the appropriate equations (Chapter 1) to calculate the TSI values for each variable.

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

Chlorophyll *a*
2018 mid-summer chlorophyll *a* = 78.55 µg/L^{-1}
Chlorophyll *a* TSI = 9.81*[ln (78.55)] + 30.6
TSI = (9.81)(4.36) + 30.6
TSI = 73.4

Total phosphorus

2018 mid-summer total phosphorus = 162.35 µg/L^{-1}
Total phosphorus TSI = 14.42*[ln (162.35)] + 4.15
TSI = (14.42)(5.09) + 4.15
TSI = 77.5

Secchi depth

2018 mid-summer Secchi depth = 0.45 m
Secchi TSI = 60 – [14.41*[ln (0.45)]
TSI = 60 – (14.41)(-0.7985)
TSI = 71.5

The numerical results of the TSI calculations for 2015 and 2018 are summarized in Table 3.5 below.

Table 3-6. The numerical results of TSI calaulations in Capaum Pond, 2015 and 2018.

Year	Chlorophyll TSI	TP TSI	Secchi TSI
2015	80.7	78.8	77.3
2018	73.4	77.5	71.5

The results of the TSI calculations can be interpreted by comparing the trophic index value with the parameters summarized in Table 3.6. Each water quality indicator (i.e., phosphorus, Secchi depth and chlorophyll a) measured in Capaum Pond resulted in a trophic index that was within the range 70-100, which denotes a hyper-eutrophic condition.

Table 3-7. Relationships among Trophic Index, chlorophyll *a*, 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

Taken at face value along with the results from the assessment of the phytoplankton community, and algal toxins, the TSI values calculated for Capaum Pond portray a highly degraded water quality where any sort of contact recreation should be avoided.

3.2 Summary

Capaum Pond can be characterized as a highly productive body of water that exhibits hyper-eutrophic conditions for the usual parameters used in the assessment of water quality during the growing season. Based upon the composition of the phytoplankton community documented during 2015 and 2018, recreational use of this pond should be avoided because a variety of Cyanophyte species occur in the pond that are known to produce harmful algal toxins.

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

Chapter 4

Summary of Water Quality in Nantucket Island Ponds Surveyed

By the Nantucket Land Council, Inc. since 2009

4.0 Introduction

This chapter provides a brief water quality summary of Nantucket Island ponds that have been monitored by the Nantucket Land Council (NLC) Inc. since 2009 when Miacomet and Hummock Ponds were surveyed cooperatively by the NLC and the UMass Field Station. During the 9-year period since 2009, the NLC has sponsored the water quality survey of 12 different ponds on the Island. In some cases, these ponds have been surveyed during multiple years

The purpose of this data summary is to provide information that will document water quality of important Island ponds through time so that reasonable and prudent decisions can be made by policy makers and administrators regarding public health and safety because many of these ponds are used for contact recreation.

4.1 Background

Water Quality Parameters. All of the parameters that are measured on a pond have certain value in assessing the overall water quality. This process should become clear when reading through the various chapters in previous reports that describe the water quality of ponds that have been monitored by the NLC. As a means of highlighting all of the water quality data collected by the NLC since 2009, Table 4-1 provides a summary of maximum, minimum and average values for the suite of parameters that have been monitored during the past 9 years on the 12 Nantucket Island Ponds surveyed to date.

Trophic Status. It has come to the attention of the NLC that many of the estuarine and fresh water ponds on Nantucket exhibit extremely high productivity with regard to the primary criteria that commonly are used to evaluate trophic status. Trophic status was described in Chapter 1 and also in the Capaum Pond chapter in this report. The evaluation criteria include total phosphorus, chlorophyll ***a***, and Secchi depth transparency.

While one year of water quality data usually is not considered sufficient to characterize a lake or pond with respect to productivity, this currently is the situation for certain Nantucket ponds that have been added to the sampling regime during recent years. Having some water quality data to analyze is better than not having any data, and evaluations for individual ponds always can be updated when more data become available.

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 values can give a relative comparison of water quality among ponds of similar size and/or geographic location.

Secchi depth 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, Secchi depth transparency is the least expensive parameter to measure.

As a means of comparing all of the trophic status data collected by the NLC since 2009, Table 4-2 provides 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.

Cyanophyte Populations. The problem with certain Cyanophyte species occurring in Nantucket Island ponds has been discussed in the series of water quality reports issued by the NLC since 2009.

As a 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 succession during the growing season. When present in large numbers as occur in algal 'bloom' conditions, however, Cyanophytes can induce physical, chemical and biological changes in the aquatic environment in which they occur and eventually cause negative changes to the ecosystem which may require some direct remedial action to reverse or overcome.

The body of knowledge surrounding these organisms and their toxins is growing rapidly. 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. Some researchers believe that it would be prudent to assume any cyanophyte population can have toxic potential in the aquatic ecosystem in which it is located.

High concentrations ('blooms') of Cyanophytes in the water column lowers transparency, reducing the depth of the photic zone (area where incident light is sufficient to allow photosynthesis to occur) and the volume of water (area of the pond) that supports other photosynthetic organisms. In addition, high concentrations of Cyanophytes and other algae in the water column result in high rates of cell die-off which settle to the bottom and causes oxygen depletion through decomposition of dead plant material.

De-oxygenation has a direct negative effect on aquatic organisms in the bottom region 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 mixing 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 metabolism by phytoplankton. The release of nutrients into the water exacerbates the cycle by encouraging increased primary productivity 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 some instances, the dead, lysed cells are Cyanophytes that produce cyanotoxins and release these toxins when ruptured. In addition to being toxic and dangerous to animals, such as cattle, dogs and cats, cyanotoxins also should be considered a public safety risk to the extent that contact or consumption by humans breathing air down-wind of the pond which contains toxin spores borne as aerosols from the scum concentrated at the surface of the pond should be avoided.

The State of Massachusetts surface water quality standards (314 CMR 4.00) do not specifically address algae; however, the Department of Public Health has developed a Frequently Asked Questions (FAQs) sheet concerning health impacts of *Microcystsis* and *Anabaena* blooms in waterbodies throughout the state. A copy of the sheet is provided in Attachment #1. It is interesting that *Aphanizomenon* is not included on this listing because it is a known producer of toxins and is one of the genera identified in Nantucket Island ponds since water quality surveys began in 2009.

In addition to the above material, the MA Department of Public Health (MDPH) has created '*Guidelines for Cyanobacteria in Freshwater Recreational Water Bodies in Massachusetts*'. This document contains a literature review of the phenomenon and MDPH recommendations. A copy of the document is in Attachment #2.

Table 4-3 summarizes the various species of Cyanophytes that have been identified in Nantucket ponds since 2009 and indicates which species are known to pose public health and safety issues with regard to contact recreation. There has been some limited monitoring of algal toxins in Nantucket ponds during previous years and algal toxins have been identified on certain occasions; however, there are insufficient data to claim that the populations of Cyanophytes that characterize Nantucket water quality pose a definite health threat for recreational users of the ponds.

4.2 Literature Cited

Zaccaroi, A. and D. Scaravelli. 2008. Toxicity of Fresh Water Algal Toxins to Humans and Animals. Pp. 46-90. In: *Algal toxins: Nature, Occurrence, Effect and Detection*. Edited by Valtere Evangelista, Laura Barsanti, Anna Maria Frassanito, Vincenzo Passarelli, and Paolo Gualtieri. NATO Science for Peace and Security Series A: Chemistry and Biology. Springer, P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Table 4-1. A summary of maximum, minimum and average values for the suite of parameters that have been monitored during the past 8 years on the 11 Nantucket Island ponds surveyed by The Nantucket Land Council, Inc. to date. Values highlighted are one-half the lower detection limit.

Nantucket Island Ponds	Secchi	Chl *a*	DO	NO3-N	NH4-N	TN	TP	TDS	spC	pH
	(m)	(µg/L)	(% sat)	(mg/L)	(mg/L)	(mg/L)	(µg/L)	(mg/L)	(µS/cm)	(s.u.)
Miacomet Pond										
minimum value	1.22	5.8	83.2	0.011	0.005	0.208	19.5	99	153	6.75
maximum value	2.57	42.8	100.6	0.080	0.057	0.986	289.0	1514	2040	8.17
average value	1.98	16.6	92.2	0.061	0.022	0.555	63.5	639	890	7.65
year monitored: 2009, 2017										
Hummock Pond										
minimum value	0.56	2.4	80.8	0.005	0.005	0.66	35.3	2785	3545	6.64
maximum value	1.68	98.0	105.3	1.010	0.195	2.20	133.2	32120	31350	8.67
average value	1.2	18.8	95.8	0.155	0.040	1.081	78.4	9956	11117	7.63
year monitored: 2009, 2012										
Head of Hummock Pond										
minimum value	0.18	2.1	37.6	0.005	0.005	0.69	73.3	410	600	6.28
maximum value	2.03	187.5	110.8	0.639	1.160	3.47	828.8	10430	12180	10.19
average value	0.76	50.1	85.3	0.045	0.209	1.45	288.4	3245	4067	7.99
year monitored: 2009, 2010, 2011, 2012, 2013, 2017										
Maxcy Pond										
minimum value	na	0.57	94.1	0.005	0.004	0.194	7.0	65	102	5.05
maximum value	na	8.1	109.6	0.033	0.010	0.480	97.0	88	137	6.55
average value	na	4.04	101.0	0.014	0.006	0.351	37.4	75	115	5.57
year monitored: 2014, 2016, 2017										
Tom Nevers Pond										
minimum value	0.18	2.1	75.6	0.005	0.009	0.600	21.6	52	81	5.60
maximum value	0.64	14.0	97.7	0.170	0.024	1.348	847.0	245	226	7.27
average value	0.31	7.28	86.9	0.033	0.015	1.108	419	101	132.9	6.27
year monitored: 2014, 2016, 2017										
Washing Pond										
minimum value	1.3	2.1	84.0	0.005	0.005	0.400	19.9	85	134	5.99
maximum value	3.5	24.6	93.9	0.028	0.200	0.671	51.5	98	156	8.37
average value	1.8	11.4	87.3	0.016	0.046	0.568	38.7	93	147	7.12
year monitored: 2014, 2016, 2017										

Table 4-1 (continued).

Nantucket Island Ponds	Secchi (m)	Chl *a* (µg/L)	DO (% sat)	NO3-N (mg/L)	NH4-N (mg/L)	TN (mg/L)	TP (µg/L)	TDS (mg/L)	spC (µS/cm)	pH (s.u.)
Capaum Pond										
minimum value	0.25	141	82.1	0.005	0.030	1.79	158.8	286	434	8.66
maximum value	0.45	249	157.9	0.005	0.010	3.56	211.7	320	483	9.96
average value	0.35	157	111.2	0.005	0.023	2.50	166.5	270	410	8.73
year monitored: 2015, 2018										
Pest House Pond										
minimum value	na	1.8		0.005	0.030	1.36	31.2			
maximum value	na	28.0		0.005	0.470	2.69	99.7			
average value	na	14.9	95.2*	0.005	0.250	2.03	65.5	27960*	28390*	8.79*
year monitored: 2015										
Gibbs Pond										
minimum value	0.33	7.5	76.0	0.005	0.020	0.56	216.7	60	93	6.21
maximum value	0.89	216.6	97.4	0.005	0.030	1.85	508.6	79	124	8.51
average value	0.49	88.5	87.4	0.005	0.021	1.44	410.7	70	109	7.47
year monitored: 2016, 2017										
Little Weweeder Pond										
minimum value	1.1	16.7	84.2	0.005	0.020	0.540	14.9	112.5	174	7.23
maximum value	1.2	23.4	126.6	0.005	0.020	0.740	23.7	112.7	176	8.91
average value	1.2	20.1	105.4	0.005	0.020	0.640	19.3	112.6	175	8.07
year monitored: 2016										
North Head Long Pond										
minimum value	0.66	3.8	93.8	0.005	0.005	1.00	56.9	12630	14270	6.65
maximum value	0.85	7.8	95.4	0.005	0.030	1.44	70.5	22060	23180	6.83
average value	0.76	5.8	94.6	0.005	0.018	1.22	63.7	17345	18725	6.74
year monitored: 2016										
Long Pond										
minimum value	0.53	1.7	67.3	0.005	0.005	1.14	102.1	2625	2680	6.93
maximum value	0.86	13.7	85.7	0.020	0.040	1.52	190.1	3441	3360	7.61
average value	0.70	8.6	74.5	0.008	0.028	1.29	128.7	2888	2922	7.40
year monitored: 2017										

* = single readings collected from pond outfall pipe which drains brackish water during falling tide and salt water during rising tide

Table 4-2. A summary of Trophic Status Indices calculated for total phosphorus, chlorophyll ***a*** and Secchi depth transparency for all 11 Nantucket Island ponds since 2009, when sufficient data were available to perform the calculations.

YEAR OF WATER QUALITY SURVEY																														
	2009			2010			2011			2012			2013			2014			2015			2016			2017			2018		
POND	TP	CH	SD	TP	CH	SD	TP	CH	SD	TP	CH	SD	TP	CH	SD	TP	CH	SD	TP	CH	SD	TP	CH	SD	TP	CH	SD	TP	CH	SD
Miacomet	E	E	E																						E	M	E			
Hummock	E	E	E							E	E	E																		
Head Hummock	HE	E	E	HE	HE	E	HE	E	E	HE	E	E	HE	E	E										HE	E	E			
Maxcy																M	M	na				M	E	na	M	0				
Tom Nevers																E	M	HE				HE	E	HE	HE	E	HE			
Washing																E	E	E				E	E	M	E	E	E			
Capaum																			HE	HE	HE							HE	HE	HE
Pest House																			E	E	na									
Gibbs																						HE	HE	E	HE	HE	HE			
Little Weweeder																						M	E	E						
North Head Long																						E	M	E						
Long																									HE	E	E			

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

Table 4-3. A summary of Cyanophyte species that have been identified in Nantucket Island ponds since 2009.

	Pond Name											
SPECIES	Miacomet	Hummock	Head of Hummock	Maxcy	Tom Nevers	Washing	Capaum	Pest House	Gibbs	Little Weweeder	North Head Long	Long
Anabaena circinalis							**2015**					
Anabaena flos aquae	**2009, 2017**	**2009, 2012**	**2009, 2011, 2012, 2013, 2014, 2015, 2017**	**2014**	**2016**	**2016**	**2015**	**2015**	**2016, 2017**	**2016**		
Anabaena spiroides	**2009**	**2009**	**2009, 2010, 2011**									
Anabaenopsis Elenkinii			**2010, 2014**	**2014**	**2016**							
Aphanocapsa elachista	**2017**		**2010, 2011, 2013**				**2018**					
Aphanizomenon flos aquae	**2009, 2017**		**2013, 2015, 2017**	**2014, 2016**		**2014**	**2015, 2018**	**2015**	**2016, 2017**	**2016**		
Chroococcus dispersus	**2017**	**2012**	**2012, 2013, 2014, 2015, 2017**	**2014, 2016**	**2014, 2016,**	**2014, 2016, 2017**	**2015**		**2017**			
C. limneticus	**2009, 2017**	**2009, 2012**	**2009, 2011, 2012, 2014, 2015, 2017**			**2014**				**2016**		
C. turgidus			**2011**									
Coelosphaerium Naegelianum	**2009**		**2009, 2012**									
Dictyosphaerium Ehrenbergianum					**2017**	**2017**			**2017**			
Gloeocapsa rupestris			**2010, 2011**									
Gomphosphaeria lacustris compacta	**2017**		**2014, 2015**		**2014, 2016**	**2014, 2016**	**2015**		**2016**			
***Lyngbya* sp.**	**2017**		**2015**									
Merismopedia glauca	**2017**	**2012, 2013**			**2014, 2016**		**2018**		**2016, 2017**			**2017**
Merismopedia punctata	**2009**	**2009**										
Microcystis aeruginosa	**2009, 2017**	**2009**	**2009, 2014, 2015, 2017**	**2014**		**2014, 2017**	**2015, 2018**					
Microcystis incerta		**2012**	**2009, 2010, 2011, 2012, 2013**									
***Oscillatoria* sp.**	**2017**							**2015**				**2017**
Rhabdoderma Gorskii									**2017**			
Woronichinia naegeliana	**2017**					**2014, 2016, 2017**	**2015, 2018**		**2016, 2017**	**2016**		

Attachment 1

MA Department of Public Health

Microcystis and *Anabaena* Algae Blooms:

Frequently Asked Questions Concerning Health Impacts

This page was intentionally left blank

DEVAL L. PATRICK
GOVERNOR
TIMOTHY P. MURRAY
LIEUTENANT GOVERNOR
JUDYANN BIGBY, M.D.
SECRETARY
JOHN AUERBACH
COMMISSIONER

The Commonwealth of Massachusetts
Executive Office of Health and Human Services
Department of Public Health
Bureau of Environmental Health
250 Washington Street, Boston, MA 02108-4619
Phone: 617-624-5757 Fax: 617-624-5777
TTY: 617-624-5286

Microcystis and *Anabaena* Algae Blooms: Frequently Asked Questions Concerning Health Impacts

Q: What is *Anabaena*? What is *Microcystis*?

A: *Anabaena* and *Microcystis* are types of cyanobacteria (commonly known as blue-green algae) that grow naturally in many waterbodies. Under certain conditions (such as warm weather and an abundance of nutrients in the water) the algae may undergo an explosive type of growth that results in dense, floating mats of algae. This is commonly referred to as an "algae bloom."

Q: Can exposure to *Anabaena* and *Microcystis* cause health effects?

A: Yes. *Anabaena* and *Microcystis* are different from most other types of algae because they can produce toxins. There are two ways to be exposed to these toxins. During a bloom, the toxins are contained within the algae cells. If these cells are ingested, they break open in the stomach and the toxins are released. Alternatively, after an algae bloom ends and the algae die, the toxins are released into the water where they can be directly ingested. The toxins can be potentially harmful to people and animals.

Q: What types of health concerns are associated with exposure to toxins from *Anabaena* and *Microcystis*?

A: Health concerns vary depending on the type of exposure (e.g., contact, ingestion) and the concentrations of toxins present. *Microcystis* produces the toxin microcystin. *Anabaena* may produce a few different toxins, including anatoxin and microcystin. Ingestion of small amounts of toxin can cause gastrointestinal distress. If elevated levels of the algal toxin anatoxin are

present in the water and ingested, serious neurological damage can result. Symptoms of anatoxin poisoning include numb lips, tingling fingers and toes, and dizziness. If elevated levels of the algal toxin microcystin are present in the water and ingested, serious liver damage can result.

Symptoms of microcystin poisoning include abdominal pain, diarrhea, and vomiting. Contact with high levels of *Anabaena* and *Microcystis* has also been found to contribute to eye, ear, and skin irritation.

Q: How can I reduce my risk of health effects associated with exposure to *Anabaena* and *Microcystis*?

A: Do not come into contact with water near an algae bloom or any algal scum onshore. This also applies to pets.

Q: How long do blooms last?

A: It depends on several factors, most importantly the weather. Since algae benefit from warm, sunny weather, as the days get shorter and cooler, the algae die off. Any rainfall will help to circulate the water and break up the bloom. In addition, over time, algae may deplete the nutrients in the water so they are unable to grow further. As algae die off, they may release toxins into the water. Thus, it is important to refrain from recreating in the area of a bloom for two weeks after it has ended.

Q: If I have had contact with an algae bloom, what should I do?

A: For questions related to health concerns, contact your health care provider, local board of health, or the Massachusetts Department of Public Health, Bureau of Environmental Health at (617) 624-5757.

Attachment 2

MA Department of Public Health

Guidelines for Cyanobacteria in Freshwater

Recreational Water Bodies in Massachusetts

This page was intentionally left blank

The Commonwealth of Massachusetts

Executive Office of Health and Human Services
Department of Public Health
Bureau of Environmental Health
250 Washington Street, Boston, MA 02108-4619
Phone: 617-624-5757 Fax: 617-624-5777
TTY: 617-624-5286

DEVAL L. PATRICK
GOVERNOR

TIMOTHY P. MURRAY
LIEUTENANT GOVERNOR

JUDYANN BIGBY, M.D.
SECRETARY

JOHN AUERBACH
COMMISSIONER

MDPH GUIDELINES FOR CYANOBACTERIA IN FRESHWATER RECREATIONAL WATER BODIES IN MASSACHUSETTS

INTRODUCTION AND BACKGROUND

This document outlines a protocol for evaluating potential health concerns related to the presence of cyanobacteria (blue-green algae) in Massachusetts recreational freshwater bodies. Blooms can form when cyanobacteria, which are bacteria that grow in water, multiply quickly and form "scums" or "mats" on the surface of the water. Blooms can occur at any time but most often occur in late summer or early fall. The most common types of cyanobacteria that bloom are *Microcystis* and *Anabaena*. Certain strains of *Microcystis* and *Anabaena* manufacture toxins called microcystin and anatoxin, respectively, and these toxins can produce adverse health effects. Toxins are released from intact cyanobacteria cells when they die in the waterbody or when they are ingested by animals or humans. Once ingested, the digestive juices destroy their cell wall (lyse the cell) and the toxin is released into the gastrointestinal tract.

The scientific literature on health effects resulting from exposures to cyanobacteria-related toxins associated with blooms is developing, with the most widely cited guidance published by the World Health Organization (WHO) in 2003 (WHO 2003). This document reviews the WHO guidance as well as the current scientific literature for the purpose of updating current MDPH guidance with respect to responding to suspected or actual cyanobacteria blooms in Massachusetts recreational freshwater bodies.

REVIEW OF LITERATURE

Cyanobacteria, under the right conditions, can multiply quickly and pose a health risk to those coming into contact with the water. This ability to multiply quickly makes monitoring their numbers important. Because the health risk rises with the cell counts, the goal of any monitoring plan is to be able to take action before levels are reached that pose health risks.

This section reviews the current literature in order to make recommendations related to the presence of cyanobacteria in a recreational water body. There are three measures on which action can be taken:

1. Observation of visible scum or mat layer
2. Total cell count of cyanobacteria (units of total cells/mL water)
3. Concentration of cyanobacteria toxin (e.g., microcystin) (units of µg toxin/L of water)

These three measures will be evaluated based on a literature review of current studies on a) cell counts and health effects, b) cyanobacteria toxin levels and health effects, and c) correlations between cell counts and toxin levels.

Literature on Cell Counts and Health Effects

A prospective cohort study of 852 people was conducted in Australia in 1995 (Pilotto et al. 1997). Participants were interviewed at five freshwater bodies that had a history of cyanobacteria blooms. Information on their health and recreational water-related activities was collected. Follow-up interviews were held two and seven days later and noted any specific health symptoms, such as diarrhea, rashes, and eye or ear irritations. The responses from the interviews were compared with cyanobacteria counts from water samples collected at the freshwater bodies on the day the participants were first interviewed. No significant difference in reported health symptoms was found at two days following exposure. However, the authors reported that exposed individuals had an elevated odds ratio for symptoms seven days following exposure to the following:

- > 5,000 cyanobacteria cells/mL for over an hour
- Bathing in water with 5,000-20,000 cyanobacteria cells/mL
- > 80,000 cyanobacteria cells/mL

The odds ratio is based upon all symptoms reported. Thus, the cell counts or exposure period were not correlated with one specific symptom, but the odds of developing one of the seven symptoms the study examined.

This study forms the basis of the WHO guidance related to cell counts of 20,000/mL. At this level, the WHO recommends that there should be notification to inform individuals about possible health risks associated with contacting the water. WHO chose the level of 20,000 and not 5,000 because they noted that the reported effects at 5,000 were mild and not reported by a large number of people (WHO 2003).

More recent studies have used different methods to evaluate health effects from cyanobacteria, but the methods used cannot be translated to estimates of cell counts or toxin levels, hence are of limited use for purposes of developing guidelines. However, they do provide additional evidence that exposure to cyanobacteria can result in health effects, particularly dermal irritant effects.

A prospective cohort study found increased reporting of respiratory symptoms and of any symptom (respiratory, gastro-intestinal illness, ear, eye, dermal, or fever) at three days following exposure to cyanobacteria cell surface area > 12 mm^2/mL (Stewart et al. 2006b). The Stewart study chose to use cell surface area instead of cell counts, which prevents direct comparison of the thresholds found in the two studies.

Microcystins and World Health Organization Guidance

The WHO recommended a drinking water guideline of 1 part per billion (ppb) microcystin, the toxin produced by certain strains of the cyanobacteria, *Microcystis*. The study forming the basis of the WHO drinking water guideline was a 13-week oral gavage mice study with microcystin (Fawell et al 1994). Based on liver histopathology and serum enzyme changes, a no-observed adverse effect level (NOAEL) of 40 µg/kg body weight/day was derived. WHO applied an uncertainty factor of 1,000 to derive a Tolerable Daily Intake (TDI) level of 0.04 ug/kg/day. [A TDI is the estimated amount of a substance that can be consumed daily over a lifetime without an appreciable health risk (WHO 2006).] WHO then applied standard exposure assumptions (e.g., a 70 kg adult drinks 2 liters of water a day) to derive a drinking water guideline of 1 ppb.

Although WHO discussed other animal studies, the above study was deemed to be the most conservative study on which to base a microcystin guideline. No other studies were available in the literature that would affect the use of the mice study as a basis for the microcystin guideline.

In order to assess health concerns related to microcystin (generally cell-bound) in recreational waters (as opposed to drinking water), WHO applied conservation exposure assumptions related to recreational water use. Specifically, WHO assumed an adult, weighing 60 kg, consumes 100 mL of water while swimming or wading, while a child, weighing 15 kg, may consume 250 mL of water during the same activities. If microcystin is present in the cyanobacteria and water (after lysing the cells) at a concentration of 1 ppb (or 1 µg/L), the total exposure to an adult would be nearly equal to the TDI while for a child, it would be about 10 times the TDI. Individuals with certain existing health conditions (i.e., liver ailments) could be at greater risk. Given the conservative assumptions used in deriving the TDI and exposure estimates for recreational water activities, WHO suggested that an appropriate guideline for microcystin in recreational waters could be 20 ppb.

Other Health Effects Studies

Two studies have examined the effects of individuals wearing skin patches containing cyanobacteria. One study involved placing dermal patches containing either whole or lysed cells at varying concentrations. This study found that approximately 20% of individuals had dermal reactions to the patches, whether they contained whole or lysed cells and independent of the cell count. The dermal reactions were reportedly all mild. The authors concluded that some percentage of the healthy population is susceptible to skin reactions from cyanobacteria (Pilotto et al. 2004). The second study involved placing dermal patches containing cyanobacteria and cyanobacteria toxins on volunteers. This study found that only one of 39 participants had a dermal reaction, and this reaction was to a non-toxin producing cyanobacteria (Stewart et al. 2006c).

Literature on Correlation Between Cell Counts and Toxin Levels

The available literature suggests there is some correlation between cyanobacteria cell counts and the toxin concentration in the water, but this correlation is uncertain. For example, the cells can begin to die, and as they die, they release the toxin. Thus, although the cell count may show a decreasing amount of cells, the toxin concentration in the water may actually increase for a period of time. In addition, it is difficult to select sampling locations as the cells and the toxins may not be equally distributed within a bloom.

Data available from Lake Champlain in Vermont show levels of microcystin greater than 20 ppb were generally found in waters with cell counts over 100,000 (Watzin et al. 2005). The WHO concluded that *Microcystis*-dominated algal blooms with 100,000 cells/mL may contain 20 ppb of toxin (WHO 2003). Thus, it is reasonable to assume, based on currently available data, that cell counts of 100,000 or more may have toxin levels of 20 ppb or more. The WHO recommended that at cell counts of 100,000 cyanobacteria cells/mL or greater, swimming should be discouraged and on-site advisory signs should be posted. This advisory also reflects concern that counts could rise rapidly, along with the associated toxin health risks. Based on the 1997 Pilotto et al. study, the WHO estimated that cell counts of approximately 20,000 could result in toxin concentrations in water ranging from about 2-4 ppb (WHO 2003).

MDPH RECOMMENDATIONS

The following paragraphs provide MDPH recommendations for cyanobacteria and toxin guidelines to prevent acute exposure to elevated levels of these substances in recreational waters. Dense blooms and scums can contain millions of cells/mL and toxin levels in the parts per million. They can form near embankments and in areas suitable for swimming and other forms of recreation. They can also move around in the water body and grow quickly, making management of them difficult (Watzin et al. 2005, WHO 1999, 2003). Exposure to high levels of cells and toxins is dangerous and the more serious published reports of acute health effects from cyanobacteria typically involves exposure to dense blooms and scums (Behm 2003, Hitzfeld et al. 2000, WHO 1999, 2003). The proposed guidelines are designed to allow preventive action to be taken prior to exposure, thereby mitigating possible health concerns.

Guideline for Cyanobacteria Toxin (Microcystin) in Recreational Water

MDPH recommends adoption of the WHO TDI of 0.04 µg/kg/day of microcystin. In order to estimate a recreational water body concentration that would result in exposures at or below the TDI, the following assumptions were made:

Adult

Weight:	70 kg
Intake:	0.05 L water/hour
Duration:	1 hour/day

Child

Weight:	35 kg
Intake:	0.1 L water/hour
Duration:	1 hour/day

These assumptions are taken from U.S. EPA guidance (1997; 1989). The average 10-year old child weighs approximately 35 kg and an average adult weighs approximately 70 kg. This average weight of a 10-year old child is also similar to the average weight of all children between the ages of 1-18 years old (EPA 1997). The intake rate is based on guidance from EPA on surface water ingestion while swimming (EPA 1989). For children, the intake rate was doubled to 100 ml, which is approximately seven tablespoons of water. According to EPA, non-competitive (recreational) swimmers consume more water than competitive swimmers (EPA 2003). Children playing in the water consume more water than those swimming for exercise. For exposure assessments of adults in swimming pools, EPA has created a model that assumes they consume either 0.0125 or 0.025 L/hr (EPA 2003). However, since this assessment is for cyanobacteria in freshwater bodies, and water from freshwater bodies is less distasteful to ingest than pool water, these lower intake rates for adults were not used. The duration of time spent in the water was estimated to be one hour per day, seven days a week during a 13-week season. The WHO TDI was based on a 13-week mice study. Thirteen weeks is approximately the length of the summer bathing season in Massachusetts.

To calculate a water concentration of microcystin that would result in a total dose of 0.04 µg microcystin/kg body weight/day (the TDI), the following equation is used:

Guideline Concentration = (weight) x (TDI) / (intake) x (duration)

Using the stated assumptions, the results indicate that a guideline based on adult exposure would be 56 µg microcystin per liter water, or 56 ppb. For a child, the guideline would be 14 ppb. Hence, to be most conservative, MDPH recommends the toxin guideline be 14 ppb.

Guidelines for Cyanobacteria Cell Counts

The available literature and the equation noted above suggest that at approximately 20,000 cells/mL, associated toxin levels may range between 2-4 ppb, while at 100,000 cells/mL, associated toxin levels may be approximately 20 ppb. If we assume a linear relationship between cyanobacteria cell counts and associated toxin levels (data are sparse in this area), a cell count of 70,000 cells/mL would correspond to a toxin level of approximately 14 ppb. This is also the concentration derived using the equation. Thus, to be protective and reduce potential exposures to levels at which there is a greater likelihood of health effects, MDPH recommends that at a cell count of 70,000 cells/mL, individuals should be advised to refrain from coming into contact with the affected water.

Recommendations for Monitoring or Advisory Posting

MDPH believes that the current literature supports the use of a cell count guideline of 70,000 cells/mL in order to prevent adverse health effects from exposure opportunities to cyanobacteria and related toxins during algal blooms. MDPH also recognizes that it is generally more feasible to monitor using cell count methods rather than toxin analytical methods. We do offer the following general guidance related to monitoring potential cyanobacteria problems with the stated goal of preventing health effects before cyanobacteria or toxins reach levels of concern or higher:

1. If a visible cyanobacteria scum or mat is evident, MDPH recommends an immediate posting by the local health department, state agency, or relevant authority to advise against contact with the water body.
2. If the cell count exceeds 50,000 cells/mL, toxin testing of lysed cells should be done to ensure that guideline of 14 ppb is not exceeded. The lysing should consist of three freeze and thaw cycles.
3. If either the cell count exceeds 70,000 cells/mL or the toxin level of lysed cells meets or exceeds 14 ppb, post an advisory against contact with the water. The lysing should consist of three freeze and thaw cycles.
4. Because cyanobacteria can multiply extremely rapidly, frequency of follow-up testing may depend in part on weather conditions, e.g., predicted hot, dry, and calm conditions, all of which promote rapid cyanobacteria generation, may suggest more frequent testing than weekly.
5. Since decreasing cell counts indicate cell die-off and lysing cells release toxins, algal toxin concentrations in the water may rise for a period of time after cell counts decrease. Many factors (e.g., wind, rain, temperature) can effect the progression of die-off, which supports a measured approach for lifting an advisory similar to that of Oregon and Australia: advisories may be lifted after two successive and representative sampling rounds one week apart demonstrate cell counts or toxin levels below those at which an advisory would be posted.

Signage should be posted at (all) water body entry points and should include the following: date of the posting, contact information for the posting authority, language (to be provided or reviewed by MDPH) advising against contact with the water, and a recommendation that pets accidentally entering the water be rinsed.

This proposed protocol does not pertain to the toxin anatoxin, which is produced by several species of cyanobacteria. There is no guidance in the literature for responding to detections of anatoxin. Thus, if anatoxin is detected, MDPH will evaluate such situations episodically, using supplemental information such as cyanobacteria counts, exposure scenarios (popular swimming site, for instance), and upcoming weather forecasts. The cyanobacteria *Anabaena*, which produces anatoxin, would be included in any cell counts of cyanobacteria. Therefore, there is some mechanism for managing the risk it poses.

References

Behm, Done. 2003. Coroner cites algae in teen's death. Milwaukee Journal Sentinel. September 6, 2003.

EPA. 1989. Risk Assessment Guidance for Superfund. Volume 1: Human Health Evaluation Manual (Part A). Environmental Protection Agency, Officer of Emergency and Remedial Response. December 1989.

EPA. 1997. Exposure Factors Handbook. Environmental Protection Agency, Office of Research and Development. August 1997.

EPA. 2003. User's Manual- Swimmer Exposure Assessment Model (SWIMODEL) Version 3.0. Environmental Protection Agency, Office of Pesticides Programs, Antimicrobials Division. November 2003.

Fawell J.K., C.P. James, and H.A. James. 1994. Toxins from blue-green algae: toxicological assessment of microcystin-LR and a method for its determination in water. Medmenham (UK): Water Research Center. p 1-46.

Hitzfeld, B., S.J. Hoger, and D.R. Dietrich. 2000. Cyanobacterial toxins: removal during drinking water treatment, and human risk assessment. Environmental Health Perspectives. Volume 108, Supplement 1. March 2000. pp:113-122.

Pilotto, L., R. Douglas, M. Burch, S. Cameraon, M. Beers, G. Rouch, P. Robinson, M. Kirk, C. Cowie, S. Hardiman, C. Moore, and R. Attewell. 1997. Health effects of exposure to cyanobacteria (blue-green algae) during recreational water-related activities. Australia and New Zealand Journal of Public Health. Volume 21, Number 6. pp: 562-566.

Pilotto, L., P Hobson, M. Burch, G. Ranmuthugala, R. Attewell, and W. Weightman. 2004. Acute skin irritant effects of cyanobacteria (blue-green algae) in healthy volunteers. Australian and New Zealand Journal of Public Health. Volume 28, Number 3. pp: 220-224.

Stewart, I., P. Webb, P. Schluter, and G. Shaw. 2006a. Recreational and occupational field exposure to freshwater cyanobacteria- a review of anecdotal and case reports, epidemiological studies and the challenges for epidemiologic assessment. Environmental Health: A Global Access Science Source. Volume 5, Number 6. www.ehjournal.net/content/5/1/6

Stewart, I., P. Webb, P. Schluter, L. Fleming, J. Burns, M. Gantar, L. Backer, and G. Shaw. 2006b. Epidemiology of recreational exposure to freshwater cyanobacteria- an international prospective cohort study. BMC Public Health. Volume 6, Number 93. www.biomedcentral.com/1471-2458/6/93

Stewart, I., I. Robertson, P. Webb, P. Schluter, and G. Shaw. 2006c. Cutaneous hypersensitivity reactions to freshwater cyanobacteria- human volunteer studies. BMC Dermatology. Volume 6, Number 6. www.biomedcentral.com/1471-5945/6/6

Watzin, M.C., E.B. Miller, M. Kreider, S. Couture, T. Clason, and M. Levine. 2005. Monitoring and Evaluation of Cyanobacteria in Lake Champlain: Summer 2004. Lake Champlain Basin Program.

WHO 1999. Toxic Cyanobacteria in Water: A Guide To Their Public Health Consequences, Monitoring, and Management. Ingrid Chorus and Jamie Bartram (eds). World Health Organization.

WHO 2003. Guidelines for Safe Recreational Water Environments, Volume 1: Coastal and Fresh Waters. World Health Organization. www.who.int/water_sanitation_health/bathing/srwe1/en/

WHO. 2006. Guidelines for Drinking-water Quality- First Addendum to Third Edition. Volume 1: Recommendations. World Health Organization.
www.who.int/water_sanitation_health/dwq/gdwq3rev/en/index.html

Appendix: Guidelines from Other Health Organizations

California State Water Resources Control Board

At cell counts greater than 40,000 cell/mL of *Microcystis* and *Planktothrix* or at cell counts greater than 100,000 cells/mL of potentially toxic cyanobacteria (e.g., *Anabaena* and *Microcystis*), the Board's draft guidelines recommend that a beach be closed. The 40,000 cells/mL value was derived using a risk assessment approach based on child's recreational exposure to the toxin (CSWRCB 2006). This approach is not described further in the Board's draft guidance document. The 100,000 cells/mL value appears to be taken from the WHO guidance.

California Department of Health Services

At cell counts greater than 20,000 cells/mL, the Department's draft guidance recommends that a beach be closed. No supporting information is given. However, it is likely that this number is taken from the WHO guidance, which advises notifying bathers of the presence of cyanobacteria at this cell count.

Vermont

At cell counts greater than 4,000 cells/mL, Vermont recommends that the water be tested for toxins. This threshold is based upon the results from 6 years of research in Lake Champlain and other waterbodies in the state. They have found that the toxin levels do not approach their guideline of 6 ppb of toxin until the cell counts are higher than 4,000 cells/mL (Watzin et al. 2003, 2005, and Stone and Bress 2007). This low threshold enables them to monitor developing situations and minimize potential exposure to elevated levels of toxin.

The Vermont guidance level of 6 ppb of toxin is based upon the same study that the WHO used to generate their provisional guideline for drinking water consumption. The study was conducted in 1994, and involved administering the cyanobacteria toxin microcystin orally to mice. Based upon liver histopathology and serum enzyme level changes, and adding an uncertainty factor of 1,000, the WHO generated a TDI (Tolerable Daily Intake) of 0.04 ug/kg/day. This TDI is a level of the toxin that should be safe to consume daily over a lifetime. Assuming that an adult weight 60 kg and drinks 2 liters of water per day, using this TDI, the WHO derived a drinking water guideline of 1 ppb of microcystin in water.

Vermont took the TDI that the WHO had generated, and using different assumptions about body weight and water consumption, generated a guideline for recreational exposure to the cyanobacteria toxin. They assumed an exposure scenario where a child, weighing 15 kg, ingests 100 mL of beach water per day (EPA guidance). Based on this scenario, Vermont calculated a recreational water guideline of 6 ppb.

The World Health Organization

The WHO does not recommend a cell count at which to test for the toxin. The lowest WHO cell count guideline is 20,000 cells/mL, and that is due to health concerns based on irritative or allergenic effects of cyanobacteria described in a study by Pilotto et al (1997 cited in WHO 2003). At this level, the WHO recommends that officials "post on-site risk advisory signs" and "inform relevant authorities". The Pilotto study is one of the two studies upon which Australia bases its 5,000 cells/mL guidance described above.

Australia

At toxin levels greater than 10 ppb, Australia recommends that a beach be closed. This concentration is based on a LOAEL derived from a pig study by Falconer et al (1994 cited WHO 1999; also discussed in Kuiper-Goodman et al. 1999 as cited Australian Guideline 2005). In this study, pigs consumed drinking water that contained microcystin. Based upon general liver damage (observed from histopathology and serum enzyme level changes), a LOAEL of 100 ug/kg/day was derived. Australia then added an uncertainty factor of 5,000 and assuming a child weighing 15 kg consume 100 mL of water for 2 weeks, generated a recreational water guideline of 10 ppb.

References

Australian Government 2005. Guidelines for Managing Risks in Recreational Waters. Australian Government: National Health and Medical Research Council. http://www.nhmrc.gov.au/publications/subjects/environmental.htm

CSWRCB 2006. California State Water Resources Control Board. Draft: Cyanobacteria in California Recreational Waters- Guidance About Harmful Algal Blooms, Their Monitoring, and Public Notification.

Kuiper-Goodman, T., I. Falconer, and J. Fitzgerald. 1999. Human health aspects. In: Toxic Cyanobacteria in Water: A Guide to their Public Health Consequences, Monitoring and Management, I. Chorus and J. Bartram (eds).

Stone, D. and W. Bress. 2007. Addressing Public Health Risks for Cyanobacteria in Recreational Freshwaters: The Oregon and Vermont Framework. Integrated Environmental Assessment and Management. Volume 3, Number 1. pp: 137-143.

Watzin, M., A. Shambaugh, E. Brines, and G. Boyer. 2003. Monitoring and Evaluation of Cyanobacteria in Lake Champlain (Summer 2002). Technical Report No. 41. Lake Champlain Basin Program.

Watzin, M.C., E.B. Miller, M. Kreider, S. Couture, T. Clason, and M. Levine. 2005. Monitoring and Evaluation of Cyanobacteria in Lake Champlain: Summer 2004. Lake Champlain Basin Program.

WHO 2003. Guidelines for Safe Recreational Water Environments, Volume 1: Coastal and Fresh Waters. World Health Organization. http://www.who.int/water_sanitation_health/bathing/srwe1/en/