Miacomet Pond Water Quality

2009

A Summary of Physical, Chemical and Biological Monitoring

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March 2010

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ACKNOWLEDGEMENTS

Funds for this work were provided by the Nantucket Land Council and by the University of Massachusetts Boston Nantucket Field Station.

The authors would like to thank the following individuals whose assistance was instrumental in completing the field work, data analysis and report writing phases of this project: Alex Barham, Cormac Collier, Dave Fronzuto, Matthew Liddle and Mirabai Perfas.

Section 1

Executive Summary

1.0 Project Location and Boundary

Miacomet Pond is located in Nantucket County, Massachusetts, and appears on the United States Geological Survey (USGS) 7.5 minute quadrangle map, Nantucket, with an occasional, created outflow through the barrier beach located at the approximate coordinates, latitude 41°14'36" and longitude 70°07'05" (Figure 1). The Pond and its watershed are within the Town of Nantucket and the Town is responsible for stewardship of the Pond. Miacomet Pond is a Class B water, primarily used as a recreational body for swimming, boating, kayaking, and fishing, and also provides important habitat for a variety of waterfowl, both migrating and resident populations.

1.1 Purpose of the Study

The primary goal of the 2009 Miacomet Pond study was to maintain continuity of regular water quality data collection which originated back to the early 1990's. A secondary goal of the study was to develop a management strategy for Miacomet Pond that would address present or potential problem areas either in the pond or in the watershed. The specific objectives were to

- Define the present water quality of Miacomet Pond and,
- Determine watershed activities that may influence the water quality of the pond.

The primary factor that motivated this investigation was a lack of funding source within the Town of Nantucket to continue a water quality monitoring program on Miacomet Pond which was initiated during 1993. Cormac Collier, Executive Director, Nantucket Land Council, Dr. Sarah Oktay, Managing Director, University of Massachusetts Boston Nantucket Field Station, and the report author (JWS) developed a proposal for the 2009 monitoring effort, and NLC and UMass Boston provided the funds to pay for costs associated with the study.

1.2 Project Description

Since the primary personnel involved with this project reside year-round on Nantucket Island, it was possible to implement a water quality study whereby Miacomet Pond was sampled every two weeks for a 3-1/2 month period. The study began during late June 2009 and continued through early October. A total of seven sampling trips were conducted; five stations along the longitudinal axis of Miacomet Pond were sampled during each trip and there was one station on the tributary from Burchell's Pond that flows into Miacomet. The effort also included special studies of chlorophyll a, the phytoplankton community, and a detailed investigation of attached aquatic vegetation.

1.3 Presentation of Report

Chapter 1 summarizes the pond-related problems, the findings of this study, goals for improving pond water quality, and a summary of the recommendations.

Chapter 2 describes the 2009 sampling program conducted on Miacomet Pond and the methodology of the sampling program.

Chapter 3 describes the existing water quality of Miacomet Pond as evaluated through the analysis of physical, chemical and biological data.

Chapter 4 includes a summary of 2009 program findings, discussion of the data, conclusions and some general recommendations that will lead to improved water quality of Miacomet Pond.

An **Appendix** included at the end of the report that contains material referenced in the report.

1.4 Project Findings and Conclusions

In spite of the brief period of sampling on Miacomet Pond, the 2009 data provide substantial evidence to support the 'eutrophic' status that has either been implied or stated in earlier reports (ACT, 1997; Conant, 2006). In fact, a thorough examination of the 2009 chemical and biological results provides sufficient evidence that Miacomet Pond is well-established as a eutrophic system.

The total phosphorus (TP) and total nitrogen (TN) levels measured in Miacomet Pond during 2009 were similar to the levels reported for 2005 by Conant (2006), suggesting that water quality conditions in the pond have remained the same or, at least, have not gotten worse during the previous four years. The 2009 study also demonstrated a distinct south-to-north gradient of plant nutrients within the pond, with the highest average concentrations occurring either at Station #6 in the lower Narrows (highest TP values) or at Station #5 in the upper Narrows (highest TN values). The gradient in average station concentration was most prominent for TP.

Miacomet Pond contributes an unknown amount of phosphorus and nitrogen loading through autochthonous (internal) sources, while an unknown proportion of the total nutrient load enters from allochthonous (external) sources. The relative contribution of nutrients from these sources should be investigated through further studies in the pond and in the watershed.

The biological samples collected from Miacomet Pond during 2009 revealed moderate-to-dense levels of phytoplankton standing crop and provided further evidence to characterize the pond's eutrophic status. Lakes and ponds with concentrations of chlorophyll *a* in the range of 10-15 µg/L are considered to be on the border between mesotrophy and eutrophy (Vollenweider and Kerekes 1980). Miacomet Pond was well-established within the eutrophic range during 2009 regardless of whether one considers all of the chlorophyll *a* samples collected from the pond (average = 20.29 µg/L) or only the summer samples when the water column temperature was > 18^{o}C (average = 25.74 µg/L). The concentration of chlorophyll *a* indicated moderate-to-dense phytoplankton in the water column; however, 'bloom' conditions never were observed on Miacomet Pond such as the conditions measured on Head of Hummock and Hummock Pond during 2009.

The diverse phytoplankton community reported from Miacomet Pond during 2009 and the seasonal succession of major groups within the community provides important information about the general trophy of the system. In the absence of any recent phytoplankton data from the pond to compare with the 2009 data, however, it is impossible to know the extent to which 2009 conditions are 'typical' of the seasonal pattern on the pond. The minor role of diatoms in the community seasonal succession may be problematic and indicative of other groups out-competing the forms adapted to cold-water environments. It is impossible to understand this situation without a complete annual cycle of phytoplankton data.

The moderate level of primary productivity demonstrated by the 2009 phytoplankton community in Miacomet Pond also characterized the 2009 aquatic plant community of the pond. During the July survey, dense and moderate growth of native plants was recorded at 35 of 51 total sites (≈70%) within the main body of the Pond. From about mid-summer 2009 and well into the fall, many of the plants growing in the water column had reached the surface and were flowering extensively, indicating that there is considerable potential for the plant community in Miacomet Pond to spread and become more evenly distributed. The extensive amounts of plant material floating on the Pond surface make it very difficult to pass through these areas with water craft. Even at current levels of plant growth in Miacomet Pond, recreational use generally is impaired due to entanglement of oars, paddles, and outboard motors from the extensive plant material on the pond surface.

High TN concentrations measured in Miacomet Pond during 2009 coupled with other water quality problems indicate that watershed loading is problematic and that the assimilative capacity of the system probably has been exceeded. The likely source of nitrogen is from (1) numerous individual septic systems in the watershed which are of different ages and working efficiencies, and (2) groundwater flow from areas such as the Miacomet Golf Course which occupies ≈75 acres of land surface and applies fertilizer to a major portion of this area on a regular basis. The seriousness of the groundwater loading problem is emphasized by the situation in the upper Narrows, adjacent to Otokomi Road. Even though most of the watershed area surrounding this portion of the pond is within the sewer district, extremely high levels of nitrate-nitrogen continuously flow into the pond, acting as a point source of pollution.

The cyanobacteria identified in Miacomet Pond during 2009 that are known producers of toxins are problematic and pose a public health and safety issue for individuals using the pond recreationally and home-owners living along the shoreline adjacent to the pond. The seriousness of this situation is particularly of concern in view of the recent scientific information linking cyanobacterial blooms in lakes and ponds with the development of sporadic ALS disease.

While reviewing material for this report, it was noted that a fish consumption advisory was issued for Miacomet Pond in 1995 due to elevated tissue mercury levels. Fifteen years have passed since this advisory, and there is no indication whether fish consumption continues to be a public health and safety issue while the pond is heavily fished by members of the year-round Island population.

A brief summary of the problems affecting Miacomet Pond are as follows:

- There is uncontrolled development within the Miacomet Pond watershed and a large number of individual septic systems whose operating efficiency is unknown,

- Nitrogen loads are considered a major problem for water quality of the pond and for the groundwater that enters the pond, particularly in the upper areas of the Narrows, where groundwater has very high concentrations of nitrate-nitrogen,

- Miacomet Pond is ‘unuseable’ by the public for either contact recreation or aesthetic enjoyment in its current state of water quality, and
- Although Miacomet Pond has been studied regularly since 1993, there is very little, if any, scientific information available concerning the effects of the watershed on the pond.

Based upon the current level of knowledge related to the Miacomet Pond ecosystem, the following are a series of recommendations that should be considered for implementation.

1.5 Recommendations

(1) The Town of Nantucket is responsible for environmental stewardship of Miacomet Pond and therefore has an obligation to fund regular monitoring of this body of water so that water quality conditions continue to be documented.

(2) As the governmental entity responsible for Miacomet Pond, the Town of Nantucket should retain a consultant to prepare a detailed Management Plan for this water body. However, a detailed Management Plan should only be prepared after there has been a more thorough assessment of factors affecting the water quality of the pond. In some cases, additional data gathering must occur to overcome deficiencies in the current status of information. These deficiencies are addressed below.

(3) Watershed deficiencies should be addressed prior to the development of a Management Plan and include (1) detailed GIS land use analysis within the watershed, documenting individual parcels, the amount of development and types of structures/impervious areas on each parcel, (2) groundwater monitoring at strategic locations along the shore-line including installation of wells, funds for certified chemical analyses, and studies to determine the direction of subsurface flows to define the exact contributory areas and develop a priority system for Title 5 inspections and remedial actions, and (3) evaluation of current soil maps and upgrading of these maps, if warranted.

(4) Pond deficiencies should be addressed prior to the development of the Management Plan and include (1) installation of a continuous water level recorder to assist with preparation of a water budget for the pond, (2) updated bathymetry of the pond, and (4) chemical analysis of bottom sediments.

(5) The shore-line of Miacomet Pond should be delineated along with detailed mapping of the shore-line emergent vegetation. During the 2009 vegetation survey, it was observed that almost all of the shore-line emergent vegetation was *Typha latifolia*.; however, there were two pockets of *Phragmites australis* observed. There should be an immediate effort to remove the *Phragmites* populations from the shore-line areas and a constant surveillance to monitor any subsequent introduction of this genus.

(6) A pumping and inspection program should be established within the watershed to test the effectiveness of individual wastewater treatment systems. In the absence of high resolution

groundwater maps that indicate directional flow within the watershed, the systems closest to the Pond should be evaluated first.

(7) Beginning in the late spring of 2010, regular (bi-weekly) samples of the phytoplankton community should be collected from Miacomet Pond and submitted to the UNH Center for Freshwater Biology for microcystin (MC) analysis.

(8) Until control of nutrient loading to Miacomet Pond can be achieved, the Town of Nantucket should explore potential funding options to purchase a mechanical harvester to remove aquatic plant biomass from Miacomet Pond. The mobilization and maintenance charges of hiring an off-Island contractor to conduct the work over a period of several years would make this approach too expensive. Owning and operating the harvester would be the most practical approach, and the equipment could be used on other Island ponds with vegetation problems. The primary author of this report (JWS) has worked with municipalities and lake associations in NYS who have adapted similar practices with great success and have been operational for several decades. Initial costs would include the harvester, conveyor (to off-load vegetation) and dump truck. Local farms or landscape professionals might want to use the harvested material as compost; otherwise, the material could be composted at the local landfill.

(10) A close watch should be maintained over the Miacomet Pond aquatic plant community to provide early detection of the introduction of an invasive species, such as *Myriophyllum spicatum*, Eurasian watermilfoil. It is surprising that no invasive species have been detected in the Pond so far, particularly given the high waterfowl traffic from Cape Cod and other areas along the eastern seaboard where invasive species are a problem.

1.6 Literature Cited

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Section 2

Methodology

2.0 Introduction

The Miacomet Pond ecosystem includes physical and chemical environments and the biotic community. The physical environment of the pond, which includes water temperature, wind-induced turbulence, and the duration and intensity of light in the water column, is directly affected by climate. The chemical characteristics of the pond are determined, primarily, by the interaction of the following three factors

- the geologic watershed and its contents,
- land use in the watershed and related human activities, and
- the hydrology of the pond

The biotic community of the pond is the result of the physical and chemical environments and reflects the quality of these components through species composition and abundance of organisms.

2.0.1 Purpose of the sampling program. Water quality data has been collected from Miacomet Pond at irregular intervals since the early 1990's. During late spring 2009, Cormac Collier, Executive Director, Nantucket Land Council (NLC), Dr. Sarah Oktay, Managing Director, University of Massachusetts Boston Nantucket Field Station and the report author (JWS) developed a proposal for the 2009 monitoring effort and the NLC and UMass Boston provided the funds to pay for costs associated with the effort.

2.0.2 Description of sampling program. Water quality was monitored from late June through early October 2009 at 5 stations located along the longitudinal axis of the Pond and a single station located along a tributary that flows from Burchell's Pond to Miacomet Pond (Figure 2). These stations were selected to coincide with stations sampled during previous surveys to determine whether there was any longitudinal gradient in water quality. Sampling was conducted on about a bi-weekly basis. The Pond was sampled a total of 7 times and the sampling dates are listed below.

Hummock Pond – 2009 Sampling Dates			
30 June	28 July	27 August	06 October
14 July	11 August	15 September	

The data and samples collected regularly from stations on the Pond included the following

1. Depth profiles of temperature and dissolved oxygen (concentration, percent saturation)
2. Secchi depth transparency
3. Raw pond water for the analysis of total phosphorus, a nitrogen series, chlorophyll *a*, specific conductance, pH and
4. Phytoplankton

A special study was conducted on 27 July to map the submersed aquatic vegetation throughout Miacomet Pond. Table 1 provides a summary of the parameters that were monitored in Miacomet Pond during 2009.

2.1 Methodology

This section explains the procedures used in the field to collect the samples and the processing that occurred, following collection, at the UMass Boston Nantucket Field Station Laboratory.

2.1.1 Routine sample collection and processing. Sample collection occurred at pre-determined stations along the longitudinal axis of the pond. Upon reaching each station, the boat was anchored and total depth of the water column was measured with a weighted Secchi disk on a marked line, and recorded. The latitude and longitude coordinates of the sampling site were recorded using a SporTrak Pro Magellan GPS unit.

Secchi depth was measured using a standard 20-cm weighted disk on a marked line. Measurements were taken on the side of the boat away from the sun in order to avoid glare which would interfere with the readings. The disk was lowered into the water column to the depth at which it just disappeared. This depth was noted. The disk then was raised from out of the range of visibility to the depth where it re-appeared. This depth was noted. The average of the 2 depths was recorded as the Secchi depth transparency at that station on that sampling date.

Vertical profiles of water temperature and dissolved oxygen were measured in-situ at 1-foot intervals at each station on each sampling date using a Yellow Springs Instrument (YSI) Model 58 digital meter.

Water samples for chemistry, phytoplankton and chlorophyll *a* analyses were collected from the water column following a determination of whether the column was stratified, either thermally or in terms of oxygen concentration. The upper zone of the water column at similar temperature (epilimnion) was sampled using the integrated hose technique; the lower zone of different temperature or oxygen concentration was sampled with a horizontal Van Dorn bottle. The collected samples were transferred to cleaned and pre-rinsed 1 liter PE sample bottles and then stored cold and in the dark until processing, usually within 2 hours of collection.

A subsample of pond water collected from the upper and lower levels of the water column at each station was analyzed on-site for specific conductance, total dissolved solids, and pH using an Ultrameter II™ (Myron L Company), and data recorded on station field sheets (Appendix 1).

The water chemistry, chlorophyll a and phytoplankton samples were processed at the UMass Boston Nantucket Field Station immediately following each pond visit. The water sample for chemistry was processed by pouring off separate 75 - 100 mL aliquots of raw sample into 4 - 125 mL PE containers with snap tops labeled with **TP**, **TN**, **NH3** and **NO3** and with accession numbers (sample label code) for the 2009 Nantucket Island sampling program. The accession format was **09-NIP-###**, with **###** being consecutive numbers, starting at 001 that identified each set of collected samples.

The samples for chlorophyll *a* determination were concentrated by filtration through a 0.45µm glass fiber filter; subsequently, 0.2 mL of $MgCO_3$ suspension was added for preservation during the final phase. The filters were kept frozen and in the dark until delivery to the analytical laboratory.

The processed chemistry and chlorophyll *a* samples were placed in a cooler with ice packs and shipped via FedEx (2nd day delivery) to the Keck Water Research Laboratory in Troy, NY. This lab is located on the campus of Rensselaer Polytechnic Institute (RPI) and is NYS certified to process and analyze the parameters included in this investigation. A Chain of Custody form (Appendix 1) accompanied the samples to the analytical lab.

The phytoplankton samples were transferred to 125 mL amber PE bottles, preserved with basic Lugol's solution and then sent to Ms. Jill Scaglione at Aquatic Analysts, Inc. in Middleville, NJ for analysis. Ms. Scaglione is certified for phytoplankton analysis and these types of samples are part of her responsibility with the environmental management firm where she is employed.

2.1.2 Aquatic plant survey. A survey of aquatic plants was conducted on Miacomet Pond on 27 July. Weather conditions were perfect (clear and calm) for a survey of this nature. Marc Bellaud from Aquatic Control Technologies, Inc. in Sutton, MA, Alex Barham, an intern at the UMass Boston Nantucket Field Station, and the report author (JWS) conducted the survey. Methods for the plant survey were derived from the point intercept sampling method developed by the U.S. Army Corps of Engineers (Madsen, 1999) and the "Point Intercept Rake Toss Relative Abundance Method (PIRTRAM)" that was modified by Cornell University Research Ponds and the New York State Department of Environmental Conservation (Lord and Johnson, 2005).

Using ArcView software, point intercept data points were created by the vertices of an approximately 50 meter grid that was superimposed over an orthophoto image of the pond. A total of 52 data points were selected for the survey. The survey data points were navigated to with a Jon boat and motor using a Garmin Map 76csx WAAS GPS unit.

Upon arrival at each survey data point, the boat was anchored at the bow. The GPS coordinates of the site were recorded and stored. Water depth was measured using a fiberglass measuring tape and weight. The water depth was recorded on a field log (Appendix 1), and depicted on a map. Any other pertinent field notes regarding the sample location also were recorded on the field log sheet.

Two throw-rake tosses were performed. The rake used for aquatic plant surveys has a specific design (Appendix 1). It is constructed with two 13.5-inch wide metal garden rakes attached back to back with hose clamps. The wooden handles are removed and a 10 meter-long nylon rope is attached to the rake heads. It is important to toss the rake the full distance (a loop at the end of the rope should be attached to the boat to prevent losing the sampling device). The rake is slowly retrieved along the bottom, and carefully lifted into the boat. All plants present on the rake were identified to the genus and species level where possible, and this information was recorded. The dominant plant at each sample point was noted. To determine the overall amount (biomass) of submersed macrophytes collected by the rake, the vegetation mass is assigned one of five densities, as shown in Table 2, based on semi-quantitative metrics (PIRTRAM values) developed by Cornell University (Lord and Johnson, 2005).

If plant identification in the field is in question, a sample of unknown macrophytes is collected and placed in a zip-loc bag with a letter or number code (A, B, 1, 2, etc.). If possible, these samples should include both submersed and floating leaves (if any), seeds, and flowers (if present), to facilitate identification. These samples are placed in a cooler stocked with blue-ice packs or ice, and returned to the ACT lab for positive identification and photographing (if necessary). Plant structures are examined under magnification, and regionally appropriate taxonomic keys (Crow and Hellquist, 2000a, b) are used to identify the aquatic plants to the lowest practical taxa.

2.2 Analytical Techniques

The methods for on-site water column measurements and field collections are summarized in Table 3. The analytical procedures for water chemistry and biological samples are presented in Table 4.

The author (JWS) and personnel from the UMass Boston Field Station collected all data and samples in the field, and processed these samples at the Field Station Laboratory.

The samples for water column nutrients were analyzed by the Keck Water Research Laboratory on the RPI Campus in Troy, NY, using the standard procedures presented in Table 4.

Chlorophyll *a*, retained by filtration, was broken down by grinding, extracted in 90% acetone, centrifuged, and then determined fluorometrically (Table 4).

2.2.1 Phytoplankton. The microscopic protocol for phytoplankton identification and enumeration is detailed in the sections below.

Counting method. At least 200 mL of sample preserved with Lugol's or glutaraldehyde is required for analysis. The inverted microscope is used routinely for phytoplankton counting; the objectives 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 are allowed to settle for an appropriate period (1 hour settling time/mm of column depth or approximately 3 days). Sedimentation is the preferred method of concentration because it is nondestructive and non-selective. After the settling period, the chamber tower is gently slid off with a cover slip, removing all but 1 ml of sample in a small well at the bottom of the chamber.

The sample is scanned using low magnification to determine the taxa present. Then, it is analyzed at 1000x using oil immersion to accurately count cells which may be present below 10-20 um in size. For biovolume estimates, it also is necessary to have high magnification in order 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 is usually 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 cells/mL. 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 taxa 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 = total area of bottom of settling chamber, mm^2

V = volume of sampled settled (50 ml)

A_f = area of field (determined by microscope calibration), mm

F = number of fields counted

Conversion to biovolume (mg^3/mL) - biomass (mg/m^3). Phytoplankton data derived on a volume-per-volume basis are more useful than numbers per milliliter. Algal cell sizes can differ in various waterbodies or from the same waterbody at different times of the year. Therefore, average measurements are made from approximately 20 individuals of each species 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 biovolume (um^3/mL) 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 (um^3/mL) by 1,000.

Editor's Note: In discussions of the phytoplankton communities of Miacomet Pond during 2009, the term 'taxa' is used instead of the term 'species' since it was not always possible to provide a definitive identification to the species level.

2.3 Literature Cited

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Section 3

The Water Quality of Miacomet Pond During 2009

3.0 Introduction

The ecosystem of Miacomet Pond includes physical and chemical environments and the biotic community. The physical environment includes water temperature, wind-induced turbulence, and the duration and intensity of light in the water column, and is directly affected by climate. The chemical characteristics of the pond are determined, primarily, by the interaction of

- the geologic watershed and its contents,
- land use in the watershed and related human activities, and
- the hydrology of the pond

The biotic community of the pond is the result of the physical and chemical environments and reflects the quality of these components through species composition and abundance of organisms.

3.1 Results

The following sections summarize the data collected from Miacomet Pond during 2009. Tables of the entire data-set are contained in a series of Appendices, which may be made available through a request to the Nantucket Land Council, and include the following:

- Appendix 2 – Field Data and Nutrient Chemistry Results
- Appendix 3 – Phytoplankton Data
- Appendix 4 – Aquatic Vegetation Data

The 2009 sampling program revealed some significant differences for certain water quality parameters between the main body of Miacomet Pond and the tributary that enters the Pond from Burchell's Pond (Station #4). In view of these differences, Station #4 and the other pond stations are discussed separately in instances where sufficient water quality distinctions are supported by the data collected.

3.1.1 Physical characteristics

General. Miacomet Pond has a reported surface area of 47.3 acres (Conant, 2006) and is oriented along a southwest-northeast axis, having a long, narrow configuration and a total length of ≈1.5 miles (including the narrow channel at the northeast end which extends to Otokomi Road). The south end of the Pond is ≈400 feet wide and tapers to ≈100 feet in width where the Burchell's Pond outlet enters the pond. Beyond this point, the Pond is very constricted, an area appropriately called the Narrows, and tapers to a width of about 10 feet at the extreme northeast end. The Pond has a watershed area of 970.6 acres (Horsley et al., 1990), which yields a drainage basin to lake basin ratio of approximately 20:1. There is no outlet from Miacomet Pond, but the Pond has been breached and discharges to the ocean by natural and intentional means, most recently in 2005 (Conant, 2006).

Water depths. Water depths recorded during the aquatic vegetation survey (27 July) were used to generate a depth map of Miacomet Pond (Figure 3); a total of 51 discrete depth measurements were recorded during the survey. The map provides useful comparative information concerning depths throughout Miacomet Pond; however, there were not enough depth points recorded to develop a true bathymetric (contour) map of the pond.

The maximum depth recorded in Miacomet Pond on 27 July was 10.8 feet and occurred at the southwest end near the barrier beach adjacent to the Atlantic Ocean (Figure 3). The deepest areas were in this area and aligned at, or adjacent to, the center of the pond along the main axis. The northern end of the main body near the inflow from Burchell's Pond decreases to about 5 feet in depth and, thereafter, the pond fluctuates between ≈3 – 4 feet through the Narrows to the far northeast end.

Water depths during 2009 were observed to fluctuate by as much as ± 1.5 feet during the entire sampling period (June - October). During this time, maximum depths up to 13 feet were recorded near the southeast end of the Pond at Station #1.

Even though no contour map could be constructed for Miacomet Pond, it is evident from Figure 3 that the pond has an extensive shallow area, providing good superposition of the photosynthetic and decomposition zones, a condition that provides the potential for high biological productivity. This characteristic was supported by data collected during the aquatic plant survey when vegetation was recorded at all 51 sampling sites on the Pond.

Thermal cycle. Water depth is too shallow along the main axis of Miacomet Pond to develop mid-summer thermal stratification. Consequently, the water column thoroughly mixes from surface to bottom throughout the ice-free period. This type of circulation pattern is typical of *polymictic* lakes which are a subset of the broader category, *holomictic* lakes. Miacomet Pond should be considered a *cold polymictic* water body (ice covered in winter) which usually forms an ice-cover each winter.

The water column at monitoring stations along the main axis of Miacomet Pond essentially was isothermal on all seven sampling dates during 2009. The greatest difference between the surface and bottom temperature at Station #1, the deepest sampling site, was 1.5^{o}C and occurred on 30 June when the water column still was warming from earlier spring conditions. Figure 4 summarizes the average water column temperature at the five Miacomet Pond stations during the 2009 sampling season. The maximum water temperature attained at all stations was ≈22 - 23°C and occurred during early August.

The extreme upper narrows of Miacomet Pond, close to Otokomi Road, exhibits a much different temperature pattern than the remainder of the Pond (Figure 4). Based upon the 2009 temperature pattern, and also the nutrient chemistry collected at this location (Station #5), it appears that this is an area in the Pond where groundwater emerges in the channel and becomes surface water. Beginning with the first sampling date on 30 June and continuing through mid-September when the average water column temperatures in the main body of the Pond were 18^{o}C or greater, the temperature at Station #5 always was cooler, by as much as 3.5 – 5.2^{o}C (see Figure 4).

The tributary from Burchell's Pond (Station #4) exhibited a pattern of water temperature similar to the sampling stations along the longitudinal axis of the Pond (Figure 5).

Transparency. Miacomet Pond was moderately clear during the 2009 sampling season as indicated by the average water column Secchi disk transparency which ranged between ≈1.0 - 2.5 meters (3.2 – 8.2 feet) at Stations #1 and #2 (Figure 6). Stations #1 and #2 were the only monitoring sites that had sufficient water depth to measure transparency during the entire season.

Station #4 is the channel that outflows from Burchell's Pond and appears to be strongly influenced by humic and fulvic acids leaching into the channel either from Burchell's Pond or the adjacent wetland, or both. Secchi depths were not always possible to record at this site since water depth was fairly shallow, averaging 28 inches for the entire season. Water color at this site was recorded as either 'brown' or 'dark brown' on every sampling date. As a comparison with the main body of Miacomet Pond, the average Secchi depth measured at Station #4 on 4 of 7 sampling visits was 22 (±4) inches while the average value for Stations #1 and #2 was 72 (±17) inches.

3.1.2 Chemical characteristics

Specific conductance and pH. The specific conductance of water measures the solution's resistance to flow of an electrical current; the resistance decreases as the ionized salt content of the water increases. Water with a low concentration of major ions such as HCO_3 (bicarbonate), CO_3^{-2} (carbonate), K^+ (potassium), Na^+ (sodium), Ca^{2+} (calcium), Cl^- (chloride), SO_4^{-2} (sulfate) and $Mg^{=2}$ (magnesium) will have the greatest resistance to flow of electrons.

The influence of wind, the Atlantic Ocean and evaporation on conductance levels at the Miacomet Pond sampling stations was evident during the 2009 season. The primary effect was an increase in Pond conductance values at southern stations through salt water intrusion driven by high wind and tidal activity influence over and through the barrier beach. Beginning on 30 June, all five stations had conductance values ranging between ≈100 - 150 µS/cm (Figure 7). Thereafter, Station #1, adjacent to the barrier beach showed a large increase to ≈1100 µS/cm on 14 July, probably the result of a storm event with high winds on 12 July and several days following. Subsequently, Station #1 and the other four Pond stations remained below ≈150 µS/cm through the 11 August sampling date (Figure 7).

All stations except Station #5 near Otokomi Road exhibited substantial increases in conductance for the sampling season beyond 11 August, although Station #3 and Station #6 showed time lags with respect to these increases (Figure 7). The high values at Stations #1 and #2 on 27 August (1390 and 953 µS/cm, respectively) probably resulted from several high wind events from the southwest starting about mid-August. Subsequently, Stations #3 and #6 exhibited increased conductance during mid-September and beyond, probably from continued high winds during most of September coupled with increased evaporation of water from the Pond surface. Station #5 adjacent to Otokomi Road was the only site not influenced by salt water intrusion and had the most consistent conductance over the entire sampling period, ranging from 145 – 210 µS/cm (Figure 7).

With one notable exception, the water column pH of Miacomet Pond at all five stations ranged between ≈6.00 – 8.00 s.u. during the 2009 sampling period (Figure 8). The notable exception occurred on 11 August when Stations #3, #2, and #1 exhibited pH values of 9.47, 8.74 and 8.17 s.u., respectively. These increases suggest high levels of primary productivity in the pond which is supported by the phytoplankton community information presented later in this report. There also is nutrient information which corroborates these findings and suggests specific watershed areas contributory to the problem.

Station #4 on Miacomet, the tributary from Burchell's Pond, exhibited patterns of water column conductance and pH similar to the pond stations (Figure 9). The highest pH, 7.30, was recorded on 11 August and the specific conductance was between ~100 – 175 µS/cm during most of the season until the last sampling date when the value increased to 509 µS/cm.

Oxygen concentration and saturation. Oxygen in lake water constantly is consumed and the two primary mechanisms that replenish oxygen supply are exchange with the atmosphere at the air-water interface and photosynthetic activity of plant material, both phytoplankton and rooted plants, in the water. Oxygen consumption results from the respiration of aerobic organisms and from decomposition in the lower waters by organisms that metabolize the organic material settling down from the productive upper levels of the water column.

Most of the Miacomet Pond stations exhibited normal levels of dissolved oxygen concentration and saturation during the 2009 sampling period. In general, concentrations ranging from ≈7 – 10 mg/L and saturation ranged from ≈80 – 120 percent between late June and early October (Figures 10 and 11). There were two notable exceptions. One exception was Station #6, which consistently exhibited the lowest concentration and saturation values from late July through late August (Figures 10 and 11). This condition could be the result of shallow water depths, good superposition of the zones of photosynthesis and decomposition, and a constant source of nutrients to the area via groundwater infiltration. The other exception was Station #5, adjacent to Otokomi Road, which exhibited elevated concentrations and saturation values early in the season as a result of the lower temperature (and increased saturation capacity) of emerging groundwater at this site.

The Burchell's Pond tributary (Station #4) had a very different concentrations and saturation values during 2009 (Figure 12). Dissolved oxygen concentrations are this site ranged between ≈2 – 4 mg/L while saturation values were ≈20 – 40 percent during the sampling period. As mentioned previously, water color at this station suggested the presence of humic and fulvic acids from the pond and surrounding wetland area. It is likely that a reaction cycle involving humic substances, and iron as a catalyst, acts as an oxygen sink in this situation (Miles and Brezonik, 1981). The cycle consists of photo-reduction of Fe (III) to Fe (II) by dissolved oxygen and would account for the frequently observed low oxygen concentration (and percent saturation) at this site.

3.1.3 Plant Nutrients

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

Total nitrogen (TN) = Organic nitrogen + 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, however, since it is readily converted to **nitrate** if enough oxygen is present for oxidation.

Total nitrogen is an essential nutrient for plants and animals; however, an excess amount of nitrogen in a waterway can lead to low levels of dissolved oxygen and negatively alter various 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.

Bacterial oxidation and reduction of various nitrogen compounds in lake water produces forms of nitrogen that are photosynthetically assimilated by aquatic plants. 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. 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 of 7.00 and below, NH_4^+ predominates and is a good source of nitrogen for plants. At the higher pH values, NH_4OH can occur in concentrations that are toxic to biological growth. pH values at the Miacomet Pond stations generally were within the range of 6 – 8 s.u. during 2009 indicating that NH_3-N probably is a good source of nitrogen for algae and higher plants. However, there was a period during August when pH values at Stations #2 and #3 approached 9.00 s.u., indicating that NH_3-N may not be a good source for algal productivity due to the increased proportions of NH_4OH and its toxicity.

Nitrate-nitrogen, **NO_3-N**, is produced by the bacterial conversion of organic and inorganic nitrogenous compounds from a reduced state to a more oxidized state and is readily assimilated by algae and other green plants. **Nitrate** and **ammonia**, collectively, 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 of the lake water.

Some important features of nitrogen in Miacomet Pond during 2009 are as follows:

- Concentrations of nitrate and ammonia were low at most pond stations during 2009, although Station #5 (head of the pond near Otokomi Road) exhibited very high nitrate concentrations during the entire sampling period,

- Concentrations of nitrate and ammonia had no definitive seasonal pattern which might be expected in north temperate lakes and ponds,
- Concentrations of nitrate and ammonia varied spatially among stations sampled in the pond on the same sampling date,
- Organic nitrogen concentrations reflected moderate levels of plankton and seston which is indicative of pond productivity,
- The tributary from Burchell's Pond provided a constant source of organic nitrogen to Miacomet Pond during the 2009 sampling period, and
- The average concentration of total nitrogen at all stations sampled in Miacomet Pond during 2009 suggests a moderately productive ecosystem when evaluating the overall water quality of the pond and comparing results to other bodies of water.

The concentrations of nitrate and ammonia in the water column of Miacomet Pond were moderate-to-low during the 2009 period of study. Nitrate-nitrogen concentrations at Stations #1, #2, #3 and #4 averaged 0.038, 0.033, 0.030, 0.079 and 1.354 mg N/L, respectively, for the 7 sampling dates in 2009. Stations #1, #2 and #3 along the main body of the Pond were very similar in nitrate concentrations throughout the season (Figure 13) and exhibited a gradual increase from beginning to end. Stations #6 in the lower Narrows had higher nitrate values during the first few sampling dates but then demonstrated a pattern similar to the main Pond stations for the remainder of the season. Station #5 at the extreme northeast end of the Pond had nitrate values in excess of ≈1.0 mg N/L during the entire period (Figure 13). These data provide strong evidence for the contributory nature of the watershed to nitrate loading and the fact that this extension of the pond basically is a channel where the groundwater emerges and becomes surface water.

A mean concentration of 0.30 mg N/L for unpolluted waters was reported by Reid and Wood (1976). Stewart and Markello (1974) reported mean annual concentrations which ranged from 0.25 – 1.25 mg N/L for 6 western New York lakes with varying size and morphometry. Nitrate levels measured during 2009 within the main body of Miacomet Pond were an order of magnitude below these literature values and were similar to levels measured during 2005 (Conant, 2006). Miacomet levels of nitrate during 2009 were an order of magnitude less than nitrate concentrations measured in Hummock and Head of Hummock Pond during the same period (Sutherland and Oktay, 2010).

Ammonia-nitrogen values were below 0.20 mg N/L at all stations during 2009 (Figure 14) and concentrations at individual station fluctuated considerably with sampling date. Stations #1, #2 and #3 exhibited similar concentrations throughout the entire season, while Station #6 and #5 generally had higher concentrations than the other stations on any given sampling date. The average concentrations of ammonia at stations #1, #2, #3, #6 and #5 during 2009 were 0.032, 0.051, 0.023, 0.095, and 0.062 mg N/L, respectively. These data are difficult to interpret since the distribution of ammonia in lake water can be highly variable regionally, seasonally and spatially within the same system in relation to the level of productivity and the extent of pollution from organic matter entering the system.

A condition of low, or non-detectable, concentrations of nitrate and ammonia during the growing season and higher values before and after this part of the year is a seasonal pattern characteristic for moderately productive waters (Hutchinson, 1967; Wetzel, 1975). The fact that both of these analytes were reported at low-to-moderate values in Miacomet Pond during 2009 provides some important insight into phytoplankton community dynamics of the system (see later section).

The seasonal pattern of total nitrogen (TN) concentration in Miacomet Pond is shown in Figure 15. There was a mid-summer peak in TN concentration during late July (Station #5) and mid-August (all other stations), followed by a general decline during the remainder of the season (Figure 15). Station #5 at the northeast end of Miacomet Pond near Otokomi Road had considerably higher concentrations of TN than any of the other stations during the entire season. The average TN values at Station #1, #2, #3, #6 and #5 were 0.61, 0.61, 0.64, 0.77, and 1.97 mg N/L, respectively, during 2009, which can be interpreted as a longitudinal gradient from south to north (Figure 16).

Conant (2006) reported somewhat higher TN values from Miacomet Pond stations during the period from May through October during 2005 which could be due to different climatic conditions between the two years. Site #3 from the 2005 study was located at the 'head' of Miacomet Pond and is comparable in location to Station #5 in the current study. Site #3 in 2005 had a single TN measurement of 0.280 mg N/L during mid August while Station #5 during the same period in 2009 exhibited an average TN value of 1.895 mg N/L. The high TN values at Station #5 are the result of consistently high nitrate values during the 2009 sampling period.

A simple method for calculating organic nitrogen in the water column is to subtract nitrate + ammonia concentrations from the TN concentration. The result of this exercise is presented in Figure 17. The average concentration of organic nitrogen at the 5 stations ranged from 0.541 – 0.590 mg N/L during the entire sampling season. Although some, probably small, portion of the organic nitrogen is in soluble (dissolved) form, the organic nitrogen concentrations are moderate and correspond to moderate concentrations and biomass of phytoplankton in the water column throughout the sampling period.

The tributary from Burchell's Pond (Station #4) had concentrations and seasonal patterns of nitrate, ammonia, total nitrogen and organic nitrogen very similar to the stations in Miacomet Pond (Figure 18). Nitrate and ammonia were low during the entire season and almost all of the total nitrogen (TN) was comprised of organic N (Figure 18).

Phosphorus. This nutrient plays a major role in biological metabolism and often limits the amount of productivity in lakes and ponds since it is the least abundant of 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 in lake water is bound organically with living material or associated with decaying material (Wetzel, 1975).

Most important in the metabolism of lakes is the **total phosphorus** (**TP**) content of unfiltered lake water which consists of **particulate phosphorus** (phosphorus in suspension in particulate matter) and the **dissolved**, or **soluble**, **phosphorus** fraction.

Particulate phosphorus can include three forms (1) phosphorus in living organisms (e.g. phytoplankton and zooplankton), (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 seems to vary in lakes and ponds, probably as a function of allochthonous material containing phosphorus, which enters the lakes at different season of the year.

A typical lake would receive significant inputs of phosphorus during periods of high runoff, such as spring snowmelt. In fact, in many temperate lakes and ponds of the northeastern US, the period of spring runoff represents about 60-70 percent of the average annual runoff that enters systems from the surrounding watershed (Sutherland et al., 1983). Systems such as Miacomet Pond have different hydrologic cycles and do not receive large inputs of TP via stormwater runoff due to the relatively flat topography of the surrounding watershed, the low relative proportion of impervious structures in the watershed, and the sandy, permeable nature of the soil.

The introduction of TP to Miacomet Pond is primarily through groundwater flow whose rate exhibits increases or decreases based upon precipitation cycles. The concentration of TP in the groundwater would be a function of land use in the watershed, soil adsorption of TP, and the effectiveness of individual wastewater treatment systems which contribute groundwater discharge to the pond.

The TP dynamics of the water column in Miacomet Pond were as expected for a north temperate body of water. Some features observed during 2009 include the following:

- Concentrations of TP in the main body of Miacomet Pond were moderate from late June through early October 2009 and concentrations of TP at the lower Narrows station (#6) were considerably higher than other stations on each sampling date,
- Miacomet Pond exhibited a longitudinal gradient of increasing TP concentration throughout the 2009 sampling period with the lowest concentrations occurring at Station #1 and the highest concentrations occurring at the lower Narrows station (#6),
- There was no depletion of TP concentration at any of the sampling stations during the period of the study indicating that a continual source of TP was available in the water column either in the form of autochthonous or allochthonous material,
- The seasonal pattern of TP concentration in Miacomet Pond was similar at all stations and a peak in TP concentration occurred on 11 August which also is reflected in the chlorophyll a concentration and phytoplankton density on that date.

The concentrations of total phosphorus (TP) in the water column of Miacomet Pond were moderate during the period of study in 2009 and exhibited a longitudinal gradient with increasing concentration from south to north. The TP concentrations at Stations #1, #2, #3, #6 and #5 averaged 32.11, 28.65, 46.82, 93.55 and 25.06 µg P/L, respectively, for the 7 sampling dates. As shown in Figure 19, there was a definite concentration gradient along the longitudinal axis of the pond with Station #6 in the lower Narrows having the highest average for the sampling period.

As shown in Figure 20, the TP concentrations measured at Stations #1, #2 and #5 generally were between 20 – 50 µg P/L on all sampling dates and exhibited the same seasonal pattern. Station #3 near the outflow of the Burchell's Pond tributary was considerably higher in TP concentration on 4 of the 7 sampling dates (Figure 20). Station #5 (lower Narrows) consistently had the highest TP concentrations on each date and exhibited the same seasonal pattern as the other stations. There was a definite peak in water column TP at each station during the 11 August sampling date and this peak corresponds to a peak in chlorophyll a and phytoplankton cell density.

3.1.4 Biota

Phytoplankton. The planktonic algae reflect water quality and other conditions in lakes and ponds through parameters such as diversity, composition, dominance and biomass (biomass). As discussed at length by Hutchinson (1957), certain algal associations occur repeatedly among lakes with different levels of nutrient enrichment and these associations are used to characterize the trophic status of water bodies. In spite of certain limitations, these characterizations are useful because they demonstrate the connection, or interface, between available nutrient supply and the qualitative and quantitative abundance of algal species.

An accurate evaluation of the phytoplankton community in Miacomet Pond was not possible due to the short-term nature of the present study. The parameters that were measured and the species associations that were observed during this period are not necessarily the same ones that would characterize the community over a longer period of time (i.e., several years). Therefore, there are certain limitations attached to predicting trophic status of the pond based upon the phytoplankton community sampled in the present study.

In spite of these limitations, the phytoplankton community observed in Miacomet Pond did exhibit important features, some that characterize the general water quality of the pond during the period of study. These features were as follows

- *Cell density* - the phytoplankton community of Miacomet Pond was comprised of several major groups during the study period; dominance generally was concentrated between 3 - 4 taxa on any particular sampling date,
- *Biomass* – the phytoplankton community of Miacomet Pond was dominated by several algal groups including Chlorophytes, Cyanophytes and Pyrrhophytes, which exhibited a seasonal succession during 2009,
- Cell densities in Miacomet Pond were moderate during almost the entire season and declined dramatically on the last sampling date,
- Miacomet Pond exhibited moderate-to-low levels of chlorophyll *a* and there was a distinct seasonal pattern exhibited in 2009,
- Miacomet Pond contained several species of Cyanophytes known to produce cyanotoxins which can be neurotoxins, hepatotoxins, cytotoxins and endotoxins, and can be toxic and dangerous to humans and animals.
- The characteristics of the phytoplankton community, individually and collectively, indicate a level of water quality in Miacomet Pond that can be classified as moderately productive and indicative of degraded water quality.

There were 54 taxa identified in phytoplankton samples collected from Miacomet Pond during 2009 and, as shown in Table 5, almost all of the major algal groups were represented. The total taxa started at 18 on 30 June and gradually increased on each successive date, reaching 34 taxa on 27 August (Figure 21); thereafter, the total taxa declined to 16 on the last sampling date, 06 October. Richness (# of taxa) on any particular sampling date generally was about one-half of the total pool of phytoplankton taxa identified from the 2009 samples.

A ranking of phytoplankton occurrence in Miacomet Pond on the 7 sampling dates showed that many taxa occurred only once, or a few times at most, and that relatively few taxa occurred in more than one-half of the samples collected (Figure 22). Eighteen (18) of the 47 taxa occurred only on a single sampling date, and 30 taxa (≈56 percent of the total) occurred in less than one-half of the samples collected. Only 6 taxa occurred on all 8 sampling dates.

Table 6 lists the taxa that occurred most frequently in the Miacomet Pond samples and some characteristics for each taxon including cell biomass, seasonality, and number of times the taxon was dominant in the community. Biomass is used to evaluate taxon biomass, or productivity, since density does not account for the significant size difference among phytoplankton taxa. A taxon was considered dominant if it contributed > 5 percent of the community total biomass.

A total of 25 taxa occurred on four or more sampling dates during 2009. Although Cyanophytes (Blue-green algae) dominated the phytoplankton community, six other taxa were biomass dominants and four other taxa were density dominants. The misleading nature of density as a community descriptor becomes evident when one views the cell biomass in Table 6 and sees the difference between the size of, for example, *Pediastrum duplex* cells and other phytoplankton taxa listed in the table. Huge differences in biomass explain how small numbers of cells can place a taxon as a biomass dominant in the community.

If only cell density is considered, then the Miacomet Pond phytoplankton community would exhibit some minor seasonality during 2009; however, Cyanophytes would constitute > 60 percent of the total community for the entire season (Figure 23). Chlorophytes, Chrysophytes and Pyrrhophytes always were present in the community, but at greatly reduced numbers when compared with the Cyanophytes. When biomass is considered, however, there was a distinct seasonality in the occurrence of phytoplankton groups in Miacomet Pond (Figure 24). Chlorophytes, Pyrrhophytes and Cyanophytes share roles of dominance as the 2009 season progresses.

Phytoplankton taxon diversity was measured with the Shannon-Wiener function[1] which calculates diversity, [H], using number of taxa and the allotment of individuals among the taxa. An increase in either factor will increase the diversity value. Biomass was used in the calculation instead of numbers of individuals since size can vary so significantly among individual taxa and biomass provides a better estimate of taxon rank or importance.

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[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 in the number of species.

Diversity was high in Miacomet Pond during the period of study indicating that biomass in the community was allocated among several taxa instead of only one, or a few, taxa. Diversity in a hypothetical community can range between values of **0** (minimum diversity) and **1** (maximum diversity). Diversity in Miacomet Pond averaged 0.7551 (±0.2444) and ranged between 0.2427 (on 06 October) and 1.000 (on 27 August). Figure 25 presents **[H]**, diversity, and **[H_{max}]**, which is the diversity when maximum equitability or allotment occurs, within the water column of Miacomet Pond. Equitability, **[E]**, is the ratio , **H/H_{max}**, and locates the community somewhere along a scale from **0** (least equitable) to **1** (most equitable). **[E]** ranged between 0.09 - 0.29 during the study, and was lowest on the last sampling date (06 October) when one species comprised 90 percent of the community biomass.

Usually 4 – 6 algal taxa were community dominants on a sampling date (Table 7), except on 06 October, when only one taxa was dominant. The most frequent dominant taxa in Miacomet Pond during 2009 were *Ceratium hirudinella* (4 dates), *Aphanizomenon flos-aquae* (4 dates), *Anabaena spiroides* (4 dates), *Anabaena flos-aquae* (3 dates), and *Cryptomonas ovata* (3 dates).

Phytoplankton community statistics were very different in Hummock Pond during 2009 since Cyanophytes were the dominant group during the entire sampling period and only 1 – 2 taxa were important in the community on any particular sampling date.

Chlorophyll *a* is the primary photosynthetic pigment of oxygen-evolving photosynthetic organisms, and is present in all algae. Chlorophyll *a* samples collected at Station #1 on all 7 sampling dates averaged 20.29 µg/L and ranged from 5.83 µg/L - 42.77 µg/L. The average mid-summer concentration for the 5 dates when pond temperature was > 18°C was 25.74 µg/L. Chlorophyll *a* concentrations were high in late June, peaked at 42.77 µg/L during mid August and then steadily declined through the remainder of the season (Figure 26). Trends in chlorophyll *a* concentration followed the same seasonal pattern as phytoplankton biomass in Miacomet Pond (Figure 26) while cell density started at ≈20,000 cells/mL in late June and steadily declined during the remainder of the season.

Community standing crop, estimated from chlorophyll *a* concentration is one of the primary factors used to predict lake trophic status. In the case of Miacomet Pond, regardless of whether one uses the mid-summer average concentration (25.74 µg/L) or the average for the entire season (20.29 µg/L), the values are well above the range of 10-15 µg chlorophyll *a*/L which is the border between mesotrophic and eutrophic conditions (Vollenweider and Kerekes, 1980).

Algal associations documented during the study provide information about the general trophy of the pond. Diatoms characteristically are dominant in alkaline waters with nutrient enrichment (Hutchinson, 1967; Wetzel, 1975). Although diatoms were part of the algal community of Miacomet Pond, they never were dominant components of the community on any sampling date. Year-round sampling would be required to determine whether diatoms ever are dominant in the pond during fall, winter or early spring. The appearance of green and BG algae in Miacomet Pond during the growing season is a sequence of associations that provides evidence that the algal community reflects conditions of moderate productivity and poor water quality.

Aquatic Vegetation. The littoral, or shallow-water, zone of most water bodies usually is occupied by attached aquatic vegetation. The extent of the littoral zone is determined by geomorphology of the basin. In lakes and ponds that are shallow and small, the littoral zone can be extensive and the littoral flora can contribute significantly to overall ecosystem productivity (Wetzel, 1975). Besides contributing to productivity through photosynthesis and biomass production, aquatic vegetation can provide an enormous surface area for colonization by microflora (other producers in the community). In addition, decaying vegetation releases phosphorus that is utilized for more productivity. The littoral zone can be the most important contributor to epilimnetic phosphorus turnover in lakes and ponds with a well-developed shallow region.

Miacomet Pond, being relatively shallow and small, has a littoral zone with attached aquatic vegetation that covers essentially the entire bottom of the pond. During the July vegetation survey, there was no lower depth limit observed for attached plants in the pond. A map of Miacomet Pond (Figure 27) showing the distribution and abundance of aquatic vegetation recorded on 27 July illustrates the extensive area of the littoral zone.

A total of twelve (12) plant species were collected from Miacomet Pond. A list of genus and species (when identified) is presented in Table 8. *Ceratophyllum* spp., although classified as an aquatic plant, has no true root structure and is distributed throughout the water column by wind, wave and current action. *Lemna* spp. is classified as a macrophyte but floats on the surface of the water. There were no nuisance aquatic species observed in Miacomet Pond during the vegetation survey.

As shown in Table 8, *Ceratophyllum demersum* was the most frequently recorded plant species, occurring at all 51 sites surveyed (frequency = 100%). The next most frequently recorded species was *Najas* spp., which occurred at 48 sites. Maps of the distribution and abundance of individual plant species in Miacomet Pond are presented in Appendix 4.

Aquatic plant abundance at the 51 surveyed sites in Miacomet Pond is summarized below. Moderate and dense growth occurred at 35 (≈70%) of the 51 sites sampled; most (25) of these sites occurred within the lower third of the pond (sites 01 – 31 on Figure 27).

From about mid-summer into the fall, many of the plants growing in the water column had reached the surface and were flowering extensively, indicating that there is considerable potential for the plant community in Miacomet Pond to spread and become more evenly distributed. Even at current levels of plant growth in the pond, recreational use generally is impaired due to entanglement of oars, paddles, and outboard motors from the extensive growth on the pond surface.

	Sites	
Aquatic Plant Abundance	**#**	**%**
Empty	0	0
Trace	2	4
Sparse	14	27
Moderate	22	43
Dense	13	26
Total	51	100

Although experiments were not conducted as part of the 2009 study, indirect evidence suggests that the extensive littoral aquatic plant community in Miacomet Pond is a very significant contributor to productivity and phosphorus turnover. Percent saturation values for dissolved oxygen in the water column were high during the 2009 growing season and phosphorus concentrations were consistently at moderate levels during the same period. Both of these conditions can result from extensive primary production and rapid turnover of nutrients within the water column (Wetzel, 1975), and suggest that the aquatic plant community in Miacomet Pond is important in this regard. As described previously, the phytoplankton community in Miacomet Pond also plays an important role in production and turnover.

3.1.5 Trophic Status

The trophic state of lakes and ponds has been a phenomenon of interest for many decades. The word 'trophic' means nutrition or growth. A **eutrophic** water body is well-nourished and has high nutrients and considerable plant growth. Water bodies with low nutrients and plant growth are **oligotrophic**. **Mesotrophic** waters fall between the eutrophic and oligotrophic categories. Lakes and ponds with extreme conditions are considered either **hyper-oligotrophic** or **hyper-eutrophic**.

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, three independent variables can be used to calculate the Carlson index including chlorophyll pigments, total phosphorus and Secchi depth. Individual TSI values can be calculated from the following equations:

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

Of these three variables, chlorophyll probably will yield the most accurate index since it is the most accurate predictor of biomass in the ecosystem. Phosphorus may be 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. Secchi depth probably is the least accurate measure but also is the most affordable and easiest measure to obtain since it is a subjective visual determination.

Following are the relationships between Trophic Index (TI), chlorophyll (in µg/L), phosphorus (in µg/L), Secchi depth (in meters), and Trophic Class (after Carlson, 1996):

TI	Chlorophyll	Phosphorus	Secchi Depth	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

Since there was sufficient water quality information collected from Miacomet Pond during 2009, all three variables were used to calculate the Carlson TSI. However, instead of using all of the data collected during the 4-month period of study, it was decided to utilize only the mid-summer values when the water column temperature in Miacomet Pond was at 18°C or greater. This temperature restriction lowered the number of sampling dates to five including 30 June, 14 July, 28 July, 11 August and 27 August.

Average values were calculated for each variable for the pond for the five summer sampling dates. The average values then were substituted into the TSI equations to calculate values for the three variables. The stepwise calculation and results of the analysis are presented below.

Although there were 3 sampling stations along the main body of Miacomet Pond during 2009, only the data from Station #1 were analyzed for TSI since chlorophyll _a_ only was collected at this site. The results of the Carlson TSI calculations for Miacomet Pond are as follows:

Chlorophyll _a_
Average summer chlorophyll _a_ = 25.74 µg/L
Chlorophyll a TSI = 9.81*[ln (25.74)] + 30.6
TSI = (9.81)(3.2) + 30.6
TSI = 62.0

Total phosphorus
Average summer total phosphorus = 35.27 µg/L
Total phosphorus TSI = 14.42*[ln (35.27)] + 4.15
TSI = (14.42)(3.6) + 4.15
TSI = 56.1

Secchi depth
Average summer Secchi depth = 1.80 m
Secchi TSI = 60 – [14.41*[ln (1.80)]
TSI = 60 – (14.41)(0.6)
TSI = 51.4

Analysis of all three variables results in the same TSI placement for Miacomet Pond. Two TSI variables, chlorophyll _a_ and phosphorus, are unequivocal in locating Miacomet Pond within the eutrophic category. Secchi depth being a subjective reading is not as robust as a calculator and provides a eutrophic classification but only just over the boundary between oligotrophic and eutrophic.

Some states, e.g., Florida, classify lakes and ponds based upon the average concentrations of TN measured. When considering the average TN concentrations measured at Stations #1-4 during 2009, Miacomet Pond would fall in the 'eutrophic' category used to classify Florida LAKEWATCH (2000) systems; systems with TN values between 0.60 and 1.50 mg N/L are classified as 'eutrophic'.

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Section 4

Project Summary, Discussion, Conclusions and Recommendations

4.0 Project Summary

The 2009 water quality study of Miacomet Pond began at the end of June, ended early in October, and sampled the pond seven times at approximately bi-weekly intervals. Samples were collected for physical, chemical and biological parameters including temperature, dissolved oxygen, nutrient chemistry, chlorophyll *a*, the phytoplankton community, and there was a special study of attached aquatic plants in July.

In spite of the brief period of sampling, the 2009 data provide substantial evidence to support the 'eutrophic' status implied or stated in earlier reports (ACT, 1997; Conant, 2006). In fact, a thorough examination of the 2009 chemical and biological results provides sufficient evidence that Miacomet Pond is well-established as a eutrophic system.

The total phosphorus (TP) and total nitrogen (TN) levels measured in Miacomet Pond during 2009 were similar to the 2005 levels reported by Conant (2006), suggesting that perhaps water quality conditions in the pond have remained the same or have not gotten any worse during the past four years. The 2009 study also demonstrated a distinct south-to-north gradient of plant nutrients within the pond. The highest average concentrations occurred either at Station #6 in the lower Narrows (highest TP values) or at Station #5 in the upper Narrows (highest TN values); the concentration gradient was most pronounced for TP.

Biological samples collected from Miacomet Pond during 2009 revealed moderate-to-high levels of phytoplankton standing crop and provided further evidence to characterize the pond's eutrophic status. However, 'bloom' conditions never were observed on Miacomet Pond such as the conditions measured on Head of Hummock and Hummock Pond during 2009.

A diverse phytoplankton community was reported from Miacomet Pond during 2009 and the seasonal succession of major groups within the community provided important information about the general trophy of the system. In the absence of any recent phytoplankton data from the pond to compare with the 2009 data, however, it is impossible to know the extent to which 2009 conditions are 'typical' of the pond's seasonal pattern. The minor role of diatoms in the community seasonal succession may be problematic and indicate that other groups out-compete the forms which are adapted to cold-water environments. It is not possible to understand this situation without a complete annual cycle of phytoplankton data.

The minor association of diatoms in the spring, followed by the appearance of greens and Blue-greens during the warmest periods of the year described a cycle that is most characteristic of a eutrophic condition. Furthermore, given the number of cyanobacteria species identified from the pond samples, the potential does exist for the development of noxious algal blooms during the warm summers months given appropriate growing conditions. It is unfortunate that no recent phytoplankton record exists for Miacomet Pond so that some sort of comparison can be made.

As summarized below, seven cyanobacteria species were identified in Miacomet Pond during 2009. Three of the seven species of cyanobacteria are known to produce neurotoxins which are harmful to humans, pets, farm animals, and wildlife.

Miacomet Pond - 2009	
*Anabaena flos-aquae**	*Coelosphaerium naegelianum*
Anabaena spiroides	*Merismopedia punctata*
*Aphanizomenon flos-aquae**	*Microcystis aeruginosa**
Chrococcus limneticus	
* capable of toxin formation; from DiTomaso, 1994.	

The moderate level of primary productivity demonstrated by the 2009 phytoplankton community in Miacomet Pond also characterized the 2009 aquatic plant community of the pond. During the plant survey, dense and moderate growth of native plants was recorded at 35 of 51 total sites (≈70%) within the main body of the Pond. From about mid-summer 2009 and well into the fall, many of the plants growing in the water column had reached the surface and were flowering extensively, indicating that there is considerable potential for the plant community in Miacomet Pond to spread and become more evenly distributed. The extensive amounts of plant material floating on the Pond surface make it very difficult to pass through these areas with water craft. Even at current levels of plant growth in Miacomet Pond, recreational use generally is impaired due to entanglement of oars, paddles, and outboard motors from the extensive plant material on the pond surface.

4.1 Discussion

Miacomet Pond is one of eleven major ponds located on the Island of Nantucket, Massachusetts, and currently can be classified as a freshwater system. The pond has certain estuarine characteristics, however, as a result of historical breaching of the barrier beach with the Atlantic Ocean. The proximity of the pond to the ocean also exerts an influence during various storm events through breaching of the barrier or salt water intrusion from high water and winds.

Although historical data for Miacomet Pond is not extensive, earlier water quality reports were produced including the Draft Water Quality Management Plan for Nantucket prepared by MA DEQE (1979) and the Nantucket Water Resources Management Plan prepared by Horsley Witten Hegemann, Inc. (1990). Beginning in 1993, the pond was monitored by the Nantucket Marine and Coastal Resources Department. Based upon the collective results from the earlier studies, the pond can be classified as eutrophic.

The first comprehensive diagnostic water quality and plant assessment of Miacomet Pond was conducted by ACT in 1997. The results from this study confirmed the eutrophic status of the pond with respect to nutrient concentrations, algal species succession and nuisance growth levels of aquatic plants. The 1997 average TP concentrations (≈30 – 80 µg P/L) were within the range reported for 2009 except for Station #6, where the 2009 average concentrations were 2 times the 1997 average concentrations. Although, the 1997 study did not specifically measure TN, values can be estimated by combining the reported nitrate and total Kjeldahl values. Based upon these calculations, the average TN values (≈1.50 – 1.80 mg N/L) in 1997 were 2 – 3 times the average concentrations measured in 2009.

Study	Date	Average TP (µg P/L)	Average TN (mg N/L)
ACT	1997	≈30 - 80	≈1.50 – 1.80
Conant	2005	≈25 - 40	≈0.85
Current	2009	≈50	≈0.93

Eight years after the ACT study, Conant (2006) reported 2005 average TP concentrations (≈25 – 40 mg P/L) similar to the 1997 values and the 2009 average values reported here. The 2005 average TN concentrations (≈0.850 mg N/L) were below the 1997 average values but slightly higher than the 2009 average values, except for Station #5 which averaged ≈2.0 mg N/L during 2009.

Collectively, these data might suggest that TP concentrations have remained about the same within Miacomet Pond during the 12-year period since 1997, while TN concentrations have been reduced to about one-half of the 1997 levels. Nutrient source reduction in the watershed is a possible explanation for the 12-year trend described here. However, it is just as likely that we are viewing three discrete seasonal patterns along a 12-year period where seasonal differences are determined by annual climate cycles and factors, and two of the patterns (2005, 2009) are similar, while the other pattern (1997) is different.

Regardless of previous water quality data collected from Miacomet Pond, the 2009 results found elevated levels of TP and TN occurring at specific locations in the pond which suggests contributory areas of groundwater inflow. The areas with elevated nutrients were located in the lower Narrows (Station #6) for TP and the upper Narrows (Station #5) for nitrate and TN.

Howes et al. (2006) attribute the nutrient enrichment problem affecting coastal embayments throughout the Commonwealth of MA and along the eastern seaboard to increasing population, development and changing land use in these areas. In many areas, these embayments have nutrient levels that are approaching or have exceeded assimilative capacity, which causes decline in ecological health. The primary nutrient causing the increased impairment is nitrogen from wastewater disposal, fertilizers and changes in groundwater hydrology associated with development. The Sesachacha Pond Embayment on Nantucket Island has been described as a coastal system suffering from nitrogen enrichment, compounded by inadequate tidal exchanges when the system is breached for management purposes (Howes et al. 2006).

Based upon historical and current water quality data, the setting of the geologic watershed, and land use and local hydrology, it appears that Miacomet Pond is experiencing the same high nutrient (nitrogen) dilemma as Sesachacha Pond and other coastal embayments. However, there are less background information and supporting data available for Miacomet Pond than the corresponding information presented by Howes et al. (2006) for Sesachacha Pond.

The surface watershed of Miacomet Pond is ≈970 acres while the size of the groundwater drainage area is unknown, but probably within ±10 percent of the surface drainage area. When considering the size of the Pond (≈50 acres), the drainage value translates to a watershed to pond ratio of ≈20:1, which is a very large contributory drainage into a relatively small volume of water.

The watershed of Miacomet Pond lies within the Town of Nantucket. Given the sandy, well-drained soils, low overall slope of local topography and the fact that relatively little development exists along the immediate pond shore-line, groundwater would be the primary mechanism for the movement of water and nutrients into the system. Water input from surface runoff appears to be minimal since the watershed soils are well-drained and the number of tributaries is minimal. There is one small tributary originating from the outflow of Burchell's Pond and several areas along Miacomet Road where runoff during storms can enter the pond.

Although a sizeable portion of the Miacomet Pond watershed is sewered, a significant portion of the watershed adjacent to the pond is not within the sewer district and is served by individual septic systems. This area includes the Miacomet Golf Course on the west side of the pond and considerable development east of the pond. Collectively, these watershed areas could contribute a substantial groundwater load of nitrogen to the pond.

The working efficiency of individual septic systems in the Miacomet watershed is unknown. Many systems are utilized for brief periods during the summer and then remain dormant; system failures seem likely when inundated with high volumes of waste for brief periods of time. Even properly located and Title 5 validated septic systems that are functioning "as advertised" could contribute excess levels of nitrogen, in the form of nitrate, to the surrounding groundwater in sandy soils.

Evesboro sand is the major soil type in the Miacomet Pond watershed that determines permeability and eroding capability. This nearly level (EvA) or gently sloping (EvB), excessively drained soil has rapid permeability in the surface layer and subsoil and very rapid permeability in the substratum (Langlois, 1979). The soil has essentially no limitations as a site for buildings or for local roads and streets and few limitations for septic tank absorption fields, but seepage of the effluent through the substratum causes a hazard of groundwater contamination.

The 2009 water quality results presented here suggest two possible situations with regard to TP concentrations and the TP gradient in Miacomet Pond. That is, either (1) a significant amount of phosphorus is remobilized within the pond (autochthonous source) during the summer months, particularly in the lower Narrows area, or (2) this zone is a location of major groundwater inflow and TP input. More investigation is required to determine which source of TP is predominant.

The specific situation involving TN loading, in the form of nitrate-nitrogen, to the pond is more clear. High levels of nitrate are entering the pond at the extreme northeast end of the upper Narrows area below Otokomi Road. Groundwater containing high nitrate levels emerges at this site and becomes surface water, thereby providing a constant source of loading to the pond.

Cyanobacteria are ubiquitous, being found in almost every habitat, and the presence of small numbers of these organisms in the phytoplankton assemblage of aquatic ecosystems is part of a natural process or sequence of events. When present in large numbers such as with 'bloom' conditions, however, cyanobacteria can induce physical, chemical and, eventually, biological changes in the aquatic environment in which they occur and eventually impart negative changes to the ecosystem which may require some direct remedial action to reverse or overcome. This appears to be the situation in HHP and could become problematic in HP in the near future.

Intense concentrations (blooms) of cyanobacteria in the water column will decrease transparency, thereby reducing the depth of the photic zone and the volume of water that supports other phytosynthetic organisms in the community. In addition, high concentrations of cyanobacteria in the water column result in high rates of cell die-off which settles to the bottom and causes oxygen depletion within the system through decomposition of the dead plant material. This de-oxygenation has a direct negative effect on aquatic organisms in the region that depend on oxygen for survival, as well as the indirect effect of toxic gas release and nutrient mobilization into the water column and, in a shallow system, mixing with the upper levels of water. The release of nutrients into the water exacerbates the cycle by encouraging increased primary productivity in an already productive or over-productive system.

By the time a dense mat of algae floats on the surface of a lake or pond, the cells already have disrupted the aquatic ecosystem in which they are located and, under certain conditions, can pose health and safety issues for users of the body of water. In the case of cyanobacteria, cells floating on the surface and forming a blue-green, paint-like surface scum, already have died and lysed, releasing their cell contents into the surrounding environment.

The Cyanobacteria species identified in Miacomet Pond and the moderate-to-high densities that occurred during 2009 are problematic for more reasons that just water quality. Three Cyanobacteria species that were dominants in the water column are known to produce toxic metabolites, cyanotoxins, which can be neurotoxins, hepatotoxins, cytotoxins and endotoxins. Besides being toxic and dangerous to animals, such as cattle, dogs and cats, cyanotoxins should be considered a public safety risk to the extent that contact and consumption by humans be avoided.

In humans, exposure to these contaminants can occur through either direct contact with the water such as with recreational usage, or by breathing in airborne components distributed with the wind. Recent research at the Dartmouth-Hitchcock Medical Center (D-HMC) provides strong evidence for far more serious implications related to the cyanobacteria situation in the Northeast US and, potentially, in the local situation observed in Miacomet Pond. Cyanobacteria produce the toxin, ß-methylamino L-alanine (ßMAA), an amino acid that is demonstrably toxic to motor neurons and has been linked to ALS and neurodegenerative disease in humans. The researchers at D-HMC have identified a higher rate of ALS among New Hampshire residents living in close proximity to lakes and ponds where blooms of neurotoxin-producing cyanobacteria have been previously documented.

4.2 Conclusions

Miacomet Pond is a eutrophic body of water with total phosphorus and chlorophyll *a* values during the 3^+-month period averaging 48.02 µg/L and 20.29 µg/L, respectively. Previous reports had labeled HP ‘eutrophic’ without really applying any analytical criteria to the associated terminology; performing a simple analysis of the 2009 data confirms the eutrophic status of Miacomet Pond.

If we accept the tenet of high phosphorus retention in sandy glacial outwash aquifers presented by Weiskel and Howes (1992), then the moderate total phosphorus values that occur in Miacomet Pond are autochthonous in origin. Presumably, the elevated TP concentrations would be a direct result of high phytoplankton and aquatic plant productivity coupled with the decomposition of abundant plant material within the micro-zone at the sediment-water interface where dissolved oxygen levels are diminished. Alternatively, however, soils in the Miacomet Pond watershed may be characterized by low retention capacity which would mean that groundwater is a major source of phosphorus to the system (allochthonous source). The fact that Station #6 in the lower Narrows consistently had higher TP values suggests that the source of TP is in groundwater from the watershed. Furthermore, there is some recent evidence from groundwater monitoring in the Hummock and Head of Hummock Pond watersheds that suggests a watershed contribution to phosphorus loading problems (Liddle et al., 2009).

Burchell's Pond exhibited some interesting water quality results during 2009. However, flow from the pond into Miacomet is very low and there probably is little to no direct impact of this tributary on Miacomet Pond water quality.

High TN concentrations measured in Miacomet Pond during 2009 coupled with other water quality problems indicate that watershed loading is problematic and that the assimilative capacity of the system probably has been exceeded. There seems to be a continuous source of nitrogen from (1) numerous individual septic systems in the watershed which are of different ages and working efficiencies, and (2) groundwater flow from large areas such as the Miacomet Golf Course which occupies ≈75 acres of land surface and applies fertilizer to a major portion of this area on a regular basis. The importance of the groundwater loading problem is highlighted in the upper Narrows area, adjacent to Otokomi Road. Even though most of the watershed surrounding this part of the pond is in the sewer district, extremely high levels of nitrate-nitrogen continuously flow into the pond, acting as a point source of pollution.

The cyanobacteria identified in Miacomet Pond during 2009 that are known producers of toxins are problematic and pose a definite public health and safety issue for individuals using the pond recreationally and home-owners living along the shoreline adjacent to the pond. The seriousness of this situation is particularly evident in view of the recent scientific information linking cyanobacterial blooms in lakes and ponds with the development of sporadic ALS disease.

The aquatic plants identified in Miacomet Pond are all native forms which, under normal conditions, would comprise a healthy component of the aquatic ecosystem. The circumstances in Miacomet Pond, however, are not normal and the aquatic plant community has become over-productive and a source of internal nutrients to the system. Allowed to continue, the plant community soon will reach 'nuisance' proportions throughout the Pond and greatly accelerate the process of eutrophication toward hyper-eutrophication.

In view of the findings revealed from the 2009 study of Miacomet Pond, the report authors offer the following recommendations to consider for implementation:

4.3 Recommendations

(1) The Town of Nantucket is responsible for environmental stewardship of Miacomet Pond and therefore has an obligation to fund regular monitoring of this body of water so that water quality conditions continue to be documented and up-to-date.

(2) As the governmental entity responsible for Miacomet Pond, the Town of Nantucket should retain a consultant to prepare a detailed Management Plan for this water body. However, a detailed Management Plan should only be prepared after there has been a more thorough assessment of factors affecting the water quality of the pond. In some cases, additional data gathering must occur to overcome deficiencies in the current status of information. These deficiencies are addressed below.

(3) Watershed deficiencies should be addressed prior to the development of a Management Plan and include (1) detailed GIS land use analysis within the watershed, documentation and inventory of individual parcels, the amount of development and types of structures/impervious areas on each parcel, (2) groundwater monitoring at strategic locations along the shore-line including installation of wells, funds for certified chemical analyses, and studies to determine the direction of subsurface flows to define the exact contributory areas and develop a priority system for Title 5 inspections, and (3) evaluation of current soil maps and upgrading of these maps, if warranted.

(4) Pond deficiencies should be addressed prior to the development of the Management Plan and include (1) installation of a continuous water level recorder to assist with preparation of a water budget for the pond, (2) updated bathymetry of the pond, and (4) chemical analysis of bottom sediments.

(5) The shore-line of Miacomet Pond should be delineated along with detailed mapping of the shore-line emergent vegetation. During the 2009 vegetation survey, it was observed that almost all of the shore-line emergent vegetation was *Typha latifolia* (cattails); however, there were two pockets of *Phragmites australis* observed. There should be an immediate effort to remove the Phragmites population from the shore-line and a constant surveillance to monitor any subsequent introduction of this genus.

(6) A pumping and inspection program should be established within the watershed to test the effectiveness of individual wastewater treatment systems. In the absence of high resolution groundwater maps that indicate directional flow within the watershed, the systems closest to the Ponds should be evaluated first.

(7) Beginning in the late spring of 2010, regular (bi-weekly) samples of the phytoplankton community should be collected from Miacomet Pond and submitted to the UNH Center for Freshwater Biology for microcystin (MC) analysis.

(8) Until control of nutrient loading to Miacomet Pond can be achieved, the Town of Nantucket should explore potential funding options to purchase a mechanical harvester to remove aquatic plant biomass from Miacomet Pond. The mobilization and maintenance charges of hiring an off-Island contractor to conduct the work over a period of several years would make this approach too expensive. Owning and operating the harvester would be the most practical approach and the equipment could be used on other Island ponds with vegetation problems. The author of this report has worked with municipalities and lake associations in NYS who have adapted similar practices with great success and have been operational for several decades. Initial costs would include the harvester, conveyor (to off-load vegetation) and dump truck. Local farms or landscape professionals might want to use the harvested material as compost; otherwise, the material could be composted at the local landfill.

(9) A close watch should be maintained over the Miacomet Pond aquatic plant community to provide early detection of the introduction of an invasive species, such as *Myriophyllum spicatum*, Eurasian watermilfoil. It is surprising that no invasive species have been detected in the Pond so far, particularly given the high waterfowl traffic from Cape Cod and other areas along the eastern seaboard where invasive species are a problem.

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Section 5

Tables

Table 1. Parameters monitored during 2009 to assess the short-term water quality of Miacomet Pond. The water column parameters were monitored regularly from late June through early October. The evaluation of aquatic plants in the pond occurred on 27 July.

Water Column
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 (concentration and percent saturation)
total dissolved solids
Biological
phytoplankton community response
Chlorophyll *a*, species composition, diversity, relative abundance, biomass
Littoral Zone
Biological
Evaluation of aquatic vegetation
Species composition, distribution and abundance maps of the pond

Table 2. Rake toss plant abundance categories for lake and pond aquatic plant surveys (after Lord and Johnson 2005).

Abundance Categories	Field Measure	Relative abundance numerical equivalent	Typical Dry Weight (g/m²) Ranges Associated with Plant
"N" = no plant(s)	Nothing	0	0.0
"T" = trace plant(s)	Fingerful	1	~ 0.0001 - 2.000
"S" = sparse plant(s)	Handful	3	~ 2.001 - 140.000
"M" = medium plant(s)	Rakeful	9	~ 140.001 - 230.000
"D" = dense plant(s)	Can't get in boat	27	~ 230.001 - 450.000+

Table 3. Physical, chemical and biological parameters included in the 2009 Miacomet Pond study of water quality, their collection technique and methodology.

PARAMETER	COLLECTION TECHNIQUE	ANALYTICAL METHODOLOGY
Physical Characteristics (Light, Dissolved Oxygen, Secchi, Temperature)	Vertical profiles at 1m intervals (except Secchi) at deep site	Standard secchi protocol; YSI dissolved oxygen-temperature meter; Licor light 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 (Integrated epilimnetic sample archived)	chlorophyll a, species identification and enumeration, biovolume
Biological Characteristics - Macrophytes	Pond map – GPS overlay- Point intercept technique	Species identification, density, diversity and dominance

Table 4. Chemical parameters and analytical methods utilized in the 2009 study of water quality in Miacomet Pond.

Parameter	Analytical Method
pH	Electrometric (US EPA Method 150.1)
Specific Conductance	Wheatstone Bridge type meter (US EPA Method
Dissolved Oxygen	Membrane Electrode (US EPA Method 360.1)
Inorganic Anions (Cl, NO_3, SO_4)	Ion Chromatography (US EPA Method 300.0)
Total Nitrogen	Persulfate Oxidation
Phosphorus (total)	Colorimetric (US EPA Method 365.2)
Ammonium	Flow Injection Analysis (Lachat)
Chlorophyll	Fluorimetric (Turner 1985)

Table 5. A list of major phytoplankton groups and taxa identified in Miacomet Pond during 2009.

Cyanophyta	**Chlorophyta**
Anabaena flos- aquae	*Selenastrum minutum*
A. spiroides	*Spirogyra* spp.
Aphanizomenon flos-aquae	*Staurastrum natator* var. *crassum*
Chrococcus limneticus	*Tetraedron minimum*
Coelosphaerium naegelianum	**Chrysophyta (Bacillariophyceae)**
Merismopedia punctata	*Achnanthes* spp.
Microcystis aeruginosa	*Asterionella formosa*
Chloromonadophyta	*Cocconeis* spp.
Gonyostomum semen	*Cyclotella* spp.
Chlorophyta	*G. olivaceum*
Ankistrodesmus falcatus	*Navicula* spp.
A. braunii	*Nitzschia* spp.
Chlamydomonas spp.	*Stephanodisus* spp.
Closteriopsis longissima	*Synedra acus*
Closterium spp.	*S. fulgens*
Coelastrum cambricum	*S. ulna*
Cosmarium spp.	*Tabellaria fenestrata*
Crucigenia tetrapedia	**Chrysophyta (Chrysophyceae)**
Eudorina elegans	*Dinobyron bavaricum* (cells)
Golenkinia radiata	*Dinobyron divergens* (cells)
Kirchneriella subsolitaria	*Mallomonas* spp.
Micractinium pusillum	*Ochromonas* spp.
Mougeotia spp.	**Euglenophyta**
Oocystis borgei	*Euglena* sp.
Pandorina morum	*Trachelomonas* spp.
Pediastrum duplex	**Pyrrhophyta (Cryptophyceae)**
Quadrigula lacustris	*Cryptomonas ovata*
Scenedesmus arcuatus Lemmerman	**Pyrrhophyta (Dinophyceae)**
S. bijuga	*Ceratium hirundinella*
S. quadricauda	*Peridinium cinctum*
Schroederia setigera	

Table 6. Characteristics of the most commonly occurring phytoplankton taxa by major group in Miacomet Pond during 2009.

Major Group	Cell Biomass	Number of times the taxa			2009
Genus (Taxon)-species	(μm^3)	Occurred	BM dominant	DN Dominant	Seasonality
Cyanophyta					
Anabaena flos-aquae	226.0	4	3	3	Late Jul-mid Sept
A. spiroides	308.0	6	4	4	Late Jun–mid Sept
Aphanizomenon flos-aquae	206.0	6	4	4	Late Jun-mid Sept
Microcystis aeruginosa	10.3	6	1	4	All dates
Chlorophyta					
Ankistrodesmis falcatus	250.0	7	0	0	All dates
A. braunii	250.0	4	0	0	Late Jul-early Oct
Closteriopsis longissima	837.3	5	0	0	Late June-mid Sept
Closterium spp.	4000.0	4	0	0	All dates
Crucigenia tetrapedia	93.3	5	0	1	Late Jun – late Aug
Eudorina elegans	1562.6	4	2	1	Late Jun – late Aug
Kirchneriella subsolitaria	171.7	5	0	0	Late Jun – mid Sept
Pediastrum duplex	8000.0	5	2	0	Late Jun – mid Sept
Scenedesmus arcuatus	100.0	5	0	0	Late Jun – late Aug
S. bijuga	100.0	7	0	0	All dates
S. quadricauda	100.0	7	0	0	All dates
Selenastrum minutum	30.9	6	0	0	All dates
Tetraaedron minimum	30.0	7	0	0	All dates
Bacillariophyta					
Cocconeis spp.	500.0	6	0	0	Mid Jul – early Oct
Cyclotella spp.	268.0	5	0	0	Mid Aug – early Oct
Navicula spp.	350.0	7	0	0	All dates
Chrysophyta					
Dinobryon divergens	171.0	5	0	2	All dates
Dinobryon spores	775.0	7	2	0	All dates
Pyrrhophyta					
Cryptomonas ovata	3890.7	7	4	1	All dates
Ceratium hirudinella	10000.0	4	4	0	Late Jun – mid Aug
Peridinium cinctum	8500.0	4	1	0	Late Jun; late Aug – early Oct
BM = biomass; DN = density; months of occurrence are abbreviated in some cases					

Table 7. The ranking of phytoplankton taxa dominance, using biomass, in Miacomet Pond on each sampling date during 2009.

Sampling Date	BV Rank	Taxon (Major Group)	% of Total Biomass
6/30/09	1	*Spiorogyra* spp. (Chlorophytes)	56
	2	*Ceratium hirudinella* (Pyrrhophytes)	13
	3	*Anabaena spiroides* (Cyanophytes)	8
	4	*Pediastrum duplex* (Chlorophytes)	5
7/14/09	1	*Spirogyra* spp. (Chlorophytes)	36
	2	*Anabaena spiroides* (Cyanophytes)	21
	3	*Ceratium hirudinella* (Pyrrhophytes)	16
	4	*Aphanizomenon flos-aquae* (Cyanophytes)	6
	5	*Pediastrum duplex* (Chlorophytes)	5
7/28/09	1	*Ceratium hirudinella* (Pyrrhophytes)	30
	2	*Anabaena spiroides* (Cyanophytes)	21
	3	*Eudorina elegans* (Chlorophytes)	17
	4	*Anabaena flos-aquae* (Cyanophytes)	11
	5	*Dinobryon* spores (Chrysophyta)	6
	6	*Cryptomonas ovata* (Pyrrhophytes)	5
8/11/09	1	*Anabaena spiroides* (Cyanophytes)	35
	2	*Ceratium hirudinella* (Pyrrhophytes)	23
	3	*Anabaena flos-aquae* (Cyanophytes)	17
	4	*Aphanizomenon flos-aquae* (Cyanophytes)	10
8/27/09	1	*Cryptomonas ovata* (Pyrrhophytes)	23
	2	*Anabaena flos-aquae* (Cyanophytes)	21
	3	*Aphanizomenon flos-aquae* (Cyanophytes)	8
	4	*Staurastrum natator* var. *crassum* (Chlorophytes)	6
9/15/09	1	*Cryptomonas ovata* (Pyrrhophytes)	43
	2	*Aphanizomenon flos-aquae* (Cyanophytes)	16
	3	*Microcystis aeruginosa* (Cyanophytes)	13
		Peridinium cinctum (Pyrrhophytes)	6
		Dinobryon spores (Chrysophyta)	5
10/6/09	1	*Cryptomonas ovata* (Pyrrhophytes)	89

Table 8. A list of aquatic plants identified in Miacomet Pond during a survey conducted on 27 July 2009. The frequency of occurrence of the individual genera are summarized.

Species	**Common Name**	**Percent**
Ceratophyllum demersum	Coontail	100
Najas spp.	Naiad; bushy pondweed	94
Potamogeton pusillus	Thin-leaf pondweed	49
Potamogeton perfoliatus	Clasping-leaf pondweed	29
Nitella sp.	Stonewort	24
Vallisneria americana	wild celery	14
Potamogeton epihydrus	Ribbon-leaf pondweed	6
Eleocharis sp.	Slender spikerush	2
Isoetes macrospora	Quillwort	2
Lemna sp.	Duckweed	2
Ruppia maritima	Widgeon-grass	2
Utricularia sp.	Bladderwort	2

Section 6

Figures

Figure 1. Copy of USGS 7.5 minute quadrangle map, Nantucket, MA, showing the location of Miacomet Pond and the general study area.

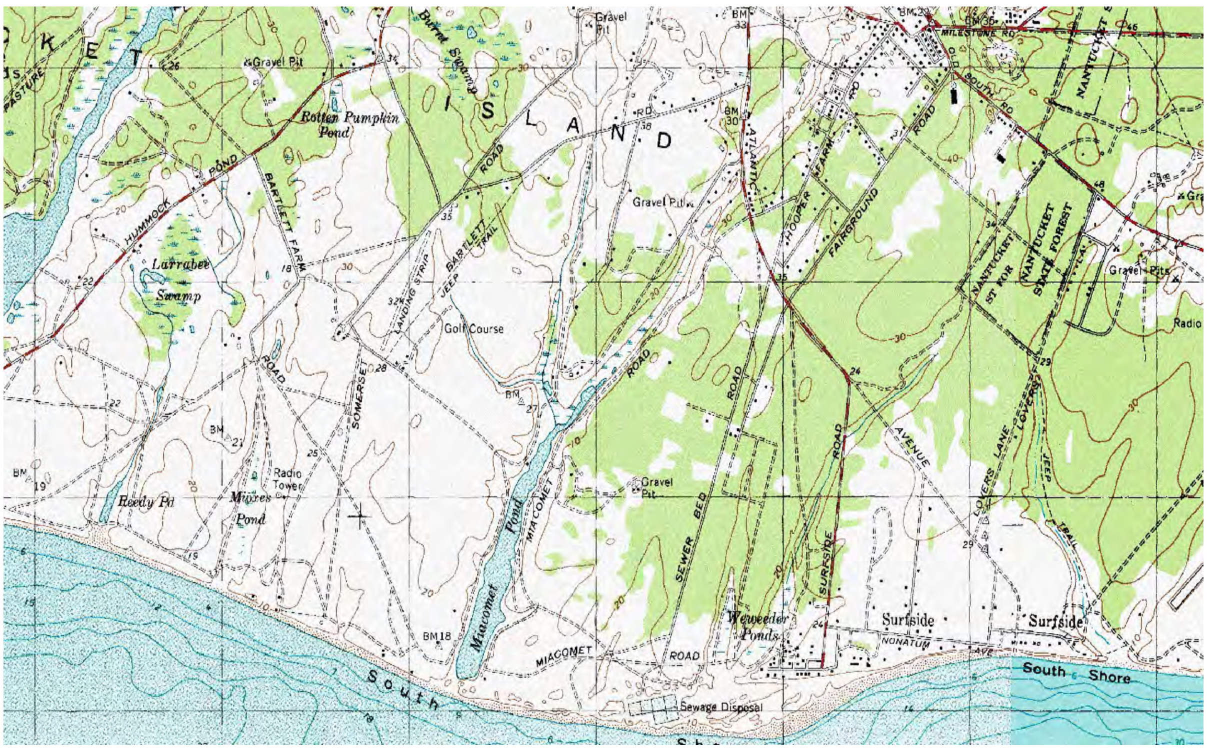


Figure 2. A photo of Miacomet Pond showing the six stations that were sampled for water quality during 2009.

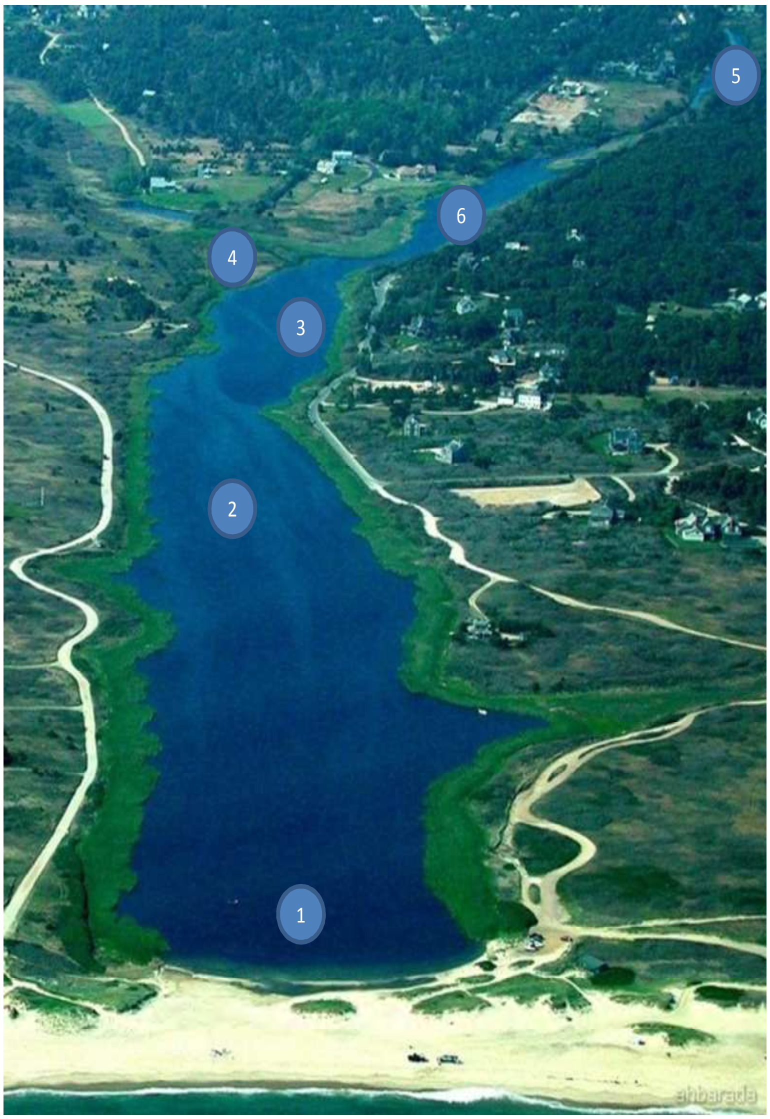


Figure 3. A map of Miacomet Pond showing water depths measured during the aquatic plant survey on 27 July 2009.

Figure 4. The average water column temperature measured at the Miacomet Pond stations during 2009.

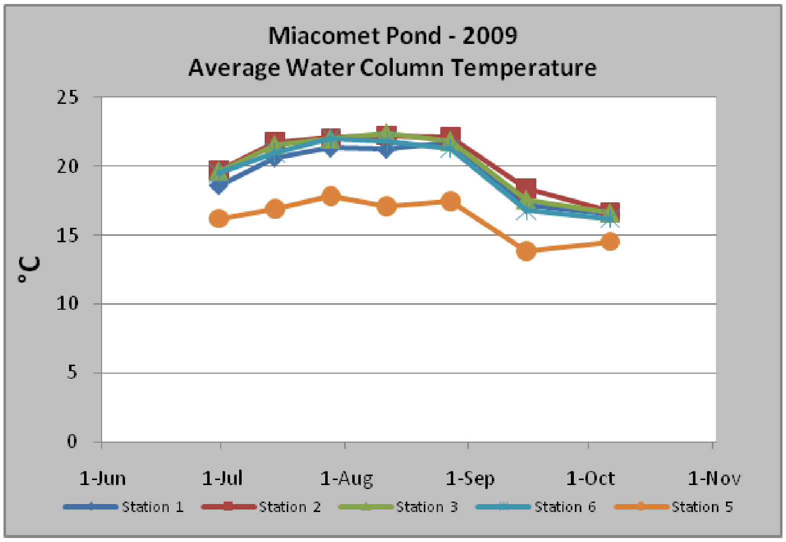


Figure 5. The pattern of water column profile temperature measured in the tributary that flows from Burchell's Pond into Miacomet Pond during 2009.

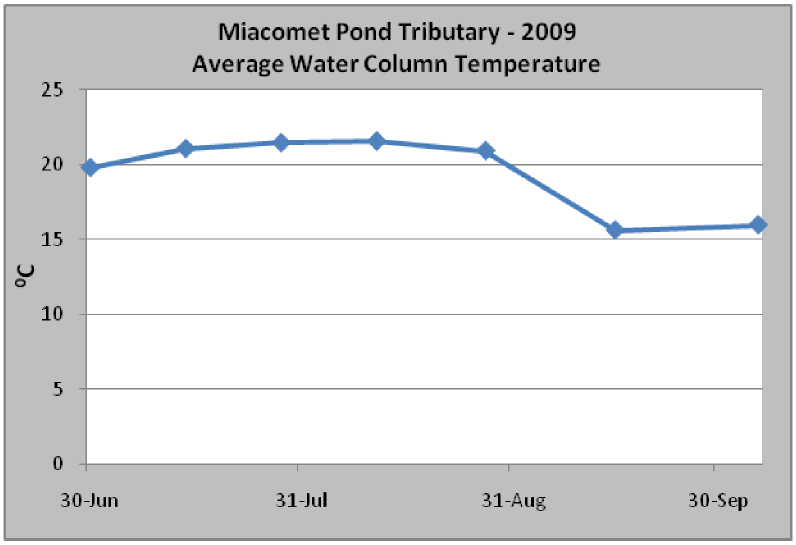


Figure 6. The pattern of Secchi depth transparency measured at Stations #1 and #2 in Miacomet Pond during 2009.

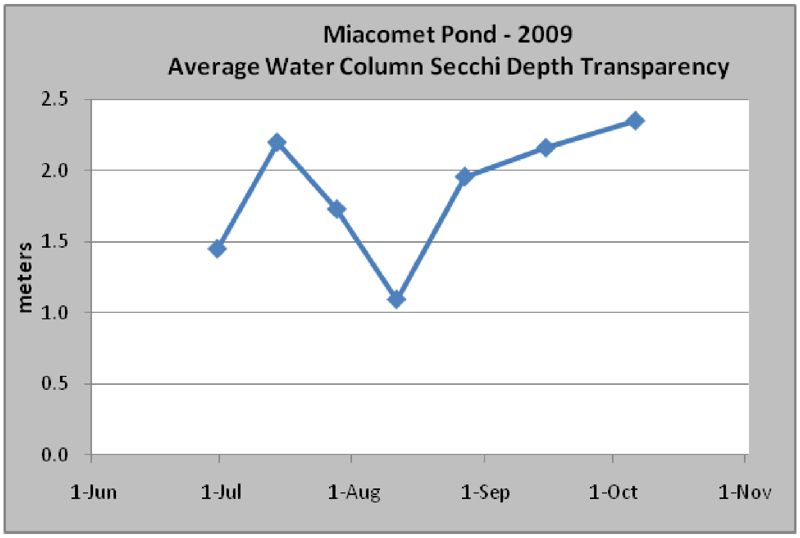


Figure 7. The pattern of water column specific conductance measured at the Miacomet Pond stations during 2009.

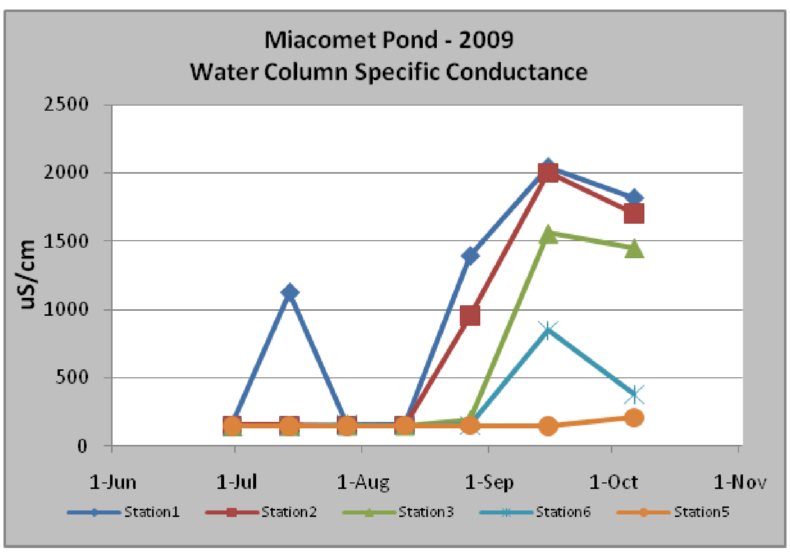


Figure 8. The pattern of water column pH measured at the Miacomet Pond stations during 2009.

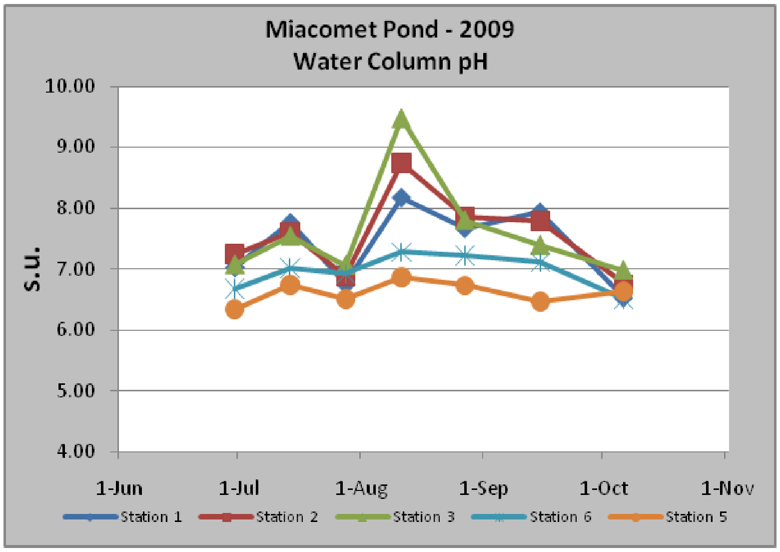


Figure 9. The pattern of specific conductance and pH measured in the tributary that flows from Burchell's Pond into Miacomet Pond during 2009.

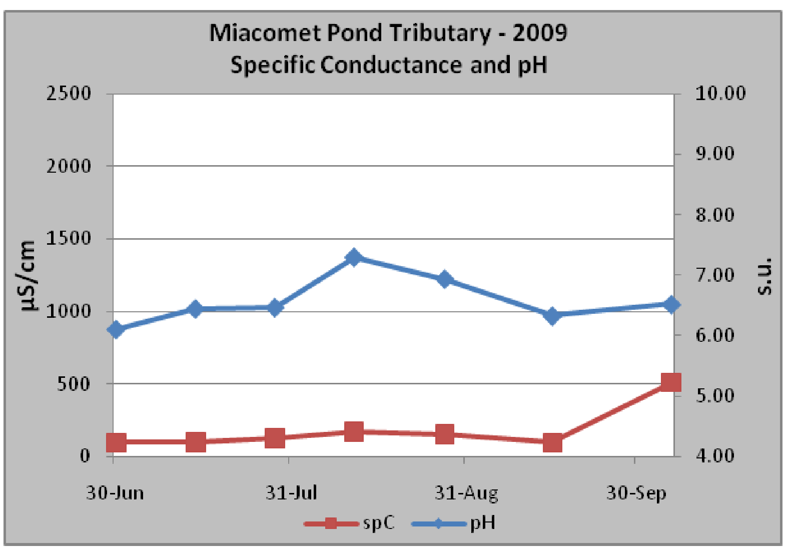


Figure 10. The pattern of average water column dissolved oxygen concentration measured at the Miacomet Pond stations during 2009.

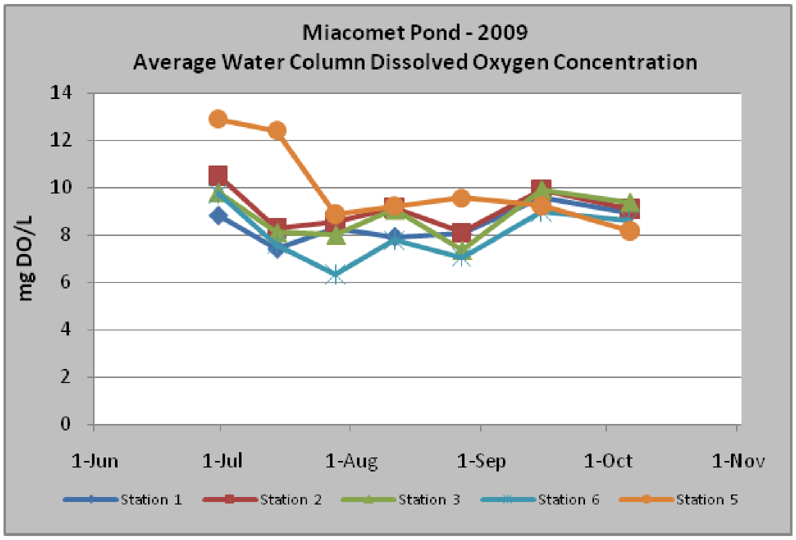


Figure 11. The pattern of water column profile dissolved oxygen percent saturation measured at the Miacomet Pond stations during 2009.

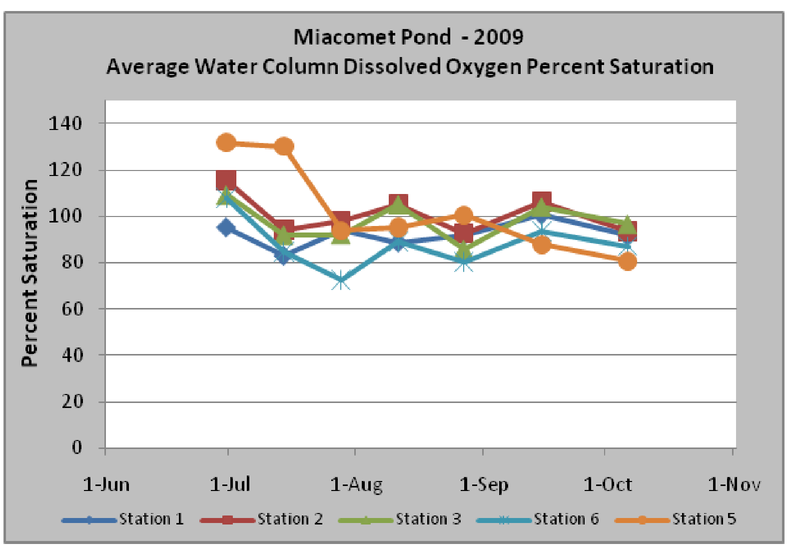


Figure 12. The pattern of water column dissolved oxygen concentrations and percent saturation values measured in the tributary that flows from Burchell's Pond into Mioacomet Pond during 2009.

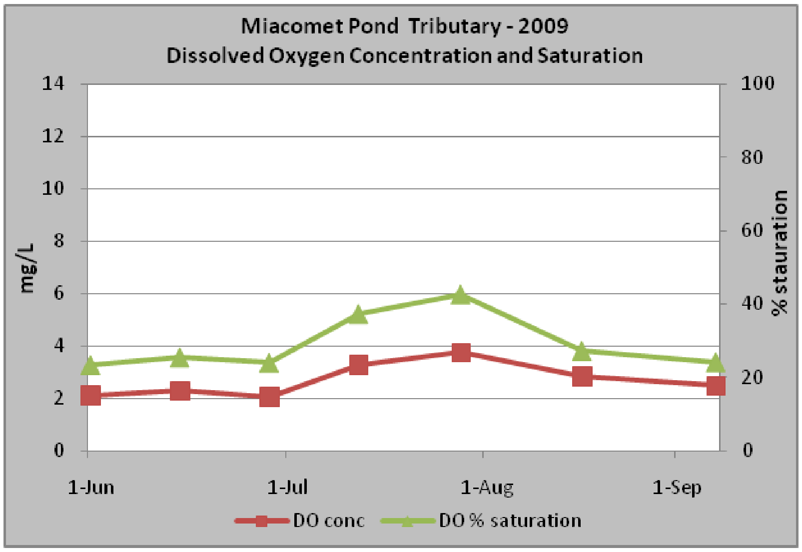


Figure 13. The pattern of water column nitrate–nitrogen concentrations measured at the Miacomet Pond stations during 2009.

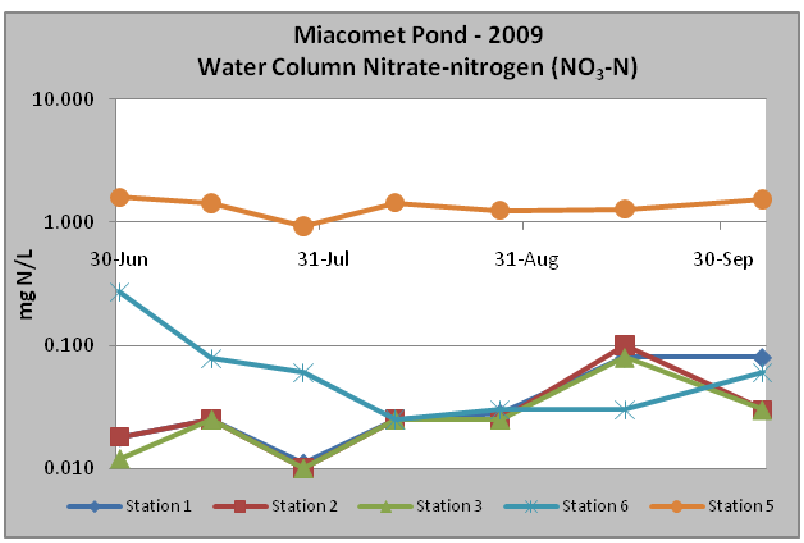


Figure 14. The pattern of water column ammonia-nitrogen concentrations measured at the Miacomet pond stations during 2009.

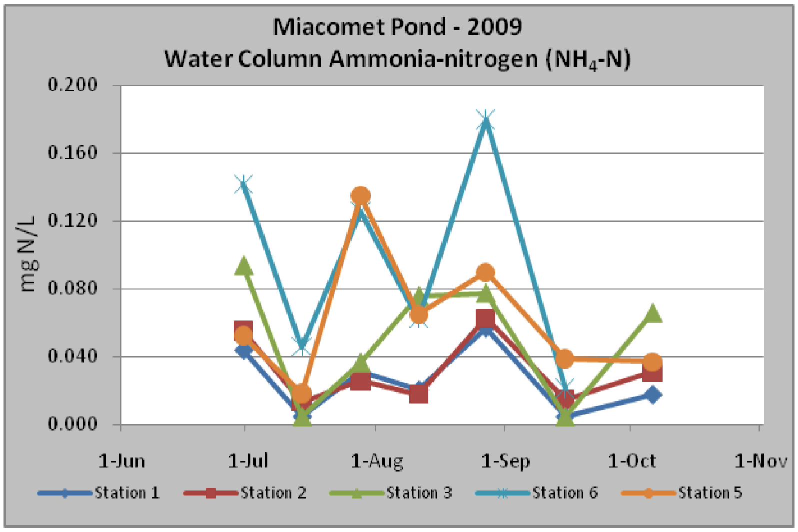


Figure 15. The pattern of water column total nitrogen concentrations measured at the Miacomet Pond stations during 2009.

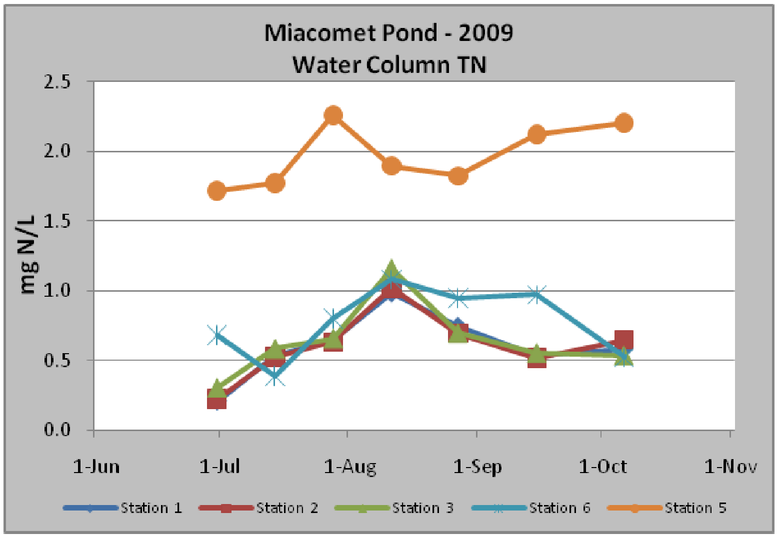


Figure 16. The average station total nitrogen concentrations measured at Miacomet Pond during 2009.

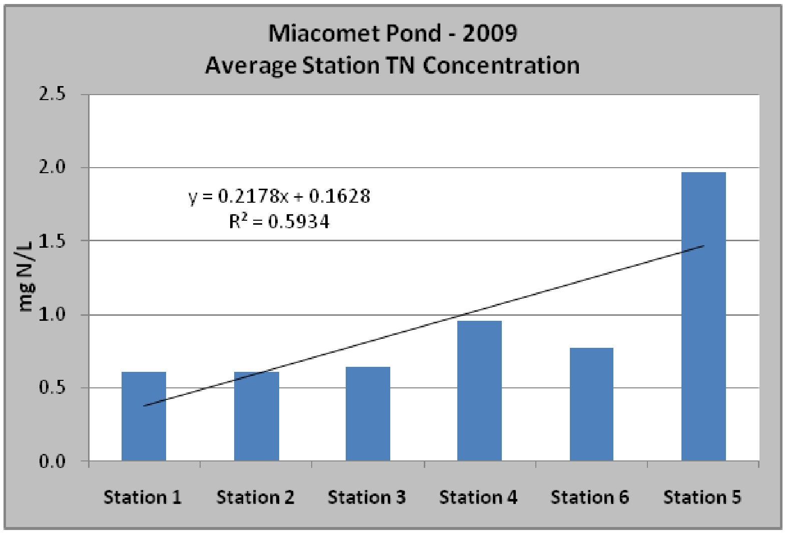


Figure 17. The average station water column concentrations of nitrate+ammonia and total nitrogen measured at Miacomet Pond during 2009 and the calculated organic nitrogen.

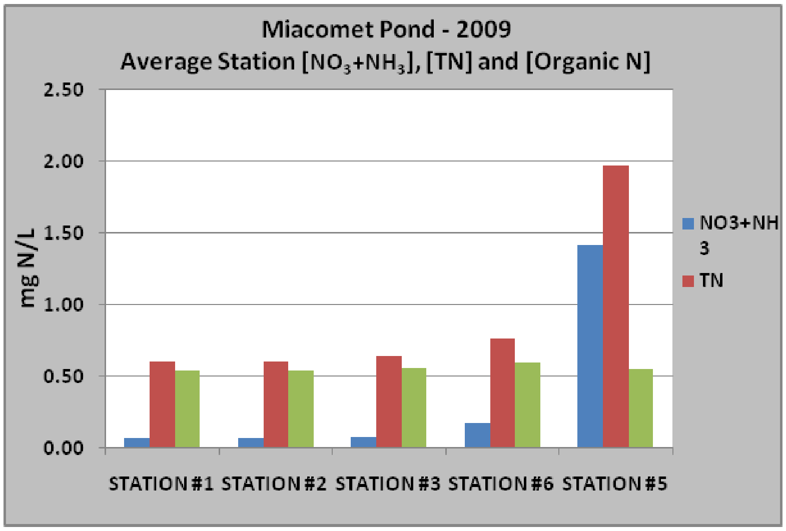


Figure 18. The pattern of water column nitrate, ammonia and total nitrogen measured in the tributary that flows from Burchell's Pond into Miacomet Pond during 2009 and the calculated organic nitrogen.

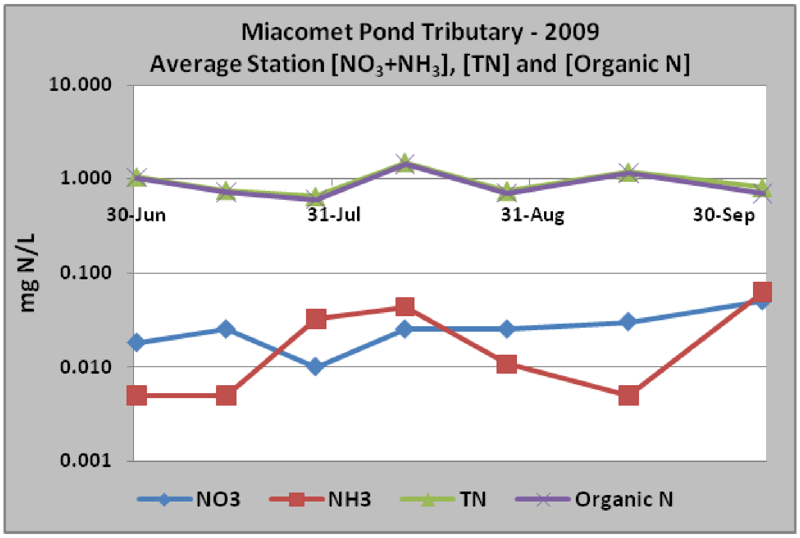


Figure 19. The average station total phosphorus concentrations measured at Miacomet Pond during 2009.

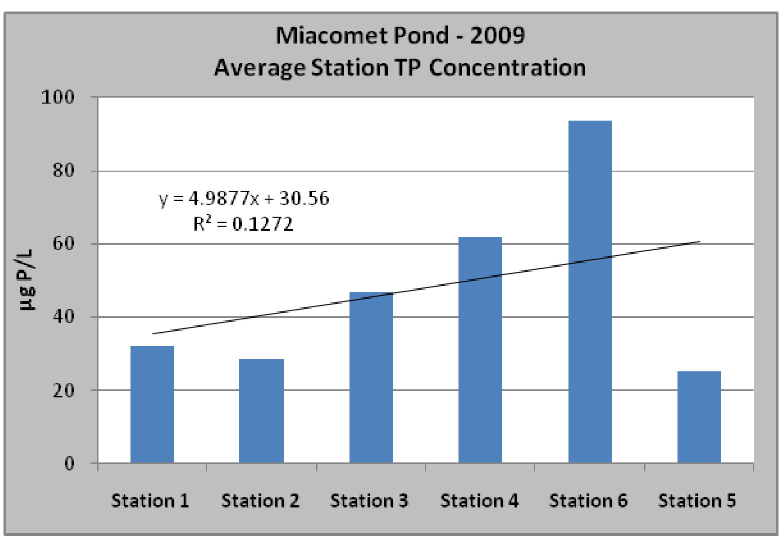


Figure 20. The pattern of water column total phosphorus measured at the Miacomet Pond stations during 2009.

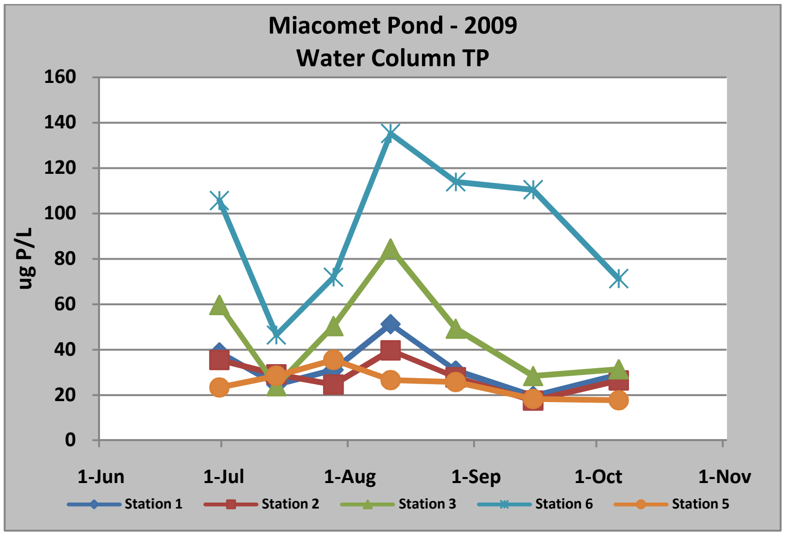


Figure 21. The water column pattern of number of phytoplankton taxa in Miacomet Pond during 2009.

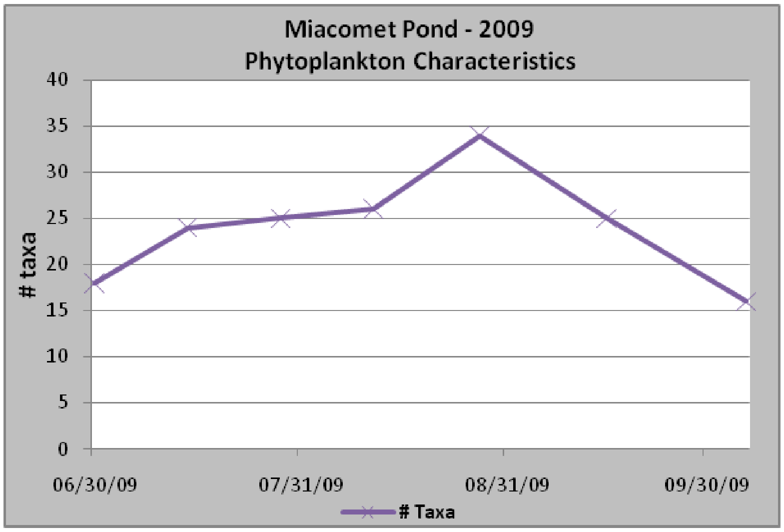


Figure 22. A ranking of phytoplankton taxa occurrence in Miacomet Pond during 2009.

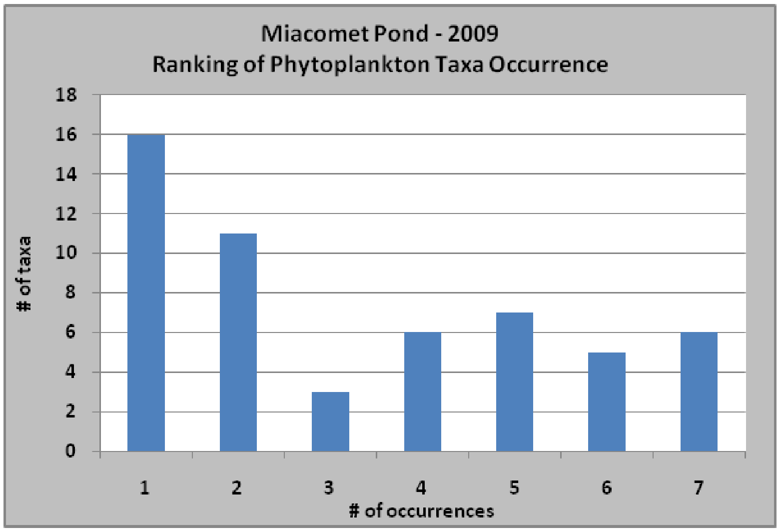


Figure 23. The pattern of density exhibited by major groups of phytoplankton in Miacomet Pond during 2009.

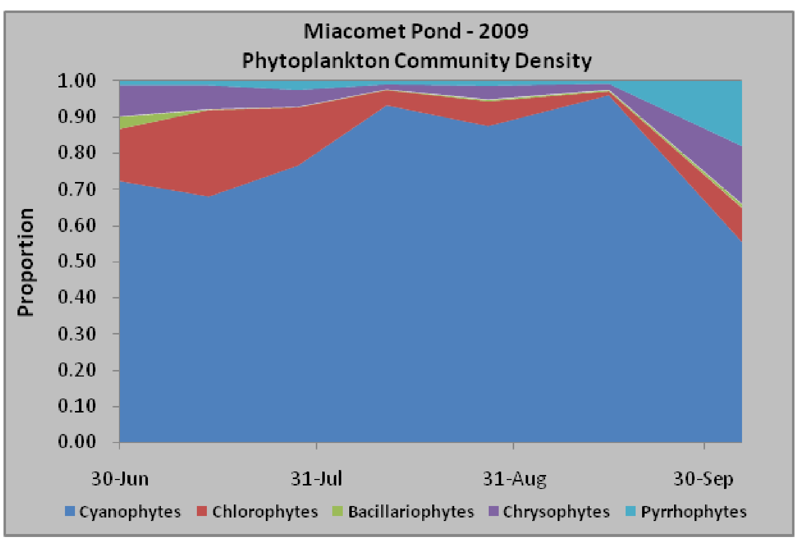


Figure 24. The pattern of biomass exhibited by major groups of phytoplankton in Miacomet Pond during 2009.

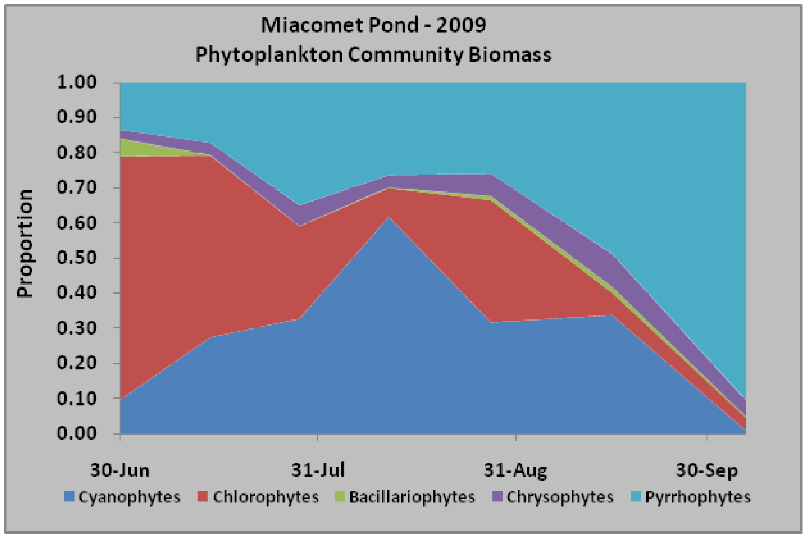


Figure 25. The pattern of phytoplankton community statistics measured in Miacomet Pond during 2009.

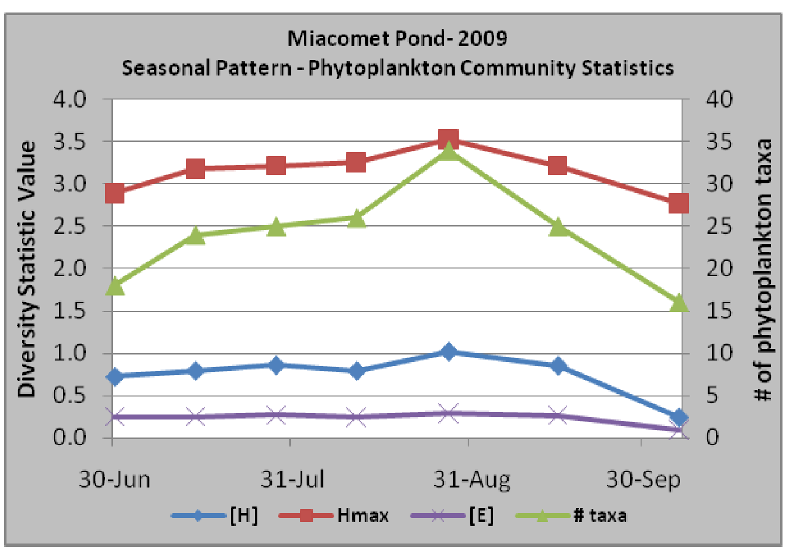


Figure 26. The pattern of chlorophyll *a* concentration in Miacomet Pond during 2009 compared with phytoplankton density and biomass.

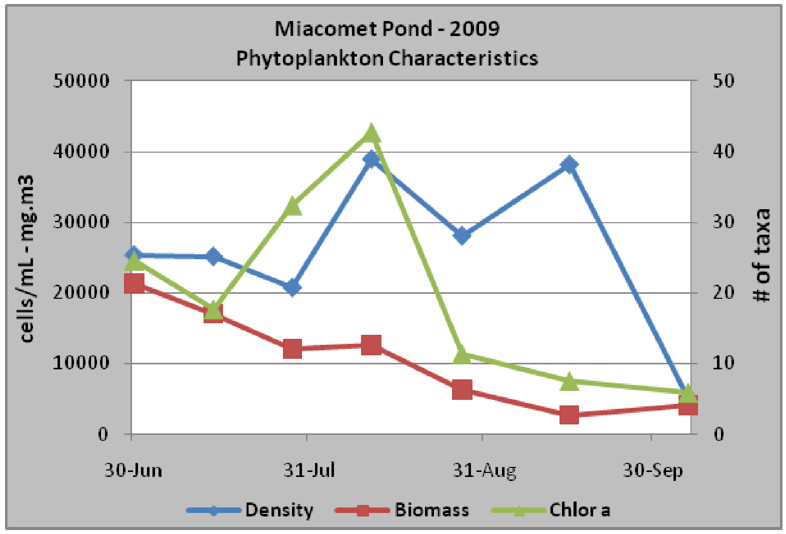
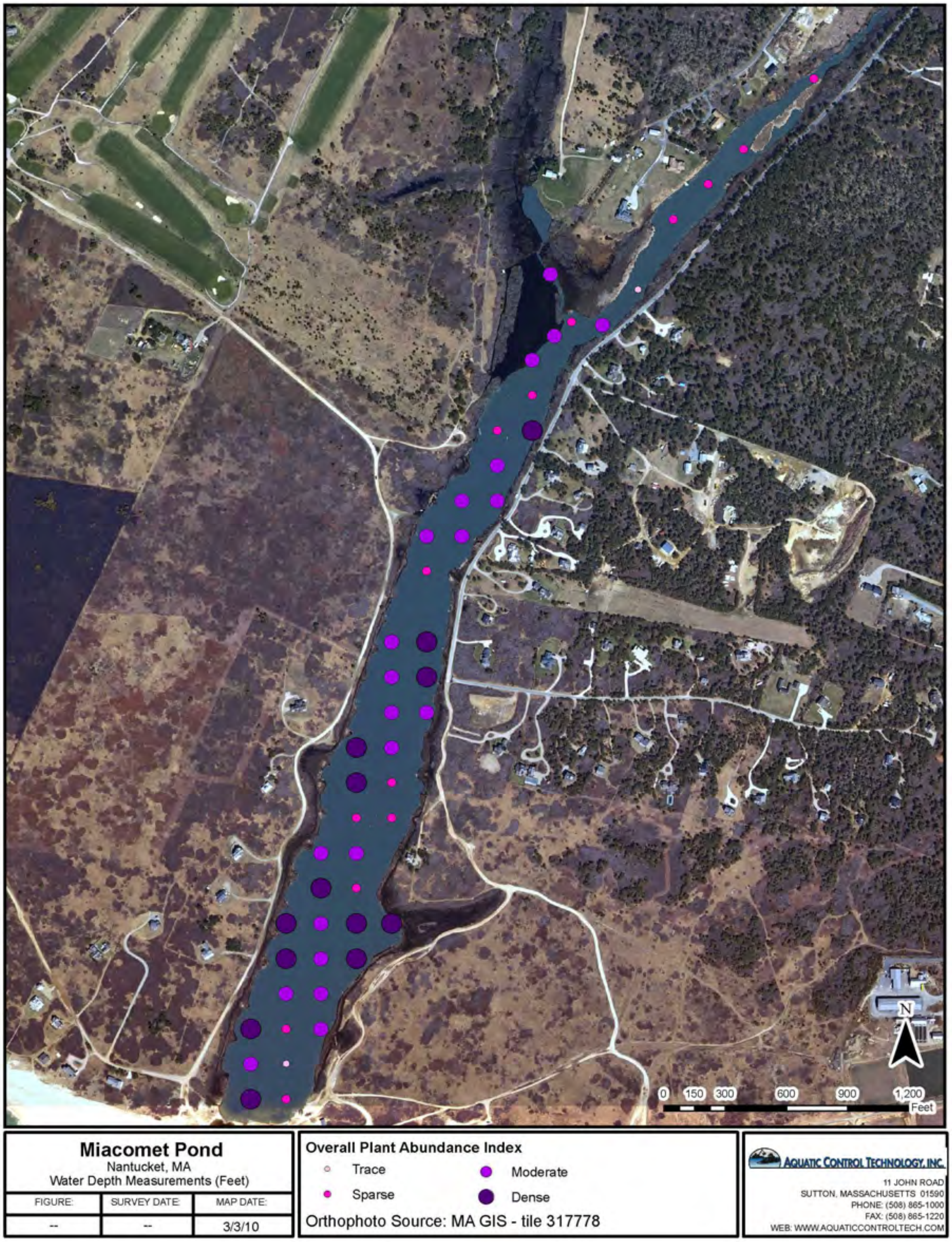


Figure 27. A map of Miacomet Pond showing the distribution and abundance of aquatic plants documented during a survey on 27 July 2009.



Appendix 1

Project Field Sheets

Chain of Custody Form

Vegetation Field Sheet

Vegetation Rake Information

MIACOMET POND
2009 WATER QUALITY SAMPLING

STATION # ______________ DATE ______________ TIME ______________

CONDITIONS ____

TOTAL DEPTH __________ WATER COLOR __________ LAT ______________

SECCHI DEPTH __________ TEAM INITIALS __________ LONG ______________

COMMENTS ____

DEPTH							

SAMPLE #	SAMPLE DEPTH	COMMENTS

OTHER ____

____

KECK WATER RESEARCH LABORATORY
CHAIN OF CUSTODY RECORD

SAMPLE ID #	FIELD REFERENCE	DATE/TIME COLLECTED	SAMPLE COLLECTION POINT (ie Surface, Epi, Hyp)	SAMPLE TYPE: (Grab, Integrated)

CUSTODY OF SAMPLES

	NAME	AFFILIATION	DATE	TIME
Sample Collected By	______________________	_____________	___/___/___	___:___
Sample Received By	______________________	_____________	___/___/___	___:___
Sample Received By	______________________	_____________	___/___/___	___:___
Cooler Temp Deg C	______________________	_____________	___/___/___	___:___

Lake Aquatic Plant Species' Presence / Relative abundance

Lake:__________________ Sampling Date:__________ Crew:______________________________

Zero, Trace, Sparse, Moderate or Dense

STATION	SAMPLE #	X COORDINATES	Y COORDINATES	DEPTH (ft)	ALL ABUNDANCE	Ceratophyllum demersum	Utricularia spp.	Najas spp.	Potamogeton perfoliatus	Vallisneria americana	Ruppia maritima	Potamogeton pusillus	Potamogeton natans	Lemna spp.	Typha spp.	Phragmites spp.					UNKNOWN-1	UNKNOWN-2	UNKNOWN-3
	1																						
	2																						
	3																						
	1																						
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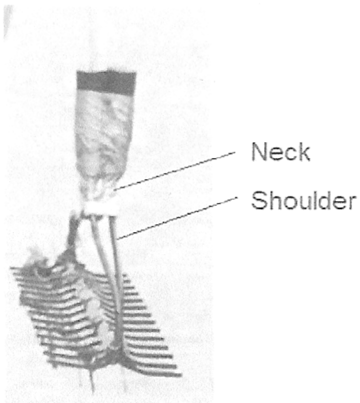

Instructions for making two-sided rake

Step 1: Cut the heads off two metal garden rakes, approximately 3-6 inches from the metal heads

Step 2: Line up the back of the heads, as show in diagram to the left

Step 3: Using plastic zip ties every 2-3 tines, attach the rakes. Tighten the ties as much as possible, and cut them off at the collar

Step 4: Connect the "necks" of the rake heads (see diagram) with 1-2 zip ties

Step 5: Connect the "shoulders" of the rake heads (see diagram) with 1 tie near the neck and 1 tie near the heads on each side of the rake(s)

Step 6: Connect the tethered line to the rake. This can be done in one of two ways: (a) drill a hole through the top of the wood handles and draw the line through the hole, tieing the line off on one side; or (b) wrap the line around the shoulders in a figure 8, and then around the outside of the shoulders, tieing the line off on one side.

Step 7: Wrap the other end of the line around a winder

Step 8: Duct tape the wood handles together to keep them from separating