# Hummock Pond Water Quality

# 2009

# A Summary of Physical, Chemical and Biological Monitoring

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# Section 1

# Executive Summary

## 1.0 Project Location and Boundary

Hummock Pond is located in Nantucket County, Massachusetts, and appears on the United States Geological Survey (USGS) 7.5 minute quadrangle map, Nantucket, with a seasonal, created outflow located at approximate latitude 43°05'32" and longitude 73°46'08" (Figure 1-1). The Pond and its watershed are located within the Town of Nantucket and the Town is responsible for stewardship of the Pond. Hummock Pond is primarily a contact recreational body of water, being used for boating, kayaking, fishing, sailing and swimming, 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 this study was to maintain the continuity of water quality data collection from Hummock Pond which originated back in the early 1990's. A secondary goal of the study was to examine the feasibility of developing a management strategy for Hummock Pond that would address present or potential problem areas either within the pond or in the watershed. The specific objectives of the study were to

- Define the present water quality of Hummock Pond and,
- Determine the activities in the watershed that may have an influence on the water quality of Hummock Pond.

The primary factor that motivated this investigation was a lack of funding within the Town of Nantucket to continue a water quality monitoring program on Hummock Pond initiated during the early 1990's. Dr. Sarah Oktay, Managing Director, University of Massachusetts Boston Nantucket Field Station, Cormac Collier, Executive Director, Nantucket Land Council, and the report author (JWS) developed a proposal for the 2009 monitoring effort and UMass Boston and NLC 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 Hummock Pond was sampled about every two weeks for a four month period. The study began during later June 2009 and continued through late October. A total of eight sampling trips were conducted; four stations along the longitudinal axis of Hummock pond were sampled during each trip. The 2009 study also included special studies of chlorophyll a, the phytoplankton community, and a detailed investigation of attached aquatic vegetation in the littoral zone of the Pond.

## 1.3 Presentation of Report

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

**Section 2** describes the 2009 sampling program conducted on Hummock Pond and the methodology of the sampling program.

**Section 3** describes the existing water quality of Hummock Pond as evaluated through the analysis of physical, chemical and biological data.

**Section 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 Hummock Pond.

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

### 1.4 Project Findings and Conclusions

Hummock Pond and Head of Hummock Pond are highly productive bodies of water plagued with excessive concentrations of phosphorus and nitrogen. It appears that both ponds are close to, or have reached, their assimilative capacity with regards to these nutrients and require the implementation of specific management practices to reverse the present trends.

Each pond contributes a certain, unknown amount of the phosphorus and nitrogen loading through autochthonous (internal) sources, while an unknown proportion of the total nutrient load enters from allochthonous (external) sources. The relative contributions of these nutrients are not known and should be determined through further scientific investigation in the ponds and watersheds.

Although the 'breaching' of Hummock Pond with the Atlantic Ocean twice each year is alleged to have a 'cleansing' effect on water quality, there actually is little, if any, data to support this claim. It is just as likely that breaching could cause nutrient enrichment since the hydraulic head created by lowering the pond levels would promote the entry of nutrient-rich groundwater from poorly operating wastewater treatment systems in the immediate watershed.

The addition of a major biological component to the 2009 monitoring program was instrumental in revealing some significant findings regarding Hummock and Head of Hummock Ponds. Although the existence of a healthy native plant community in Hummock Pond had been alluded to in previous studies and reports, the current study documented the distribution and abundance of the native community, which can be described as 'nuisance levels' of growth, and serves as a reference for future studies and remedial practices. On the contrary, Head of Hummock Pond was totally devoid of a littoral zone plant community which speaks to other, potentially more serious, problems within this ecosystem.

The most startling discovery from the 2009 biological data was the total dominance of Cyanobacteria populations on both ponds during the entire period of sampling. The water quality and human health and safety issues associated with these organisms through their production of neurotoxins and the recent link to neurodegenerative diseases are cause for great concern, particularly for individuals who have resided in close proximity to the ponds for long periods of time.

Immediate and appropriate remedial action within the ponds will be able to successfully reverse this current trend of dominance within the phytoplankton community, while the lack of any remedial action will allow the system to self-perpetuate and progressively get worse as each year passes. Even the control of nitrogen loading within the ponds will do little to change the current seasonal sequence of events since Cyanobacteria are known for their nitrogen-fixing capability which gives them a definite competitive advantage over other forms of phytoplankton in the ecosystem.

A brief summary of the problems affecting Hummock and Head of Hummock Ponds are as follows:

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

- Nitrogen loads are considered a problem for water quality of the ponds and the groundwater that enters the ponds,

- Hummock Pond and Head of Hummock Pond are 'unusable' by the public for either contact recreation or aesthetic enjoyment in their current state of water quality, and

- Although Hummock Pond has been studied since 1994, 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 Hummock and Head of Hummock Pond ecosystems, the report authors have presented a series of recommendations that should be considered for implementation.

**1.5 Recommendations**

(1) The Town of Nantucket is responsible for environmental stewardship of Hummock Pond and Head of Hummock Pond and therefore has an obligation to continue regular monitoring of these water bodies so that water quality conditions are documented and up-to-date.

(2) As the governmental entity responsible for Hummock Pond and Head of Hummock Pond, the Town of Nantucket should retain a consultant to prepare a detailed Management Plan for these two bodies of water. However, a detailed Management Plan should not be prepared for the ponds until there has been a more thorough assessment of factors affecting the water quality of the ponds and, 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 that should be addressed prior to the development of a Management Plan include (1) detailed GIS land use analysis within the watershed, documenting individual parcels, the amount of development and types of structures on each parcel, including impervious areas, (2) enhanced monitoring of groundwater including installation of more 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, (3) evaluation of current soil maps and upgrading of these maps if warranted by a lack of resolution, particularly since the use of fertilizer in the watershed is becoming so controversial and the effectiveness of soil in removing nutrients is unknown.

(4) Pond deficiencies should be addressed prior to the development of the Management Plan and include (1) enhanced water quality sampling before and after the breaching of Hummock Pond with the Atlantic Ocean to evaluate the effect of the breaching, (2) installation of a continuous water level recorder to assist with preparation of a water budget for the Ponds, (3) updated bathymetry of the ponds, and (4) chemical analysis of bottom sediments.

(5) The current shore-line of Hummock and Head of Hummock Ponds should be delineated along with detailed mapping of the shore-line *Phragmites* population using high resolution GPS. In some areas, the *Phragmites* is encroaching upon the open water in measureable amounts each year and eventually will cause segmentation into smaller water bodies, particularly along the narrow northeast end.

(6) A pumping and inspection program should be established within the watershed for testing 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 samples of the phytoplankton community should be collected from Hummock and Head of Hummock Pond and submitted to the UNH Center for Freshwater Biology for microcystin (MC) analysis.

(8) Installation of an aeration system as suggested by Knoecklein (2006) is recommended to maintain sufficient dissolved oxygen levels in the lower waters of Head of Hummock Pond to prevent phosphorus mobilization. This system should be installed as soon as possible to alleviate some of the long-term water quality problems discussed in this report and other reports. The primary goal would be to substantially reduce the impact of the Cyanobacteria blooms occurring in Head of Hummock Pond.

(9) Until control of nutrient loading to the ponds can be achieved, the Town of Nantucket should explore potential funding options to purchase a mechanical harvester to remove aquatic plant biomass from Hummock 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 method and the equipment could be used on other Island ponds with vegetation problems. One of the authors 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 use the harvested material as compost; otherwise, the material could be composted at the local landfill.

(10) It is imperative that a close watch be maintained over the Hummock 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 plant species are a well-documented problem.

## 1.6 Literature Cited

Knoecklein, G. 2006. Hummock Pond 2005 Monitoring Report. Prepared for Nantucket Marine and Coastal Resource Department. Northeast Aquatic Research, LLC. 54 pp.

# Section 2

# Methodology

## 2.0 Introduction

The Hummock Pond ecosystem includes both 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 Hummock Pond since 1994 by the Marine and Coastal Resource Department on Nantucket Island. However, due to local budgetary constraints, funding was not available to continue the program during 2009 and continuity of the data record was in jeopardy. Dr. Sarah Oktay, Managing Director, University of Massachusetts (UMass) Boston Nantucket Field Station, Cormac Collier, Executive Director, Nantucket Land Council (NLC) and the report author (JWS) developed a 2009 monitoring proposal, and UMass Boston and the NLC provided the funds to implement the program.

**2.0.2 Description of sampling program.** Water quality was monitored from late June through October 2009 at 4 stations located along the longitudinal axis of the Pond (Figure 2). These stations were selected to coincide with stations sampled during previous surveys; however, the total number of stations was reduced from previous surveys to lower the total cost associated with the 2009 sampling effort. Stations #1, #2, and #3 were located along the main axis of the Pond (south, middle and northern portions), while Station #4 was located at the deep area in Head of Hummock Pond.

Sampling was conducted on about a bi-weekly basis. The Pond was sampled a total of 8 times; the sampling dates are listed below.

| **Hummock Pond – 2009 Sampling Dates** | | | |
|---|---|---|---|
| 24 June | 21 July | 18 August | 30 September |
| 07 July | 04 August | 08 September | 27 October |

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 24 and 25 August to map the submersed aquatic vegetation throughout Hummock Pond and Head of Hummock Pond. Table 1 provides a summary of the parameters that were monitored in Hummock 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. The boat was anchored at each station and total depth of the water column was measured with a weighted Secchi disk on a marked line, and recorded. Latitude-longitude was 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-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 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). Data were recorded on individual 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 a series of 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 MgCO3 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 (2$^{nd}$ day delivery) to the Keck Water Research Laboratory in Troy, NY. This lab is located on the campus of Rensselaer Polytechnic Institute (RPI) and 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**. On 24 and 25 August 2009, a survey of aquatic plants was conducted on Hummock Pond. Weather conditions were suitable (clear and calm) on both days for a survey of this nature. Chris Doyle from Allied Biological, Inc. in Hackettstown, NJ and the report author (JWS) conducted the survey using the point-intercept technique developed by Madsen (1999) and later modified by Lord (2005).

Prior to the survey, random sample locations were plotted on a hand-drawn map of the pond focusing on the littoral areas. The points were aligned in transects in an effort to sample along the shoreline and in the open water communities. When using this technique, the total number of sample locations is based on the total acreage of the water body. In general, one sample location per acre (minimum 50 sample locations) is surveyed. If the water body is over 100 acres, the number of sample locations is reduced to about 100.

Using the hand-drawn map as a guide, the survey boat is piloted to the first sample location. Upon arrival, the GPS coordinates of the sample location are recorded using a Trimble GeoXH 2008 series handheld GPS unit with sub-meter accuracy. The water depth also is measured using a weighted and marked line. The water depth is recorded on a field log, and is depicted on a map. Any other pertinent field notes regarding the sample location also are recorded on a vegetation field log (Appendix 1).

Next, a vegetation rake attached to a 10 m length of rope is tossed from either side of the boat. The rake used for aquatic macrophyte surveys has a specific design (Appendix 2). It is constructed with two 13.5-inch wide metal garden rakes attached back to back with several 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. To determine the overall amount 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 developed by Cornell University (Lord and Johnson, 2005).

The collected plant densities are recorded as No plants (empty rake), Trace (one or two stems per rake toss, or the amount that can be held between two fingers), Sparse (three to 10 stems, but lightly covering the rake, or about a handful), Medium (more than 10 stems, and covering all the tines of the rake), or Dense (entire rake full of stems, and one has trouble getting the mass into the boat). These densities are abbreviated in the field notes as 0, T, S, M, and D. The collected macrophytes are sorted by genus (or species if possible) and one of the five densities (as described above) is assigned to each plant genus. Finally, overall floating macrophyte density within a 10 m diameter of the survey boat is assigned a density, as well as an estimated density for each separate genus (or species). The data are recorded in the field notes and the procedure is then repeated for the remaining sample points.

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 Allied Biological 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 properly preserved (Lugol's or glutaraldehyde) sample is required for analysis. The inverted microscope is used routinely for phytoplankton counting. The objectives of the inverted microscope are located below a movable stage and the light source comes from above, permitting viewing of organisms that have settled to the bottom of a chamber. A sample is prepared by filling duplicate cylindrical 50 ml Ütermohl settling chambers which have a thin, clear glass bottom. The samples 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 since 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 chamber bottom.

The sample is first scanned using low magnification to determine the taxa present. It is then analyzed at 1000x using oil immersion in order to accurately count cells which may be present below 10-20 um in size. For biomass 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. T**he 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 bodies of water or within the same body of water 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 biomass ($um^3$/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 ($mg^3$/mL) by 1,000.

**<u>Editor's Note</u>**: In discussions of the phytoplankton communities of Hummock Pond and Head of Hummock 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

Crow, G.E. and C.B. Hellquist. 2000a. Aquatic and Wetland Plants of Northeastern North America, A Revised and Enlarged Edition of Norman C. Fassett's A Manual of Aquatic Plants. Vol 1, Pteridophytes, Gymnosperms, and Angiosperms: Dicotyledons. University of Wisconsin Press, Madison, WI. 448 pp.

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# Section 3

## The Water Quality of Hummock Pond During 2009

## 3.0 Introduction

The Hummock 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 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 and discuss the data collected from Hummock Pond during 2009. Tables of the entire data-set are contained in a series of Appendices which are available upon request, 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 significant differences between the main body of Hummock Pond (HP) and Head of Hummock Pond (HHP) for certain of the parameters measured. In view of these differences, the two bodies of water are discussed separately in the instances where sufficient water quality distinctions are supported by the data collected.

### 3.1.1 Physical characteristics

**General.** Hummock Pond is about 2.3 miles long and extends in a southwest to northeast direction from the barrier beach at the Atlantic Ocean. The surface area is reported to be about 142 acres at normal water level (Conant, 2008). The widest part of the Pond, 1500 – 2000 feet depending upon water level, is toward the southwest end. Toward the northeast end, the Pond tapers considerably in width with some areas only 100 – 200 feet across from shore-line to shore-line. Near the northeast tip of Hummock Pond, a narrow channel about 5-10 feet wide provides access to Head of Hummock Pond, a small kettle-type body of water with a surface area of ≈15 acres. Hummock Pond has no outlet but is purposely breached two times each year to promote flow and water exchange with the Atlantic Ocean.

**Water depths.** Water depths were recorded during the aquatic vegetation survey (24 and 25 August) and were used to generate a map of Hummock Pond (HP) and Head of Hummock Pond (HHP) showing relative water depths (Figure 3). A total of 115 discrete depth measurements were recorded on HP and HHP during the survey. JWS was not aware of a water level measuring device located on HP during the season and water depths were observed to fluctuate by as much as ± 1.5 feet during the sampling period (June - October). Regardless, the depth map provides useful comparative information concerning depths throughout HP and HHP. There were not enough depth points recorded to develop a true bathymetric (contour) map of the ponds.

As shown on Figure 3, maximum depths in HP lie along a narrow axis at the southwest end near the barrier beach adjacent to the Atlantic Ocean. The deepest areas are aligned near the center as one proceeds along the main body of HP; the narrow area which occurs about mid-distance along the main body and progresses to the northeast end is ≈3 - 5 feet deep. HHP is bowl or kettle-shaped, and appears to have the deepest areas with 11.08 feet being recorded during the August survey and readings up to 13.33 feet being recorded during the regular 2009 sampling surveys.

Even though no contour map could be constructed for HP, 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. Based on data in Knoecklein (2006), when the water level of HP is within 'normal full condition', the pond bottom is within ≈2 feet of the surface (less than 2 feet deep) over about 65 percent of the pond surface area.

**Thermal cycle.** The temperature data collected from HP and HHP during 2009 provided the first indication that these bodies of water were distinct.

**HP**

Water depth is too shallow along the main body of HP to develop mid-summer thermal stratification and the water column 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. HP could be considered a *cold polymictic* pond which usually forms an ice cover each winter.

The water column along the main axis of HP was isothermal on all eight 2009 sampling dates. In other words, the greatest difference between the surface and bottom temperature on any sampling date at Stations #1, #2 and #3 was less than 1°C. Figure 4 summarizes the average water column temperature at the three HP stations during the 2009 sampling season. The maximum water temperature attained at all sampling stations was about 23°C and occurred during early August.

**HHP**

HHP exhibited a different circulation and stratification pattern in 2009 than the main body of HP, and appears to circulate from surface to bottom twice each year, once in the spring and again in the late summer-early fall, with a brief period of stratification in between these two periods. This pattern is characteristic of *dimictic* waters and the most common type of thermal stratification pattern observed in waters of the cool temperate region. HHP, however, does not have sufficient depth to form a true *hypolimnion* during periods of thermal stratification and, for that reason, is not a 'typical' *dimictic* water.

Summer thermal stratification in a typical *dimictic* lake would divide the water column into three distinct regions: *epilimnion*, *metalimnion* and *hypolimnion*. The *epilimnion* is the upper water stratum that essentially is isothermal during summer and circulates during periods of wind-driven turbulence. This zone overlies the *hypolimnion* which is a relatively deep, cold, undisturbed region. Based upon the productivity of the *epilimnion*, the *hypolimnion* may show oxygen depletion during periods of intense phytoplankton and zooplankton growth. The *metalimnion* is the stratum that separates the upper and lower regions of the water column and exhibits the maximum rate of temperature decrease with depth.

HHP exhibits incomplete stratification during the summer months (Figure 5). The pond has an *epilimnion* and slight evidence of a *metalimnion* through mid-August, but the shallow nature of the system precludes the extended formation of a typical *hypolimnion*.

In late June, when sampling was initiated, HHP already had completed spring turnover and the water column from the surface to bottom (12 feet) was about 16°C (Figure 5). By early July, the upper and lower waters in HHP exhibited a distinct 7°C temperature difference. The upper stratum continued to gain heat and the pattern of temperature difference became most pronounced by 18 August, when there was slight evidence of a 3-layered system of thermal stratification. Thereafter, thermal stratification broke down and the water column in HHP was isothermal during September and October.

**Transparency.** HP and HHP were moderately turbid during the entire 2009 sampling season as indicated by the Secchi disk transparency which ranged between 0.5 and 1.5 meters (1.5 – 4 feet) among all sampling stations. Stations #1 and #2 had similar Secchi depth readings on all sampling dates, and transparency at these two stations consistently was greater than the readings at Stations #3 and #4 (Figure 6). Station #3 is adjacent to a forested area (Lost Farm) along the eastern shore and water column transparency here appears to be strongly influenced by humic and fulvic acids leaching into the pond from the watershed. Station #3 had the lowest transparency reading on each sampling date and the lowest average reading (0.75 meters) for the sampling season. Water color at this site was recorded as 'brown' or 'dark brown' on each date. Transparency at Station #4 (HHP) was low (avg. = 0.84 m) and influenced by the presence of Blue-green algae (Cyanobacteria) during the entire season (Figure 6).

### 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.

Surface water conductance levels at the four sampling stations in HP and HHP during 2009 were moderately high, ranging between ≈2000 – 6500 µS/cm, reflecting estuarine conditions and salt water intrusion from the spring opening to the Atlantic Ocean. Figure 5 summarizes the seasonal progression of conductance values at the 4 sampling stations; the values at each sampling site exhibited a consistent decline throughout the 2009 season. Station #4 in HHP being the greatest distance from salt water influence had the lowest conductance readings all season (Figure 7).

The water column of HP at Stations #1 and #2 exhibited elevated pH values (above 8 standard units) on several different occasions during 2009 which probably reflect high levels of primary productivity at these locations. Otherwise, pH values along the main body of HP were within the range of 6 - 8 standard units throughout most of the season (Figure 8).

Station #4 at HHP, however, had elevated pH values on five separate occasions between early July and early September and had values in excess of 9 (s.u.) on two of those occasions (Figure 8). These higher pH readings from the HHP are the result of Blue-green (Cyanobacteria) blooms during almost the entire growing season.

**Oxygen concentration and saturation.** Oxygen in lake water constantly is consumed and the two primary mechanisms that replenish the 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.

**HP**

Stations #1 and #2, south and mid-pond, exhibited normal levels of dissolved oxygen concentration and saturation during the 2009 sampling period, ranging from ≈7 – 10 mg/L and 85 – 105 percent saturation, respectively, between late June and mid-September (Figures 9 and 10). Values of chlorophyll *a* in the water column during this period were relatively high, ranging from 16 - ≈40 µg/L and averaging ≈26 µg/L. These values are indicative of high levels of phytoplankton productivity and suggest a major role of these organisms in replenishing the dissolved oxygen content in the water column. The orientation of **HP** along a southwest-northeast axis and prevailing winds from the south and southwest during most of the growing season also suggests that wind-driven turbulence is an important factor in dissolved oxygen replenishment of the water column.

The average water column oxygen concentration and saturation levels at Station #3 were consistently below values for Station #1 and #2 on the same sampling dates during 2009 (Figures 9 and 10). As mentioned previously, water color at this station indicated the presence of humic and fulvic acids from the surrounding forested areas. 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.

**HHP**

HHP (Station #4) exhibited oxygen concentration and saturation patterns during 2009 that are characteristic of a north temperature dimictic lake with high productivity. The upper region of the water column was either saturated or supersaturated with dissolved oxygen (100 - >150%) from early July until mid-September when thermal stratification broke down and the entire water column was at 100% saturation for the remainder of the season. Temperatures in the water column were > 18°C until the end of September which translates to an extended growing season when most of the photosynthetic activity occurs in the pond. Chlorophyll *a* values in HHP during the corresponding time period ranged from ≈5 – 62 µg/L and averaged 40 µg/L, which are indicative of bloom conditions of phytoplankton. Given the elevated topography surrounding HHP which protects the surface from extensive wind-driven turbulence, and the lack of attached plants throughout the entire littoral area (see later section), it appears that phytoplankton productivity is the primary source of oxygen replenishment in HHP.

The region of HHP below 9 – 10 feet was devoid of oxygen from early July through early September (Figure 11). Subsequently, the oxygen stratification broke down and the entire water column had the same oxygen concentration from surface to bottom.

The seasonal profile of oxygen concentration/saturation exhibited by HHP during 2009 is characteristic of waters that are experiencing significant algal blooms. During most of the growing season, the upper waters are occupied by dense growth of phytoplankton which continually photosynthesize and respire and supersaturate the surrounding water with oxygen. The brief life cycle of the phytoplankton leads to a constant supply of dead cells and colonies that settle down into the lower waters and decompose, using available oxygen in the lower strata and causing the oxygen depleted condition.

### 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 Station #1, #2, and #3 in HP during the 2009 growing season averaged 7.70 (± 0.01) units indicating that $NH_3$-N probably is a good source of nitrogen for algae and higher plants. However, pH values at Station #4 in HHP during the 2009 growing season averaged 8.95 (± 0.48) units 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 HP and HHP during 2009 are as follows:

- Concentrations of nitrate and ammonia were moderate to low when compared with literature values for other north temperate lakes and ponds,
- Concentrations of nitrate and ammonia varied seasonally in a pattern similar to other 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 high levels of plankton and seston which is indicative of pond productivity,
- TN concentrations in the upper and lower levels of HHP during the temporary period of stratification in 2009 were significantly different from each other as the season progressed and are indicative of the large amount of organic nitrogen filtering down from the upper levels where high levels of primary productivity were occurring.
- The average concentration of total nitrogen in the pond at all stations sampled during 2009 suggests a highly productive condition when evaluating the water quality of HP and HHP and comparing results to other bodies of water.

The concentrations of nitrate and ammonia in the water column of Hummock Pond and Head of Hummock were moderate-to-low during the 2009 period of study. Nitrate-nitrogen concentrations at Stations #1, #2, #3 and #4 averaged 0.26, 0.29, 0.14 and 0.07 mg N/L, respectively, for the 8 sampling dates in 2009. The highest values recorded at Stations #1, #2 and #3 occurred in the 24 June samples (Figure 12); thereafter, values at all stations were less than 0.10 mg N/L until either mid-August or early September, when values at all stations increased to 0.20 mg N/L or greater. A general 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.

Knoecklein (2006) reported that most water column values of nitrate/nitrite samples collected from HP and HHP during 2004 were below the detection limit of 20 ppb (0.02 mg/L). This condition often is reported from lakes and ponds during mid-summer and indicates that available nitrogen in the form of nitrate is being consumed by members of the phytoplankton community as soon as it is produced in the water column. The fact that detectable levels of nitrate-nitrogen were observed in Hummock Pond during the entire 2009 season could either provide preliminary evidence of changes in the nitrogen chemistry of the Pond since the earlier work or point to important characteristics of the phytoplankton community composition which will be discussed in a later section of this report.

Ammonia-nitrogen values generally were below 0.20 mg N/L at all stations during 2009, although Stations #3 and #4 had considerably higher values on 3 separate occasions (Figure 13). The average concentrations of ammonia at Stations #1, #2, #3 and #4 during 2009 were 0.029, 0.025, 0.164 and 0.167 mg N/L, respectively. These data are more 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 both before and after this part of the year is a seasonal pattern that is characteristic for moderately productive waters (Hutchinson, 1967; Wetzel, 1975). The fact that both of these analytes were reported at low-to-moderate values in HP and HHP during 2009 provides some important insight into phytoplankton community dynamics of the system.

A simple method for calculating organic nitrogen in the water column is to subtract ammonia + nitrate concentrations from the TN concentration. The result of this exercise is presented in Figure 14. The average concentration of organic nitrogen at the 4 stations ranged from ≈0.650 – 1.10 mg N/L during the entire sampling season. Although some, probably small, portion of the organic nitrogen is in soluble, or dissolved, form, the organic nitrogen concentrations are high and correspond to high concentrations and high biomasss of phytoplankton in the water column throughout the sampling period.

The seasonal pattern of total nitrogen (TN) concentration in HP and HHP is shown in Figure 15. The average values at Station #1, #2, #3 and #4 were 1.00, 0.95, 1.16 and 1.28 mg N/L, respectively, during 2009. All stations exhibited a mid-summer peak in TN concentration during late July - early September, followed by a decline during the remainder of the season (Figure 15). Station #4, HHP, had the highest TN concentration of all stations from early August through the end of October.

Knoecklein (2006) reported similar TN values during mid-summer (June, July and August) of 2005 but then described increasingly higher values (up to 3.50 mg N/L) though the remainder of the season. It is not possible to determine whether the increasing TN values late in the 2005 season were nitrogen intrusion from the surrounding watershed or nitrogen internal to the system which is being regenerated by the cycle of productivity and decomposition.

A sufficient number of water chemistry samples were collected from the lower levels of Station #4 in HHP during the 2009 stratification to compare TN concentrations between upper and lower levels. As shown in Figure 16, TN concentrations were similar in upper and lower levels of HHP through early July; thereafter, TN concentrations in the lower levels increased substantially and remained ≈ 0.50 mg N/L greater than concentrations in the upper levels on the same sampling date. The high TN values in the lower waters appear to be the result of a high internal loading from organic matter in the form of dead and dying algal cells from upper level ‘bloom’ conditions, which settled into the lower regions during an extended period between mid-July and mid-September.

**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 north 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 HP and HHP 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 primary introduction of TP to HP probably is through groundwater flow at a fairly consistent rate which exhibits increases or decreases based upon annual precipitation cycles. The actual concentration of TP in the groundwater would be a function of land use within the watershed and the effectiveness of individual wastewater treatment systems which contribute groundwater discharge to the Ponds. The flow of groundwater in the watershed would vary based upon precipitation patterns during the year.

The TP dynamics of the water column in HP and HHP were not entirely as expected for a north temperate body of water. Some features observed during the 2009 study include the following:

- Concentrations of TP in HP were moderate-to-high from June through October 2009 and concentrations of TP in the upper water of HHP were very high during the same time period,

- HP and HHP 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 in the upper levels of Station #4,
- 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.
- Concentrations of TP in the lower waters of HHP were either the same as, or greater than, TP concentrations in the upper water levels in HHP on any sampling date, probably reflecting the mobilization of TP from the bottom sediments during anoxic conditions in the lower waters.

The concentrations of total phosphorus (TP) in the water column of HP and HHP were moderate-to-high 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 and #4 averaged 71.82, 86.73, 169.91 and 490.99 µg P/L, respectively, for the 8 sampling dates.

As shown in Figure 17, the values recorded at Stations #1 and #2 in HP were similar during the sampling season and did not deviate appreciably from the average values. Station #3 had similar values during the first few samples collected and then, in mid-July, started increasing steadily to a high value of 264.79 µg P/L on 08 September, and decreased steadily thereafter. Station #4 in HHP exhibited extreme TP concentration starting about in mid-July when the concentrations rose to ≈ 400 µg P/L and then continued to increase to between ≈550 - 750 µg P/L for the remainder of the sampling season.

In view of the physical, chemical and biological conditions measured in HHP during 2009, it is likely that the source of high TP concentrations is the persistent 'bloom' conditions that occurred, coupled with the decomposition of organic matter in the lower waters, the development of anoxic conditions and re-mobilization of TP from the bottom sediments. Knoecklein (2006) recorded even higher values of TP in HHP during 2004 and 2005 which he attributes to re-generation from the lower, anoxic waters.

Knoecklein (2006) suggests that the high TP concentrations in HHP have a direct influence on TP concentrations measured at other sampling stations via the hydraulic connection between the two ponds. Although this is possible, it seems unlikely given the volume of water that would have to move from HHP to HP and the fact that the prevailing wind during the late spring, summer and early fall is from the south, which would affect water currents. Some further investigation is required.

Water samples collected from the lower levels of HHP during the 2009 period of stratification revealed that TP concentrations in this zone were elevated for a brief time (mid-July to late August) but were similar to concentrations in the upper levels early and late in the season (Figure 18).

### 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 lake 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 HP and HHP was not possible due to the short-term nature of the 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).  As a result, there are certain limitations attached to predicting trophic status of the Pond based upon the phytoplankton community.

In spite of the limitations mentioned above, the phytoplankton community observed in HP and in HHP did exhibit important features that characterize the general water quality of the Ponds during the period of study.  These features were as follows

- *Cell density* - the phytoplankton communities of HP and HHP were dominated by Blue-green algae (Cyanobacteria) during the period of study; dominance in HP was concentrated between 1-2 species and dominance in HHP was concentrated among 2-4 species,
- *Biomass* – the phytoplankton community of HP was dominated by several algal groups including Chlorophytes, Chloromonads, Pyrrhophytes, and Cyanophytes, which exhibited a seasonal succession during 2009; the phytoplankton community of HHP was dominated by Chlorophytes, Pyrrhophytes and Cyanophytes in a distinct seasonal succession,
- Cell densities in HP and HHP were very similar during the first half of the 2009 survey period; subsequently, cell densities in HHP increased dramatically and remained very high through the end of October 2009, while cell densities in HP remained at the levels observed during the first half of the sampling season,
- HP and HHP exhibited high levels of chlorophyll *a* and there was a distinct seasonal pattern exhibited in both bodies of water,
- HP and HHP 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 phytoplankton characteristics, individually and collectively, reflect a level of water quality in HP and HHP that can be classified as highly productive and indicative of poor water quality.

**HP**

There were 46 taxa identified in phytoplankton samples collected from HP during 2009.  As shown in Table 5, almost all of the major algal groups were represented.  The greatest number of taxa, 28, occurred on 07 July followed by a secondary peak of 20 taxa on 18 August.  Thereafter, a total of ≈15 taxa occurred in the water column during the remainder of the season (Figure 19).  Richness (# of taxa) on any particular sampling date generally was about one-half to one-third of the total pool of phytoplankton identified from the 2009 samples.

A ranking of phytoplankton occurrence in HP on the 8 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 20). Eighteen (18) of the 47 taxa occurred only on a single sampling date, and 37 taxa (≈65 percent of the total) occurred in less than one-half of the samples collected. Only 4 taxa occurred on all 8 sampling dates.

Table 6 lists the taxa that occurred most frequently in the HP 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 10 taxa occurred on five or more sampling dates during 2009. However, Cyanophytes (BG algae) almost exclusively dominated the phytoplankton community; only three other taxa, were biomass dominants and only one other taxon was a density dominant. The misleading nature of density as a community descriptor becomes evident when one views the cell biomasss in Table 6 and sees the difference between the size of, for example, *Gonyostomum semen* 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 dominant member in the phytoplankton community.

If only cell density is considered, then the HP phytoplankton community would not show any seasonality during 2009 (Figure 21); BG algae were the density dominants of the phytoplankton community for the entire season. Chlorophytes (green algae) were the only other group to exhibit dominance, and only on a single occasion. However, when biomass is considered, there was a distinct seasonality in the occurrence of phytoplankton groups in HP. Although BG algae dominated community biomass during most of the 2009 season, other groups such as the Chlorophytes, Pyrrhophytes, Chloromonads and Chrysophytes exhibited a distinct seasonality of appearance throughout the season (Figure 22).

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.

Diversity was moderate in HP 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 HP averaged 0.4631 (± 0.0326) and ranged between 0.0547 (on July 21st 2009) and 0.915 (on August 18th 2009). Figure 23 presents **[H]**, diversity, and **[$H_{max}$]**, which is the diversity when maximum equitability or allotment occurs, for the water column of HP. 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

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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.

0.02 and 0.31 during the study, and was lowest (0.02 and 0.09) during mid-July and early September. The two periods of low equitability in 2009 correspond to the times in HP when the number of phytoplankton species was low and 90 percent or more of the community biomass was represented by a single BG algal taxon, *Anabaena spiroides*.

Usually only a few algal taxa were dominant in the community (Table 7). A taxon was considered dominant if it comprised 5 percent, or more, of the total biomass on a particular sampling date. The most frequent dominant taxa in HP during 2009 were *Anabaena spiroides* (5 dates), *Microcystis aeruginosa* (4 dates), *Ankistrodesmus falcatus* (3 dates), and *Gonyostomum semen* (3 dates).

Chlorophyll *a* is the primary photosynthetic pigment of all oxygen-evolving photosynthetic organisms, and is present in all algae. Chlorophyll *a* samples collected at Station #1 on all 8 sampling dates averaged 29.32 µg/L and ranged from 4.36 µg/L to 98.00 µg/L. The average mid-summer concentration for the 5 dates when pond water temperature was 18°C or greater was 37.07 µg/L. Chlorophyll *a* concentrations were high in late June, peaked at 98.00 µg/L during mid-to-late July and then steadily declined through the remainder of the season (Figure 23). Trends in chlorophyll *a* concentration followed the same seasonal pattern as phytoplankton cell density and biomass in HP (Figure 24).

Community standing crop, estimated from chlorophyll *a* concentration is one of the primary factors used to predict lake trophic status. In the case of HP, regardless of whether one uses the mid-summer average concentration (37.07 µg/L) or the average for the entire season (29.32 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 HP algal community, they never were dominant during the study. Year-round sampling would be required to determine whether diatoms ever are dominant during fall, winter or early spring. The appearance of green and BG algae in HP during the growing season is a sequence of associations that provides additional evidence that the algal community reflects conditions of high productivity and poor water quality.

**HHP**

A total of 55 taxa were identified in phytoplankton samples collected from HHP during 2009. As shown in Table 8, all of the major algal groups were represented. The highest number of taxa, 35, occurred on 08 August followed by a secondary peak of 30 taxa on 27 October, the final sampling date (Figure 25). Richness (as taxa) on any given sampling date generally was about one-half to one-third of the total pool of organisms identified from the 2009 samples, and averaged 25.1 (±5.5) species for the season.

A ranking of phytoplankton occurrence over the 8 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 26). Fifteen (18) of the 55 taxa occurred only on a single sampling date, and 33 taxa

(60 percent of the total) occurred in less than one-half of the samples collected. Only 4 taxa occurred on all 8 sampling dates.

Table 9 lists the taxa that occurred most frequently in the HHP samples and some characteristics for each taxon including cell biomass, seasonality, and number of times the taxon was dominant in the community. A total of 21 taxa in HHP occurred on 5 or more sampling dates during 2009. However, Cyanophytes (BG algae) almost exclusively dominated the phytoplankton community; only 6 other taxa were found to be biomass dominants and no other taxa were density dominants.

Based upon cell density, the HHP phytoplankton community would show only minimal seasonality during 2009 (Figure 27); BG algae were the density dominants (> 90%) of the phytoplankton community for the entire season. On the basis of biomass, however, there was a distinct seasonality in the occurrence of phytoplankton groups in HHP. Although BG algae dominated community biomass during most of the 2009 season, other groups such as the Chlorophytes, Pyrrhophytes and Bacillariophytes exhibited a distinct seasonality throughout the season (Figure 28).

Diversity was moderate in HHP 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 HHP averaged 0.7503 (± 0.1514) and ranged between 0.5156 (on July 7$^{th}$ 2009) and 0.9583 (on October 27$^{th}$ 2009). Figure 29 presents diversity, [H], and [$H_{max}$], which is the diversity when maximum equitability or allotment occurs, for the water column of HP. 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 0.17 and 0.30 during the study and never exhibited a low point as did the HP community.

Usually only a few algal taxa were dominant in the community (Table 10). The most frequent dominant taxa in HHP during 2009 were *Microcystis aeruginosa* (6 dates), *Anabaena spiroides* (5 dates), *Cryptomonas ovata* (5 dates), and *Coelastrum cambricum* (4 dates).

Chlorophyll *a* samples collected at Station #4 on all 8 sampling dates averaged 39.85 µg/L, with a range from 5.67 µg/L to 62.06 µg/L. The average mid-summer concentration for the 5 sampling dates when the water temperature of the pond was 18°C or greater was 42.05 µg/L.

Chlorophyll *a* concentrations started low in late June and early July and by early August had reached a plateau around 60 µg/L where concentrations remained until late September-early October. Thereafter, chlorophyll a concentrations declined to 37.20 µg/L by the end of October (Figure 30). Trends in chlorophyll a concentration did not coincide with the seasonal pattern of phytoplankton cell density and biomass in HHP (Figure 29), as had been demonstrated in HP.

Community standing crop for HHP was very high during 2009. Regardless of whether the mid-summer average concentration (42.50 µg/L) or the average for the entire season (39.85 µg/L) was considered, both values are well above the range of 10-15 µg chlorophyll *a*/L, which is the border between mesotrophic and eutrophic conditions.

Algal associations documented in HHP during the study provide additional information about the general trophy of the pond. Although diatoms were part of the algal community of HHP, they never were dominant during the study period. As mentioned previously, year-round sampling would be required to determine whether diatoms ever are dominant during fall, winter or early spring. However, the appearance of green and BG algae in HHP during the warmest periods of the year is a sequence of associations that provides further evidence that the algal community reflects mesotrophic-to-eutrophic conditions, although the extended dominance of BG algae throughout the entire study period probably is more suggestive of a strictly eutrophic condition.

**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.

HP, being relatively shallow and small, has a sizeable littoral zone with attached aquatic vegetation. During the August vegetation survey, the lower limit of attached plants consistently was about 8 feet. A map of HP and HHP (Figure 31) showing the distribution and abundance of aquatic vegetation recorded on 24 and 25 August 2009 illustrates the extensive area of the littoral zone. It appears from Figure 31 that the lower depth limit of vegetation in the pond was about 8 feet. In general, no plants were collected from areas > 8 feet deep along the main axis of the pond from the widest area toward the southwest tip and also in HHP, which contained no attached plants and only trace amounts of vegetation were collected and recorded from a total of 15 sampling sites. The center axis near the northeast end of HP is shallow but also was devoid of plants, probably due to reduced light transmission from the concentration of humic and tannic substances in the water in this area.

A total of twelve (12) plant species were collected from HP and HHP. A list of genus and species (when identified) is presented in Table 11. Benthic filamentous algae are not considered aquatic plants in the true sense of the term; *Fontinalis* is a moss that grows attached to the bottom. *Ceratophyllum* sp., although classified as an aquatic plant, have no true root structure and are distributed throughout the water column by wind, wave and current action. Finally, *Lemna* is classified as an aquatic plant but floats on the surface of water bodies. There were no nuisance aquatic species observed in either HP or HHP.

As shown in Table 7, *Potamogeton perfoliatus* was the most frequently recorded plant species, occurring at 70 of 115 sites (frequency = 61%). *P. perfoliatus* was recorded as 'dense' at 12 sites (10%), 'medium' at 37 sites (32%), 'sparse' at 23 sites (20%) and 'trace' at 17 sites (15%). Similar statistics are presented for all of the other plants collected from HP. There were no plants collected from a total of 26 sites (23% of the sites sampled); over one-half of the sites without plants occurred in HHP. Maps of the distribution and abundance of individual plant species in HP are presented in Appendix 4.

Medium and dense growth occurred at 49 (35%) of the 115 sites sampled; many of these areas were located in the narrow arm of HP that extends from the main body toward the northeast end (Figure 31). The remaining medium and dense growth areas are scattered throughout the main body of the pond and the narrow southwest corner. 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 HP to spread and become more evenly distributed. Even at current levels of plant growth in HP, recreational use generally is impaired due to entanglement of oars, paddles, and outboard motors from the extensive growth on the pond surface.

Although experiments were not conducted as part of this study, certain indirect evidence suggests that the extensive littoral aquatic plant community in HP 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 high 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 HP is important in this regard. As described previously, the phytoplankton community in HP also plays an important role in production and turnover, and the role of the phytoplankton in HHP in this capacity would be particularly important since there is no established aquatic plant community.

### 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** lakes and ponds fall somewhere between the eutrophic and oligotrophic categories. Lakes and ponds with extreme conditions may be considered **hyper-oligotrophic** or **hype-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 HP and HHP 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 HP and HHP was at 18°C or greater. This temperature restriction lowered the number of sampling dates to five including 07 July, 21 July, 04 August, 18 August, and 08 September.

Average values were calculated for each variable for HP and HHP for the five summer sampling dates. The average values then were substituted into the equations above to calculate the TSI values for the three variables. The stepwise calculation and results of the analysis are as follows:

**HP**

Although there were 3 sampling stations along the main axis **of HP** during 2009, only the data from Station #1 were analyzed for TSI since chlorophyll *a* only was collected at this site and not at Stations #2 and #3. The results of the Carlson TSI calculations for HP are as follows:

**Chlorophyll *a***
Average summer chlorophyll *a* = 22.95 µg/L
Chlorophyll a $TSI = 9.81*[\ln (22.950] + 30.6$
$TSI = (9.81)(3.1) + 30.6$
$TSI = 61.3$

**Total phosphorus**
Average summer total phosphorus = 72.1 µg/L
Total phosphorus $TSI = 14.42*[\ln (72.1)] + 4.15$
$TSI = (14.42)(4.3) + 4.15$
$TSI = 66.2$

**Secchi depth**
Average summer Secchi depth = 0.99 m
Secchi $TSI = 60 – [14.41*[\ln (0.99)]$
$TSI = 60 – (14.41)(0.0)$
$TSI = 60.0$

TSI analysis of all three variables results in about the same relative TSI reading for HP, clearly placing the Pond well within the eutrophic range regardless of which variable is used. In fact, based upon the TSI for phosphorus, the Pond is not that far away from being considered hyper-eutrophic.

**HHP**

As discussed in prior sections of this chapter, HHP displays many different characteristics when compared with HP and probably should be considered a different water body, at least on the basis of water quality, even though there is a hydraulic connection. In spite of the connection between HP and HHP via a long narrow channel, there is no information about the predominant flow of water between the two bodies and the extent of mixing. Presumably, many different factors would contribute to this movement including prevailing wind directions, the hydrologic head of groundwater from portions of the HHP watershed which are higher in elevation than the surface of the pond itself. Under the variety of circumstances occurring at any given time, mixing between HP and HHP probably goes in both directions, depending upon conditions at play.

Carlson trophic indices were calculated for HHP in view of the above and for the purposes of comparison. The full analysis was made possible since chlorophyll *a* samples were collected from HHP during each 2009 sampling date. The results of the HHP Carlson TSI calculations are as follows:

**Chlorophyll *a***
Average summer chlorophyll *a* = 55.57 µg/L
Chlorophyll a TSI = 9.81*[ln (55.57)] + 30.6
TSI = (9.81)(4.0) + 30.6
TSI = 69.8

**Total phosphorus**
Average summer total phosphorus = 487.5 µg/L
Total phosphorus TSI = 14.42*[ln (487.5)] + 4.15
TSI = (14.42)(6.2) + 4.15
TSI = 93.6

**Secchi depth**
Average summer Secchi depth = 0.80 m
Secchi TSI = 60 – [14.41*[ln (0.80)]
TSI = 60 – (14.41)(-0.22)
TSI = 63.2

Two TSI variables, chlorophyll *a* and phosphorus, are unequivocal in locating HHP near, or well within, the hyper-eutrophic category, respectively. Secchi depth being a subjective reading is not as robust as a calculator and provides a eutrophic classification. Given that total phosphorus results were available for the upper and lower levels of the water column during 2009, the TSI index for this variable probably would be considerably higher if we were able to factor in the average of the summer readings for the 2 zones of the water column, which is not possible since relative volumes of the regions are not known.

Some states, e.g., Florida, classify lakes and ponds based upon the average concentrations of TN measured in a system. When considering the average TN concentrations measured at Stations #1-4 during 2009, both HP and HHP 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 water quality of Hummock Pond was monitored in 2009 to maintain an almost continuous data record that began in 1994. The 2009 study began at the end of June, ended late in October, and sampled Hummock Pond (HP) and Head of Hummock Pond (HHP) 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 both ponds. HP and HHP were sampled 8 times in 2009.

In spite of the brief period of sampling, there is very compelling evidence from the 2009 data to support the 'eutrophic' status presented in earlier reports by the Marine and Coastal Resource Department (Curley, 2004, 2003, 2001; Conant, 2006, 2008) and by Knoecklein (2006). In fact, a thorough examination of the 2009 chemical and biological results provides sufficient evidence that HP is well-established as a eutrophic system and HHP is close to, or already situated in, a hyper-eutrophic state.

As reported in earlier studies, HP and HHP exhibited elevated levels of total phosphorus and total nitrogen during 2009. In addition, as described by Knoecklein (2006) for water quality data collected during 2004 and 2005, there was a distinct concentration gradient of both plant nutrients within the pond during 2009. The highest average concentrations occurred in HHP (Station #4) and the northeast end of HP (Station #3), while Stations #1 and #2 toward the south end had lesser average concentrations during the period. The difference in average concentration between Station #4 and Station #1 was most pronounced for TP (Figure 32); however, a distinct gradient also was apparent for TN (Figure 33).

Biological samples collected from HP and HHP during 2009 revealed very high levels of phytoplankton standing crop within both ecosystems providing further evidence that characterized their 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). HP and HHP were well-established within the eutrophic range during 2009 regardless of whether one considers all of the chlorophyll *a* samples collected from the ponds or only the summer samples when the water column temperature was > $18^{o}$C. In fact, the concentrations of chlorophyll *a* in HHP from mid-July through the end of September averaged 51.0 (± 12.8) ug/L and were indicative of continuous 'bloom' conditions of phytoplankton. Although the appearance of algal blooms during the warmest periods of the year may characterize algal associations of typical north temperate lakes, blooms in excess of 3 – 4 months are not 'typical' of a healthy system and emphasize the extreme productivity of HHP.

The total dominance of Blue-green algae (Cyanobacteria) in the phytoplankton communities of HP and HHP during 2009 provides further convincing evidence of the unhealthy status of these ecosystems. Although the phytoplankton assemblages of HP and HHP were diverse in terms of total numbers of taxa identified, all major groups except the Cyanophytes were scarce throughout the sampling period regardless of whether cell density or biomass was considered.

As summarized below, there were 3 Cyanobacteria species identified in HP and 5 species identified in HHP during 2009. The three species identified in HP also occurred in HHP, with two additional species found in the HHP samples. Three of the seven species of Cyanobacteria are known to produce neurotoxins which are harmful to humans, pets, farm animals, and wildlife.

| Hummock Pond | Head of Hummock Pond | |
|---|---|---|
| *Anabaena flos-aquae** | *Anabaena flos-aquae** | *Coelosphaerium naegelianum* |
| *Anabaena spiroides* | *Anabaena spiroides* | *Microcystis incerta** |
| *Microcystis aeruginosa** | *Microcystis aeruginosa** | |
| * capable of toxin formation; from DiTomaso, 1994. | | |

The high level of primary productivity demonstrated by the 2009 phytoplankton communities in HP and HHP also characterized the aquatic plant community of HP during 2009. During the survey of HP, dense and moderate growth of native plants was recorded at 49 of 97 total sites (50%) within the main body of the pond. This high proportion of dense and moderate growth sites actually translates to 60% since 15 sites within HP were too deep to support growth of attached vegetation. 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 HP 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 HP, recreational use generally is impaired due to entanglement of oars, paddles, and outboard motors from the extensive plant growth on the pond surface.

Quite a different situation occurred in HHP during 2009, where an attached aquatic plant community was non-existent. Most areas of HHP probably are too deep to be considered littoral zone and support an attached plant community; however, the absence of attached plants along the shoreline in shallow areas where light penetration is not be an issue suggests that other, perhaps toxic, factors might be in play and preventing the establishment of a littoral zone community.

### 4.1 Discussion

HP and HHP form a simple estuary system located on the Island of Nantucket, Massachusetts. HP, and probably HHP to a lesser extent, is stabilized as an estuarine system by periodic management breaching of the barrier beach which separates the pond from the waters of the Atlantic Ocean. The pond usually is breached in the spring and the fall of each year and closes itself from the ocean after a period of three to seven days on average. The purpose of breaching is to lower nutrient levels, primarily nitrogen, raise salinity through the exchange of brackish pond water with higher quality marine waters and remove accumulated organic matter from the pond. Others reasons given for the breaching include alleviation of flooded conditions and enhancement of marine fisheries (Conant, 2008). It is not certain how long ago the practice was initiated, or whether a record even exits. However, material reviewed for this report has documented the spring and fall events as far back as 1994.

In spite of regular breaching each year, there appears to be a lack of water quality data to substantiate any of the reasons given for following this practice. The authors of this report contend that while there may be some perceived water quality advantage gained through this practice, it is just as likely that significant water quality damage can result from the breaching. For example, lowering the water level increases the hydraulic head between the pond and the groundwater in the watershed which would increase the flow of nutrient-rich groundwater water, particularly from areas where poorly operating individual wastewater treatment systems are located, into the pond.

Howes et al. (2006) attribute the nutrient enrichment problem affecting coastal embayments throughout the Commonwealth of MA and along the entire 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 information, water quality data collected since 1994, the setting of the geologic watershed, and land use and local hydrology, it would seem that HP and HHP are experiencing the same high nutrient (nitrogen) dilemma as Sesachacha Pond and other coastal embayments. However, there appears to be far less background information and supporting data available for HP and HHP than the corresponding information presented by Howes et al. (2006) for Sesachacha Pond.

The surface watershed of HP and HHP is ≈2,230 acres while the groundwater drainage area is ≈2000 acres. When considering the size of the pond (≈150 acres), these drainage values translate to a watershed to pond ratio of ≈15:1, which is a substantial contributory drainage into a relatively small volume of water; about 300 acre-feet at 'full' condition (Knoecklein, 2006). Given the sandy, well-drained soils, low overall slope of local topography and the fact that relatively little development exists along the shore-line of the ponds, groundwater would seem to be the primary mechanism for the movement of water and nutrients into the system.

The watershed of HP and HHP lies within the Town of Nantucket. A major portion of the water and nutrient input to HP and HHP is groundwater from the watershed and precipitation falling directly on the surface of the pond. 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 a small tributary originating near No Bottom Pond, northeast of the intersection of Crooked Lane and Madaket Road, which travels through Millbrook Swamp before entering the northeast end of Hummock Pond. Given the low flows observed in this channel over the period of a year (JWS, unpublished data), it is unlikely that this tributary provides any significant volume of surface runoff to the HP-HHP system. It is more likely that the tributary serves as a conduit for transport of nutrient material from Millbrook Swamp when the system becomes a 'source' during periods of high discharge following major storm events.

Groundwater could provide a substantial load of nitrogen to HP and HHP since there is considerable development in the portion of the watershed north and east of the ponds. Almost all of the developed area within the watershed is served by individual waste water treatments systems of unknown working condition. Many of these systems are utilized for very brief periods during the summer and then remain dormant for the remainder of the year; 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 as nitrate to the surrounding groundwater in sandy soils.

Weiskel and Howes (1992) reported that phosphorus is highly retained during groundwater transport through sandy glacial outwash aquifers, such as in the watershed to the Sesachacha Pond System, by sorption to aquifer minerals. Since there is no information provided in Howes et al. (2006) on the specific soil type(s) in the watershed of Sesachacha Pond, it is impossible to known whether Hummock and Sesachacha Ponds share the same soil types.

There are two soil types in the HP and HHP watershed that determine permeability and eroding capability. The northern section is classified as “Medisaprists-Barryland Variant association”, consisting of organic mucky deposits, combined with outwash soils that are poorly drained. The southern section is classified as “Evesboro association” defined by gently sloping sandy soils that drain rapidly (Oldale, 1992). Results reported in Liddle et al (2009) for groundwater piezometers monitored in the HP and HHP watershed suggest that significant levels of ortho-phosphate (available phosphorus) and nitrate are being transported in the groundwater and constitute a loading source to the ponds.

The water quality results from 2009 presented herein suggest that a significant amount of phosphorus is remobilized within the ponds (autochthonous source) during the summer months, based upon the oxygen depleted zone in HHP and the combination of shallow depth and longitudinal axis of HP oriented parallel to the summertime prevailing winds which would afford thorough mixing and mobilization along the deep trench where $O_2$ levels at the sediment water interface would foster mobilization.

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 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 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 scum, already have died and lysed, releasing their cell contents into the surrounding environment.

The Blue-green algae observed in HP and HHP during 2009 and the extended blooms of these organisms are problematic for more reasons that just water quality. At least 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. In addition to being toxic and dangerous to animals, such as cattle, dogs and cats, these 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 HP and HHP. 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

Although HP and HHP are connected hydraulically, each pond should be considered a separate body of water in terms of inherent water quality issues and specific recommendations for treatment. The fact that the two bodies of water are connected implies that each one has the potential to influence the water quality of the other. However, the relative extent of that influence, if any, is unknown.

The phytoplankton communities of HP and HHP may provide some important insight into the ‘separate’ nayure of the two bodies of water. During 2009, there were 46 taxa of phytoplankton identified in HP and 55 taxa identified in HHP. Although many of the same taxa were found in both ponds, there were a total of 20 taxa that were unique to either one pond or the other, which is not a situation that would occur if any sort of thorough mixing was occurring between the two ponds.

### Hummock Pond (HP)

HP is a eutrophic body of water with total phosphorus and chlorophyll *a* values during the 4-month period averaging 109.49 µg/L and 29.32 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 trophic status of HP.

If we accept the tenet of high phosphorus retention in sandy glacial outwash aquifers presented by Weiskel and Howes (1992), then the elevated total phosphorus values that occur in HP 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, it may be that soils in the HP watershed are characterized by low retention capacity which would mean that groundwater is a major source of phosphorus to the system (allochthonous source). There is some recent evidence from groundwater monitoring in the HP watershed that suggests a watershed contribution to this problem (Liddle et al., 2009).

The longitudinal gradient in the TP concentration in HP during 2009 provides indirect evidence of the influence of HHP on the northeast end of HP, as suggested by Knoecklein (2006). Alternatively, however, the higher TP concentrations in that region could result from phosphorus mobilization within the bottom sediments due to humic and tannic compounds in the water that reduce the oxygen concentration and saturation values. Or, higher phosphorus in this area also could be 'source' input from the Millbrook Swamp during or following major precipitation events. There is not enough evidence to determine which situation or combination of situations is occurring.

The high concentrations of TN observed in HP during 2009 coupled with the documented water quality degradation indicate that watershed loading is problematic and the assimilative capacity of the system probably has been exceeded. A continual source of nitrogen presumably comes from numerous individual septic systems in the HP watershed which are of different ages and working efficiencies.

The Cyanobacteria identified in HP during 2009 that are known producers of toxins are problematic and pose a definite public health and safety issue for individuals using HP 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 HP are all native forms which, under normal conditions, would comprise a healthy component of the aquatic ecosystem. The circumstances in HP, 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 along the present course, the plant community soon will reach 'nuisance' proportions throughout the pond and greatly accelerate the process of eutrophication.

**Head of Hummock Pond (HHP)**

HHP is a eutrophic body of water, bordering on hypertrophy, with concentrations of total phosphorus and chlorophyll *a* averaging 490.99 µg/L and 39.85 µg/L, respectively, during the 4-month monitoring period in 2009. The high levels of total phosphorus documented in HHP apparently are generated within the system, given the extreme levels of primary productivity and phytoplankton biomass that sink to the lower waters where decomposition, oxygen depletion and phosphorus mobilization complete the remainder of the internal cycle. The high seasonal concentrations of chlorophyll *a* in the HHP system merely reflect the bloom conditions of phytoplankton, specifically the Cyanobacteria that were observed and measured in the water column during the 2009 monitoring period.

The primary source of the high total nitrogen concentrations documented in HHP during 2009 is more difficult to explain than situation in HP. As acknowledged in Knoecklein (2006), the watershed for HHP is relatively small (41 acres) and only 4 homes are within the watershed divide that contributes directly to the pond. Either these homes are contributing an external load directly from wastewater treatment systems to HHP via groundwater flow or HHP is successfully mobilizing nitrogen internally, particularly during the period when massive quantities of dead algal cells are settling down to the lower levels of the water column and decomposing under mid-summer anoxic conditions. However, the fact that low levels of nitrate and ammonia were consistently measured in the lower waters during this period seems to contradict this internal loading source.

As with HP, the Cyanobacteria identified in HHP during 2009 that are known producers of toxins are problematic and pose a definite public health and safety issue for individuals using HHP recreationally and home-owners living along the shoreline adjacent to the pond. The seriousness of this situation cannot be over-emphasized in view of the recent scientific information linking Cyanobacterial blooms in lakes and ponds with the development of sporadic ALS disease.

The lack of aquatic plants in HHP is problematic and in direct contrast to the situation observed within HP where nuisance growth of native species is occurring. The fact that all of the primary productivity in the system resides within the phytoplankton community is a direct indication of the severe ecosystem imbalance in HHP.

### 4.3 Recommendations

(1) The Town of Nantucket is responsible for environmental stewardship of Hummock Pond and Head of Hummock Pond and therefore has an obligation to continue regular monitoring of these water bodies so that water quality conditions are documented and up-to-date.

(2) As the governmental entity responsible for Hummock Pond and Head of Hummock Pond, the Town of Nantucket should retain a consultant to prepare a detailed Management Plan for these two bodies of water. However, a detailed Management Plan should not be prepared for the ponds until there has been a more thorough assessment of factors affecting the water quality of the ponds and, 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 that should be addressed prior to the development of a Management Plan 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) enhanced groundwater monitoring including installation of more 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 by a lack of

resolution, particularly since the use of fertilizer in the watershed is becoming so controversial and the effectiveness of soil in removing nutrients is unknown.

(4) Pond deficiencies should be addressed prior to the development of the Management Plan and include (1) enhanced water quality sampling before and after the breaching of Hummock Pond with the Atlantic Ocean to evaluate the effect of the breaching, (2) installation of a continuous water level recorder to assist with preparation of a water budget for the ponds, (3) updated bathymetry of the ponds, and (4) chemical analysis of bottom sediments.

(5) The current shore-line of Hummock and Head of Hummock Ponds should be delineated along with detailed mapping of the shore-line *Phragmites* population using high resolution GPS. In some areas, the *Phragmites* is encroaching upon the open water in measureable amounts each year and eventually will cause segmentation into smaller water bodies, particularly along the narrow northeast end.

(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 Hummock and Head of Hummock Ponds and submitted to the UNH Center for Freshwater Biology for microcystin (MC) analysis.

(8) Installation of an aeration system as suggested by Knoecklein (2006) is recommended to maintain sufficient dissolved oxygen levels in the lower waters of Head of Hummock Pond and prevent phosphorus mobilization. This system should be installed as soon as possible to alleviate some of the long-term water quality problems discussed in this report and other reports (Knoecklein, 2006). The primary goal would be to substantially reduce the impact of the Cyanobacteria blooms occurring in Head of Hummock Pond.

(9) Until control of nutrient loading to the ponds can be achieved, the Town of Nantucket should explore potential funding options to purchase a mechanical harvester to remove aquatic plant biomass from Hummock 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. One of the authors 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 use the harvested material as compost; otherwise, the material could be composted at the local landfill.

(10) It is imperative that a close watch be maintained over the Hummock 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 plant species are a well-documented problem.

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Section 5

Tables

Table 1. Parameters monitored during 2009 to assess the short-term water quality of Hummock and Head of Hummock Ponds. The water column parameters were monitored regularly from late June through October. The evaluation of aquatic plants in the ponds was a special study conducted during 24 and 25 August.

| 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 |
| 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 | Field Measure | Relative abundance | Typical Dry Weight ($g/m^2$) |
|---|---|---|---|
| "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 | Rakeful | 9 | ~ 140.001 - 230.000 |
| "D" = dense plant(s) | Can’t get in | 27 | ~ 230.001 - 450.000+ |

Table 3. Physical, chemical and biological parameters included in the 2009 Hummock and Head of Hummock 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 | 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, biomass |
| Biological Characteristics - Macrophytes | Pond map – GPS overlay- Point intercept technique | Species identification, density, diversity and dominance |

Table 4. Chemical parameters and analytical methods for the 2009 study of water quality in Hummock and Head of Hummock Ponds.

| Parameter | Analytical Method |
|---|---|
| pH | Electrometric (US EPA Method 150.1) |
| Specific Conductance | Wheatstone Bridge type meter (US EPA |
| 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 the taxa that were identified in Hummock Pond during 2009.

| **Cyanophyta** | **Chrysophyta (Bacillariophyceae)** |
|---|---|
| *Anabaena flos-aquae* | *Achnanthes* sp. |
| *A. spiroides* | *Amphiprora* sp. |
| *Chroococcus limneticus* | *Amphora* sp. |
| *Merismopedia punctata* | *Cocconeis* sp. |
| *Microcystis aeruginosa* | *Cyclotella* sp. |
| **Chloromonadophyta** | *Fragilaria crotonensis* |
| *Gonyostomum semen* | *Gomphonema abbreviatum* |
| **Chlorophyta** | *G. lanceolatum* |
| *Ankistrodesmus falcatus* | *G. olivaceum* |
| *Chlamydomonas* spp. | *Gyrosigma* sp. |
| *Closterium* spp. | *Navicula* sp. |
| *Crucigenia tetrapedia* | *Nitzschia* sp. |
| *Eudorina elegans* | *Pinnularia* sp. |
| *Kirchneriella subsolitaria* | *Rhoicosphenia curvata* |
| *Oocystis borgei* | *Stauroneis* sp. |
| *O. parva* | *Stephanodisus* sp. |
| *Pandorina morum* | *Surirella* sp. |
| *Pediastrum duplex* | *Synedra acus* |
| *Scenedesmus arcuatus Lemmerman* | *S. fulgens* |
| *S. bijuga* | *Tabellaria fenestrata* |
| *S. quadricauda* | **Chrysophyta (Chrysophyceae)** |
| *Selenastrum minutum* | *Dinobyron bavaricum* (cells) |
| *Spirogyra* sp. | *Dinobyron divergens* (cells) |
| | *Dinobyron* spores |
| | *Ochromonas* sp. |
| | **Pyrrhophyta (Cryptophyceae)** |
| | *Cryptomonas ovata* |
| | **Pyrrhophyta (Dinophyceae)** |
| | *Peridinium cinctum* |

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

| Major Group | Cell Biomass | Number of times the taxa | | | 2009 |
|---|---|---|---|---|---|
| Genus (Taxon)-species | ($\mu m^3$) | Occurred | BM dominant | DN dominant | Seasonality |
| | | | | | |
| Cyanophyta | | | | | |
| *Anabaena spiroides* | 308.0 | 6 | 5 | 5 | Mid-July→Oct |
| *Microcystis aeruginosa* | 10.3 | 8 | 4 | 8 | All season |
| Chloromonadophyta | | | | | |
| *Gonyostomum semen* | 7543.2 | 5 | 3 | 0 | All season |
| Chlorophyta | | | | | |
| *Ankistrodesmus falcatus* | 250.0 | 8 | 3 | 1 | All season |
| Bacillariophyta | | | | | |
| *Cocconeis* sp. | 500.0 | 8 | 0 | 0 | All season |
| *Cyclotella* sp. | 268.0 | 6 | 0 | 0 | June→early Sept |
| *Gomphonema olivaceum* | 610.0 | 6 | 0 | 0 | July→Oct |
| *Navicula* spp. | 350.0 | 8 | 0 | 0 | All season |
| *Synedra* sp. | 350.0 | 7 | 0 | 0 | All season |
| Chrysophyta | | | | | |
| *Dinobryon* spores | 775.0 | 5 | 2 | 0 | June-early July; August→late Sept |
| BM = biomass; DN = density; months of occurrence are abbreviated in some cases | | | | | |

Table 7. Ranking of phytoplankton taxa dominance, using biomass, in Hummock Pond on each sampling date during 2009.

| Sampling Date | BM Rank | Taxon (Major Group) | % of Total Biomass |
|---|---|---|---|
| | | | |
| 06/24/09 | 1 | *Pandorina morum* (Chlorophyta) | 54 |
| | 2 | *Eudorina elegans* (Chlorophyta) | 20 |
| | 3 | *Closterium* spp. (Chlorophyta) | 5 |
| | | | |
| 07/07/09 | 1 | *Anabaena flos-aquae* (Cyanophyta) | 47 |
| | 2 | *Peridinium cinctum* (Pyrrhophyta) | 19 |
| | 3 | *Ankistrodesmus falcatus* (Chlorophyta) | 9 |
| | 4 | *Dinobryon* spores (Chrysophyta) | 7 |
| | 5 | *Microcystis aeruginosa* (Cyanophyta) | 6 |
| | | | |
| 07/21/09 | 1 | *Anabaena spiroides* (Cyanophyta) | 98 |
| | | | |
| 08/04/09 | 1 | *Gonyostomum semen* (Chloromonadophyta) | 74 |
| | 2 | *Anabaena spiroides* (Cyanophyta) | 10 |
| | 3 | *Ankistrodesmus falcatus* (Chlorophyta) | 7 |
| | 4 | *Microcystis aeruginosa* (Cyanophyta) | 6 |
| | | | |
| 08/18/09 | 1 | *Anabaena spiroides* (Cyanophyta) | 32 |
| | 2 | *Peridinium cinctum* (Pyrrhophyta) | 14 |
| | 3 | *Microcystis aeruginosa* (Cyanophyta) | 12 |
| | 4 | *Dinobryon* spores (Chrysophyta) | 12 |
| | 5 | *Gonyostomum semen* (Chloromonadophyta) | 9 |
| | 6 | *Ankistrodesmus falcatus* (Chlorophyta) | 8 |
| | | | |
| 09/08/09 | 1 | *Anabaena spiroides* (Cyanophyta) | 89 |
| | | | |
| 09/30/09 | 1 | *Anabaena spiroides* (Cyanophyta) | 84 |
| | 2 | *Gonyostomum semen* (Chloromonadophyta) | 7 |
| | | | |
| 10/27/09 | 1 | *Spirogyra* sp. (Chlorophyta) | 85 |
| | 2 | *Microcystis aeruginosa* (Cyanophyta) | 9 |

Table 8. A list of major phytoplankton groups and the taxa that were identified from Head of Hummock Pond during 2009.

| **Cyanophyta** | **Chrysophyta (Bacillariophyceae)** |
|---|---|
| *Anabaena flos-aquae* | *Achnanthes sp.* |
| *A. spiroides* | *Amphiprora sp.* |
| *Chroococcus limneticus* | *Cocconeis sp.* |
| *Coelosphaerium naegelianum* | *Cyclotella sp.* |
| *Microcystis aeruginosa* | *Cymbella sp.* |
| *M. incerta* | *Fragilaria crotonensis* |
| **Chloromonadophyta** | *Gomphonema abbreviatum* |
| *Gonyostomum semen* | *G. lanceolatum* |
| **Chlorophyta** | *G. olivaceum* |
| *Ankistrodesmus falcatus* | *G. truncatum* |
| *Botryococcus braunii* | *Gyrosigma sp.* |
| *Chlamydomonas spp.* | *Navicula spp.* |
| *Closterium spp.* | *Neidium sp.* |
| *Coelastrum cambricum* | *Nitzschia sp.* |
| *Cosmarium spp.* | *Rhoicosphenia curvata* |
| *Crucigenia tetrapedia* | *Rhopalodia gibba* |
| *Elakatothrix gelatinosa* | *Stauroneis sp.* |
| *Eudorina elegans* | *Stephanodisus sp.* |
| *Kirchneriella subsolitaria* | *Surirella sp.* |
| *Oocystis borgei* | *Synedra acus* |
| *O. parva* | *S. fulgens* |
| *Pandorina morum* | *S. ulna* |
| *Pediastrum duplex* | **Chrysophyta (Chrysophyceae)** |
| *Quadrigula lacustris* | *Dinobyron* spores |
| *Scenedesmus arcuatus* Lemmerman | *Ochromonas* sp. |
| *S. bijuga* | **Euglenophyta** |
| *S. quadricauda* | *Trachelomonas* sp. |
| *Selenastrum minutum* | **Pyrrhophyta (Cryptophyceae)** |
| *Sphaerocystis schroeteri* | *Cryptomonas ovata* |
| *Tetraedron minimum* | **Pyrrhophyta (Dinophyceae)** |
| | *Peridinium cinctum* |

Table 9. Characteristics of the most commonly occurring phytoplankton taxa by major group in Head of Hummock Pond during 2009.

| Major Group<br>Genus (Taxon)-species | Cell Biomass<br>(μm$^3$) | Number of times the taxa<br>Occurred | BM dominant | DN Dominant | 2009<br>Seasonality |
|---|---|---|---|---|---|
| Cyanophyta | | | | | |
| *Anabaena flos-aquae* | 226.0 | 6 | 3 | 3 | July→Oct |
| *Anabaena spiroides* | 308.0 | 5 | 5 | 1 | Mid-July→Oct |
| *Microcystis aeruginosa* | 10.3 | 8 | 8 | 6 | June→Oct |
| Chlorophyta | | | | | |
| *Ankistrodesmus falcatus* | 250.0 | 5 | 1 | 0 | All season |
| *Closterium* spp. | 4000.0 | 5 | 0 | 0 | July |
| *Coelastrum cambricum* | 1046.8 | 6 | 4 | 0 | All season |
| *Oocystis borgei* | 135.0 | 5 | 0 | 0 | Mid-July→Oct |
| *O. parva* | 581.0 | 5 | 0 | 0 | July→Oct |
| *Pandorina morum* | 1196.4 | 5 | 1 | 0 | All season |
| *Scenedesmus quadricauda* | 100.0 | 8 | 0 | 0 | All season |
| *Selenastrum minutum* | 30.9 | 5 | 0 | 0 | Aug→Oct |
| *Tetraedron minimum* | 30.0 | 6 | 0 | 0 | Mid-July→Oct |
| Bacillariophyta | | | | | |
| *Cocconeis* sp. | 500.0 | 5 | 0 | 0 | Mid-August |
| *Cyclotella* sp. | 268.0 | 8 | 0 | 0 | All season |
| *Gomphonema olivaceum* | 610.0 | 7 | 0 | 0 | All season |
| *Navicula* spp. | 350.0 | 8 | 0 | 0 | All season |
| *Stephanodiscus spp.* | 2000.0 | 5 | 2 | 0 | Early July, mid- |
| *Synedra acus* | 350.0 | 7 | 0 | 0 | July→Oct |
| Chrysophyta | | | | | |
| *Dinobryon* spores | 775.0 | 6 | 2 | 0 | All season |
| Euglenophyta | | | | | |
| *Trachelomonas* sp. | 1144.5 | 7 | 0 | 0 | All season |
| Pyrrhophyta | | | | | |
| *Ceratium ovata* | 3890.7 | 7 | 5 | 0 | All season |
| BM = biomass; DN = density; months of occurrence are abbreviated in some cases | | | | | |

Table 10. Ranking of phytoplankton taxa dominance, using biomass, in Head of Hummock Pond on each sampling date during 2009.

| Sampling Date | BM Rank | Taxon (Major Group) | % of Total Biomass |
|---|---|---|---|
| | | | |
| 06/24/09 | 1 | *Microcystis aeruginosa* (Cyanophyta) | 32 |
| | 2 | *Coelastrum cambricum* (Chlorophyta) | 21 |
| | 3 | *Sphaerocystis schroeteri* (Chlorophyta) | 11 |
| | 4 | *Peridinium cinctum* (Pyrrophyta) | 11 |
| | 5 | *Ankistrodesmus falcatus* (Chlorophyta) | 8 |
| | 6 | *Gonyostomum semen* (Chloromonadophyta) | 6 |
| | | | |
| 07/07/09 | 1 | *Anabaena flos-aquae* (Cyanophyta) | 71 |
| | 2 | *Peridinium cinctum* (Pyrrophyta) | 11 |
| | 3 | *Closterium* spp. (Chlorophyta) | 6 |
| | | | |
| 07/21/09 | 1 | *Cryptomonas ovata* (Pyrrophyta) | 56 |
| | 2 | *Anabaena spiroides* (Cyanophyta) | 25 |
| | 3 | *Microcystis aeruginosa* (Cyanophyta) | 6 |
| | | | |
| 08/04/09 | 1 | *Anabaena flos-aquae* (Cyanophyta) | 48 |
| | 2 | *Cryptomonas ovata* (Pyrrophyta) | 29 |
| | 3 | *Coelastrum cambricum* (Chlorophyta) | 9 |
| | 4 | *Dinobryon* spores | 5 |
| | | | |
| 08/18/09 | 1 | *Anabaena flos-aquae* (Cyanophyta) | 32 |
| | 2 | *Anabaena spiroides* (Cyanophyta) | 21 |
| | 3 | *Microcystis aeruginosa* (Cyanophyta) | 17 |
| | 4 | *Cryptomonas ovata* (Pyrrophyta) | 7 |
| | 5 | *Coelastrum cambricum* (Chlorophyta) | 6 |
| | | | |
| 09/08/09 | 1 | *Microcystis aeruginosa* (Cyanophyta) | 51 |
| | 2 | *Chrococcus limneticus* (Cyanophyta) | 7 |
| | 3 | *Eudorina elegans* (Chlorophyta) | 7 |
| | 4 | *Stephanodiscus* sp. (Chrysophyta) | 7 |
| | 5 | *Microcystis incerta* (Cyanophyta) | 6 |
| | 6 | *Cryptomonas ovata* (Pyrrophyta) | 6 |
| | 7 | *Anabaena spiroides* (Cyanophyta) | 5 |
| | | | |
| 09/30/09 | 1 | *Microcystis aeruginosa* (Cyanophyta) | 54 |
| | 2 | *Anabaena spiroides* (Cyanophyta) | 23 |
| | 3 | *Microcystis incerta* (Cyanophyta) | 7 |
| | | | |
| 10/27/09 | 1 | *Microcystis aeruginosa* (Cyanophyta) | 32 |
| | 2 | *Cryptomonas ovata* (Pyrrophyta) | 17 |
| | 3 | *Anabaena spiroides* (Cyanophyta) | 9 |
| | 4 | *Coelastrum cambricum* (Chlorophyta) | 8 |
| | 5 | *Pandorina morum* (Chlorophyta) | 7 |
| | 6 | *Stephanodiscus* sp. (Chrysophyta) | 5 |

Table 11. A list of aquatic plants identified in Hummock Pond and Head of Hummock Pond during a survey on 24 and 25 August 2009. The frequency of occurrence, distribution and abundance of the individual genera are summarized.

| Aquatic Plants | Hummock Pond Aquatic Plant Distribution and Abundance | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | | Trace | | Sparse | | Medium | | Dense | | Empty | |
| | Sites | % | Sites | % | Sites | % | Sites | % | Sites | % | Sites | % |
| **Total** | 115 | 100% | 17 | 15% | 23 | 20% | 37 | 32% | 12 | 10% | 26 | 23 |
| *Potamogeton perfoliatus* | 70 | 61% | 29 | 41% | 26 | 37% | 13 | 19% | 2 | 3% | | |
| *Potamogeton pusillus* | 65 | 57% | 29 | 45% | 18 | 28% | 17 | 26% | 1 | 2% | | |
| *Ceratophyllum echinatum* | 38 | 33% | 8 | 21% | 13 | 34% | 17 | 45% | 0 | 0% | | |
| *Potamogeton pectinatus* | 34 | 30% | 21 | 62% | 10 | 29% | 3 | 9% | 0 | 0% | | |
| *Ruppia maritima* | 28 | 24% | 22 | 79% | 5 | 18% | 1 | 4% | 0 | 0% | | |
| *Vallisneria americana* | 27 | 23% | 13 | 48% | 13 | 48% | 1 | 4% | 0 | 0% | | |
| Benthic Filamentous Algae | 24 | 21% | 16 | 67% | 5 | 21% | 2 | 8% | 1 | 4% | | |
| *Ceratophyllum demersum* | 23 | 20% | 12 | 52% | 7 | 30% | 2 | 9% | 2 | 9% | | |
| *Nitella* spp. | 18 | 16% | 13 | 72% | 4 | 22% | 1 | 6% | 0 | 0% | | |
| *Najas flexilis* | 12 | 10% | 4 | 33% | 5 | 42% | 3 | 25% | 0 | 0% | | |
| *Lemna minor* | 4 | 3% | 3 | 75% | 1 | 25% | 0 | 0% | 0 | 0% | | |
| *Fontinalis* spp. | 1 | 1% | 1 | 100% | 0 | 0% | 0 | 0% | 0 | 0% | | |

# Section 6

# Figures

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

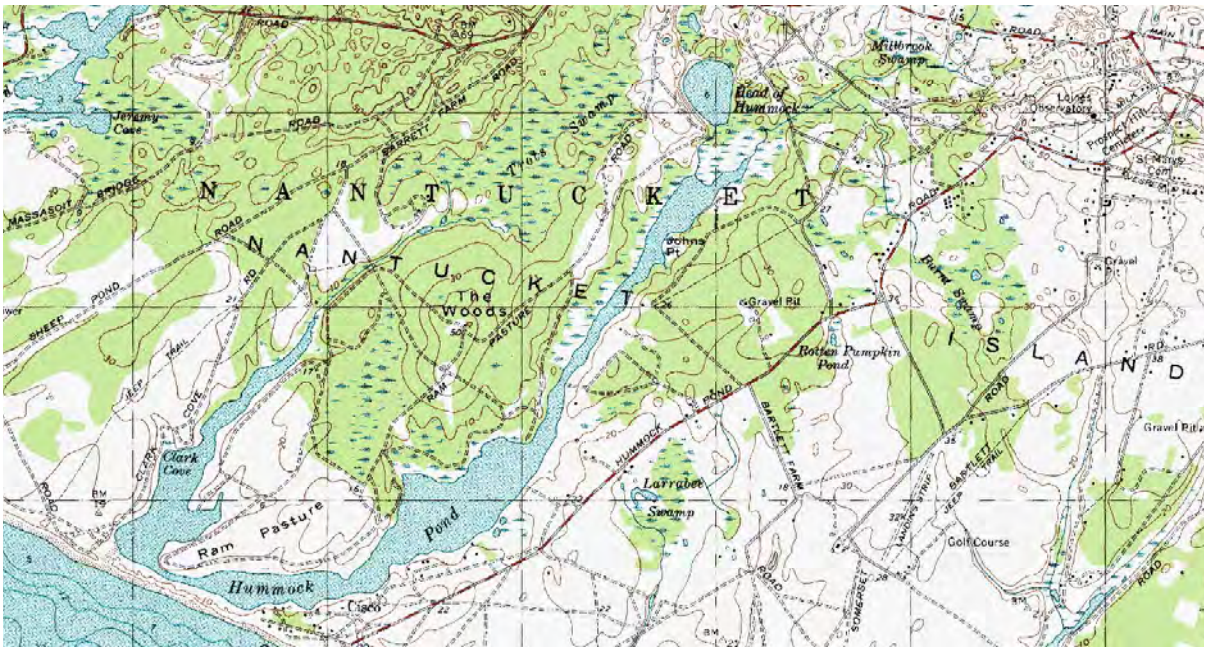


Figure 2. A photo of Hummock and Head of Hummock Ponds showing the four Stations that were sampled for water quality during 2009.

Figure 3. A map of Hummock and Head of Hummock Ponds showing water depths measured during the aquatic plant survey on 24 and 25 August 2009.

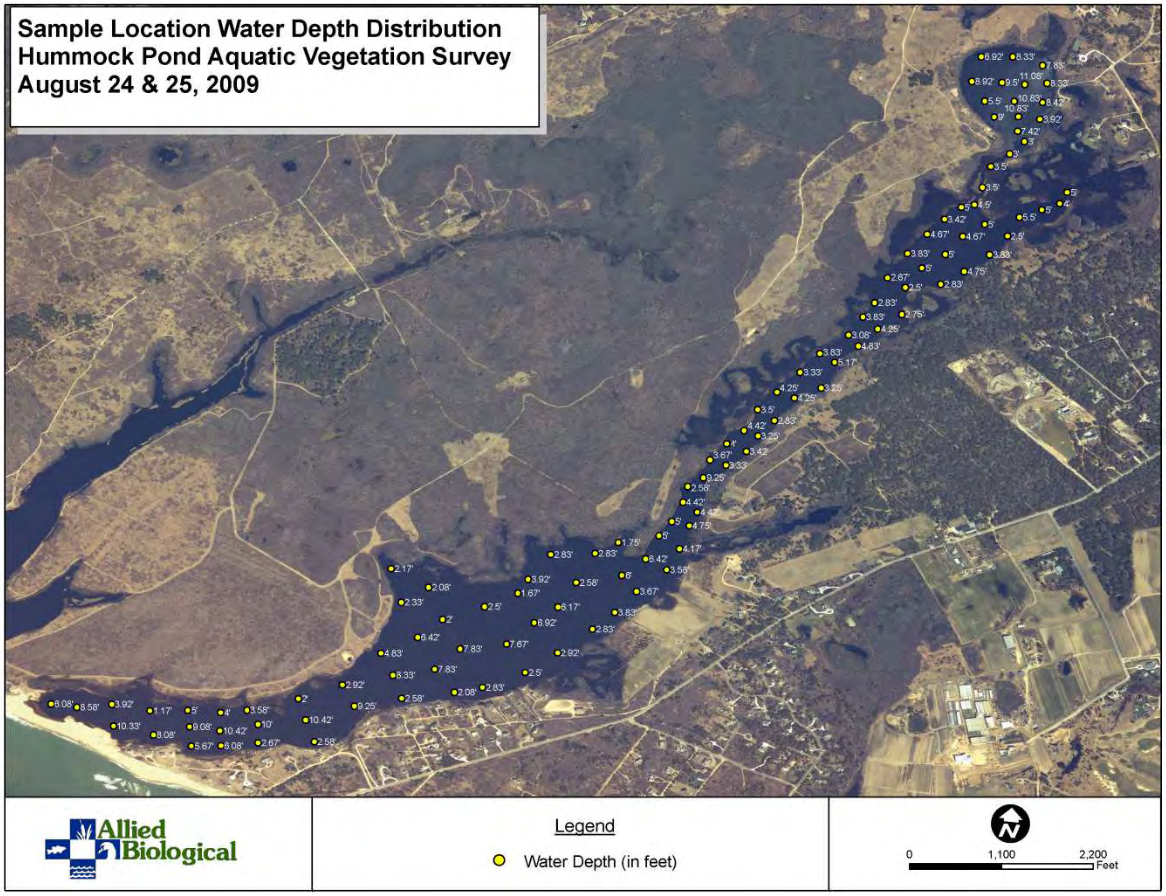


Figure 4. The average water column temperature measured at the Hummock and Head of Hummock Pond stations during the 2009 sampling season.

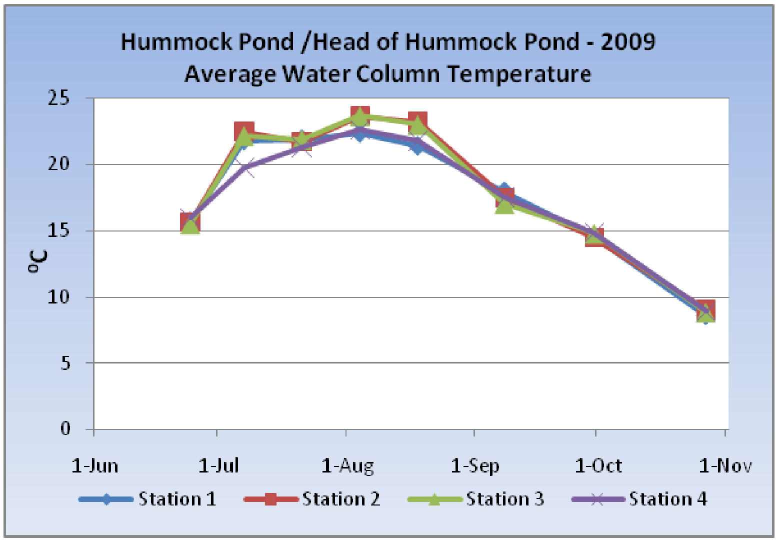



Figure 5. The pattern of water column profile temperature measured in Head of Hummock Pond during eight sampling dates in 2009.

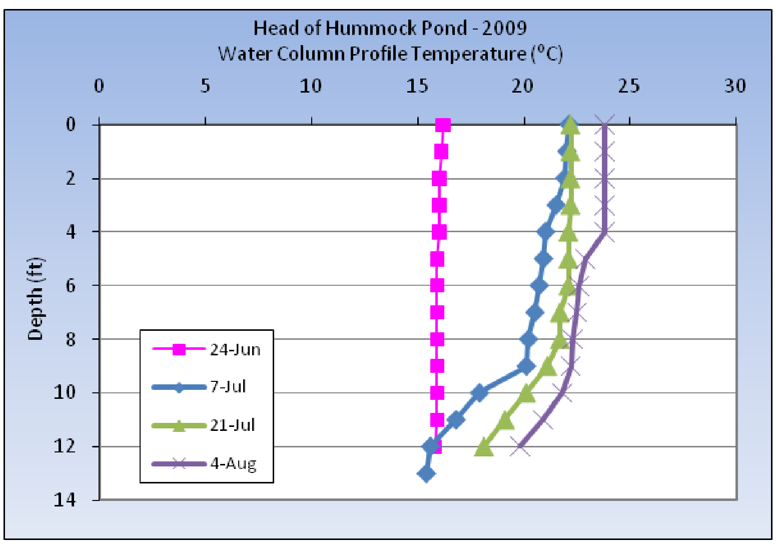


Figure 5. (continued).

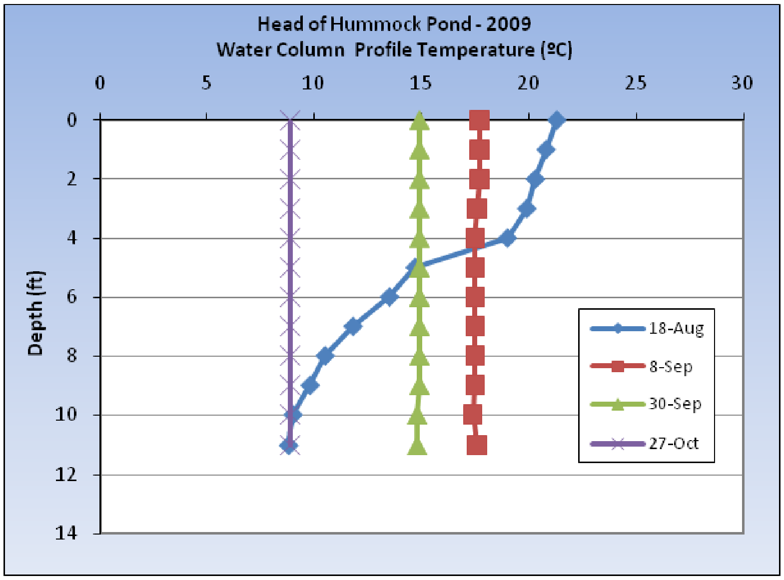



Figure 6. The pattern of Secchi depth transparency measured at the Hummock and Head of Hummock Pond stations during 2009.

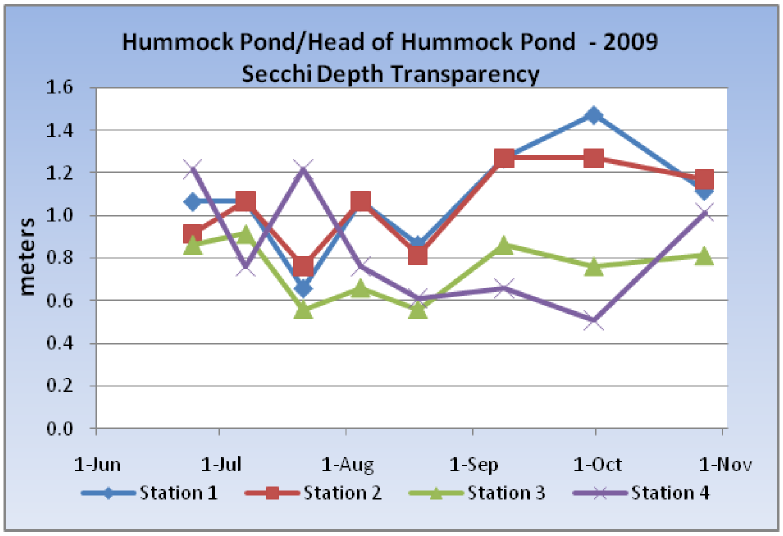


Figure 7. The pattern of water column specific conductance measured at the Hummock and Head of Hummock Pond stations during 2009.

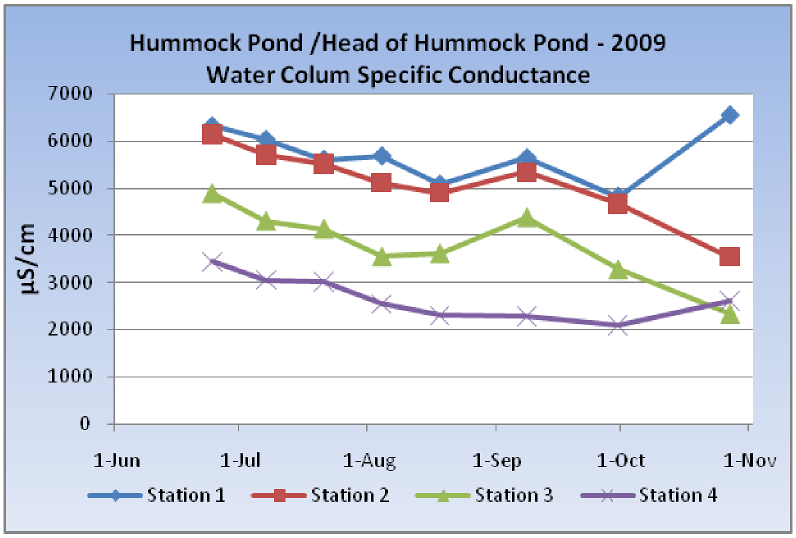



Figure 8. The pattern of water column pH measured at the Hummock and Head of Hummock Pond stations during 2009.

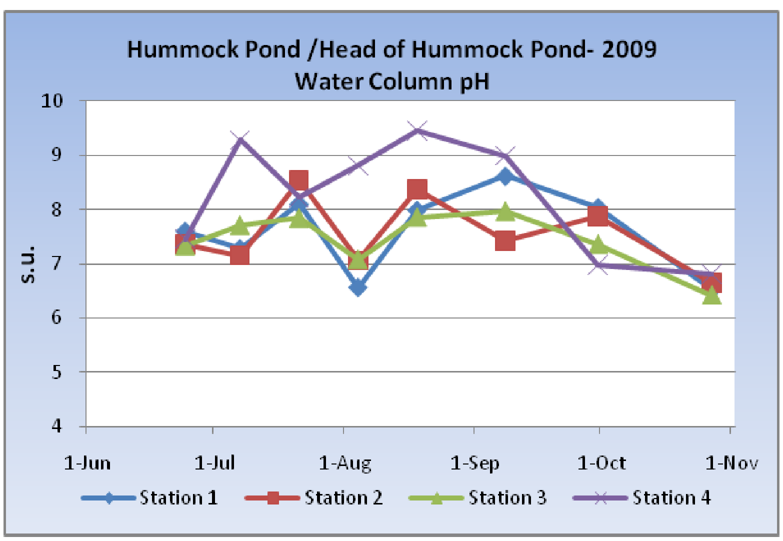


Figure 9. The pattern of average water column dissolved oxygen concentration measured at the Hummock and Head of Hummock Pond stations during 2009.

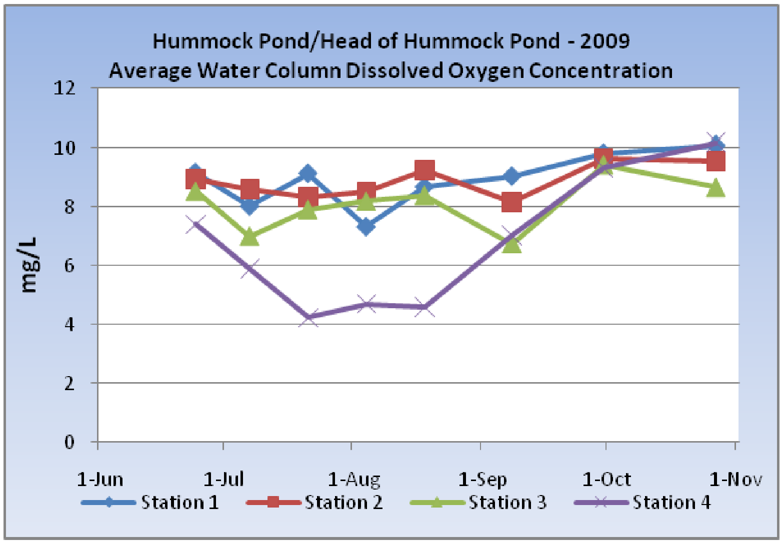



Figure 10. The pattern of average water column dissolved oxygen percent saturation measured at the Hummock and Head of Hummock Pond stations during 2009.

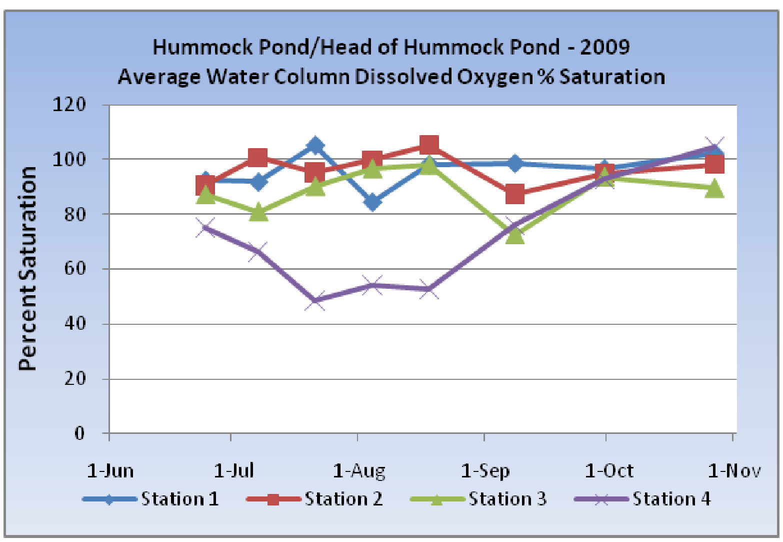


Figure 11. The pattern of water column profile dissolved oxygen percent saturation measured at the Head of Hummock Pond station during 2009.

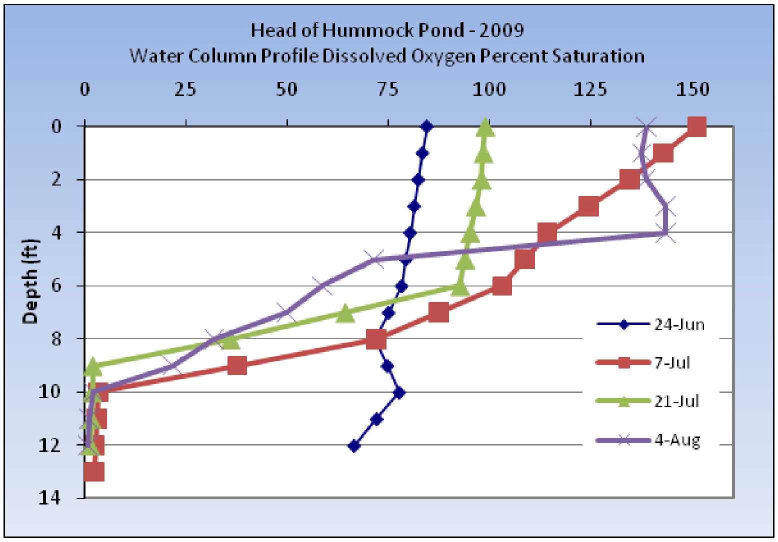



Figure 11. (continued).

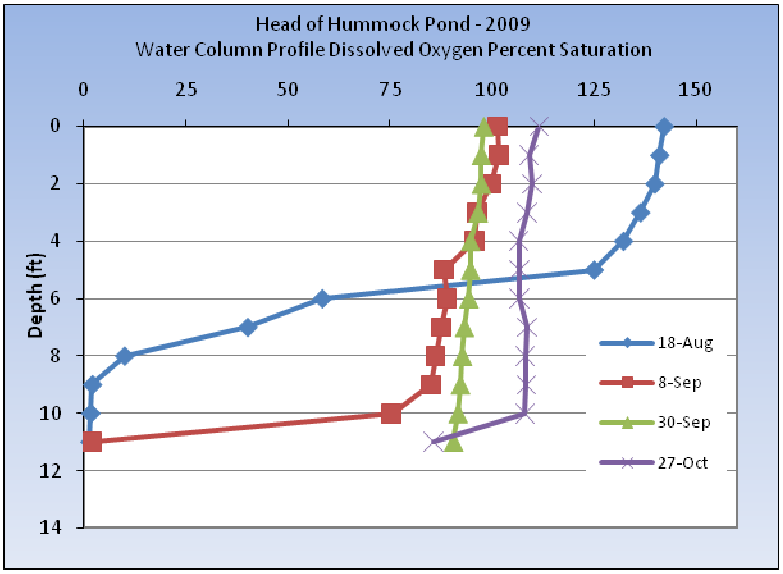


Figure 12. The pattern of water column nitrate-nitrogen concentrations measured at the Hummock and Head of Hummock Pond stations during 2009.

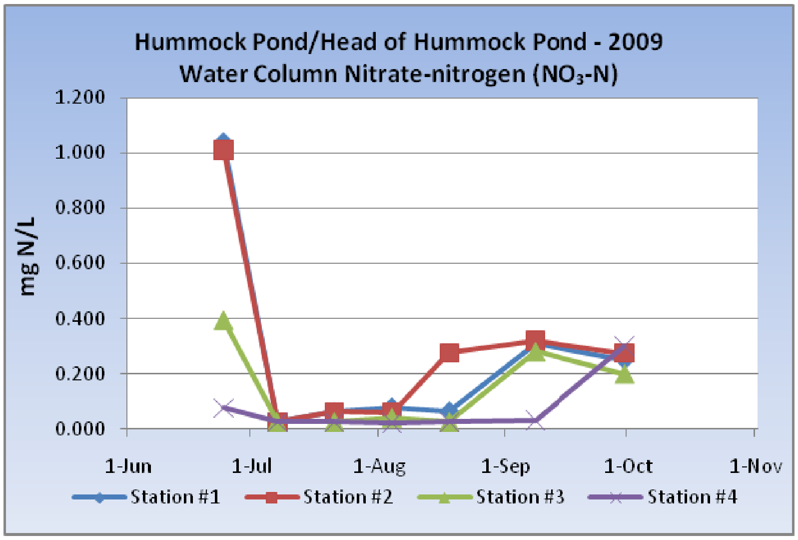



Figure 13. The pattern of water column ammonia-nitrogen concentrations measured at the Hummock and Head of Hummock Pond stations during 2009.

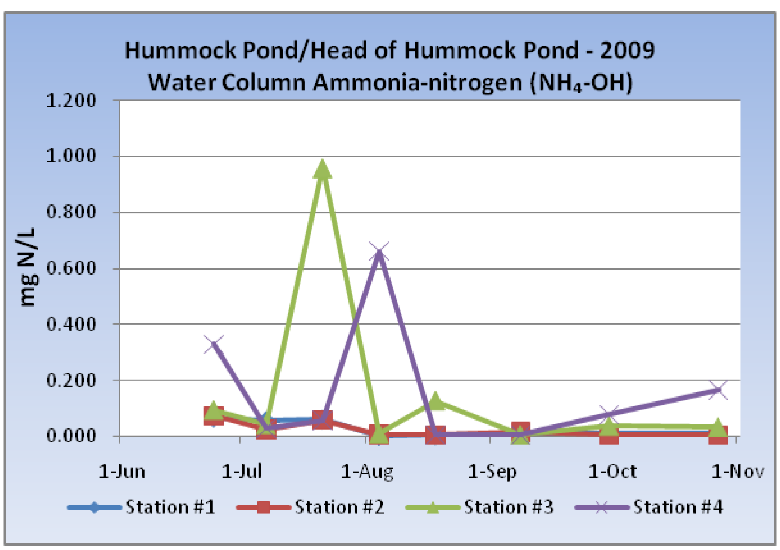


Figure 14. The average station water column concentrations of nitrate+ammonia and total nitrogen measured at the Hummock and Head of Hummock Pond stations during 2009 and the calculated organic nitrogen concentrations.

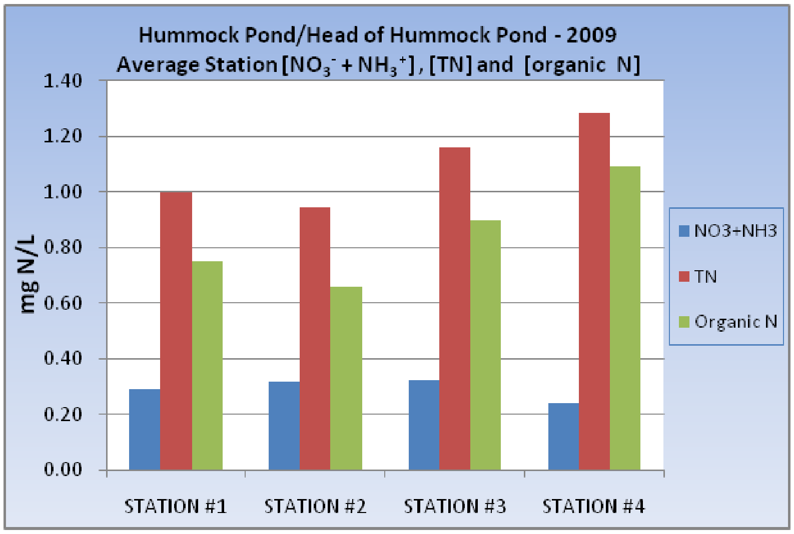



Figure 15. The pattern of water column total nitrogen concentrations measured at the Hummock and Head of Hummock Pond stations during 2009.

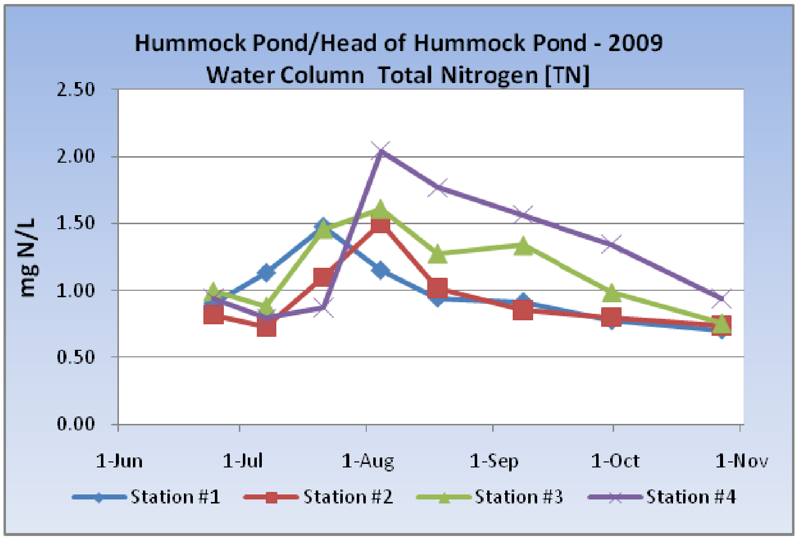


Figure 16. A comparison of total nitrogen concentrations measured in the upper and lower regions of Head of Hummock Pond during 2009.

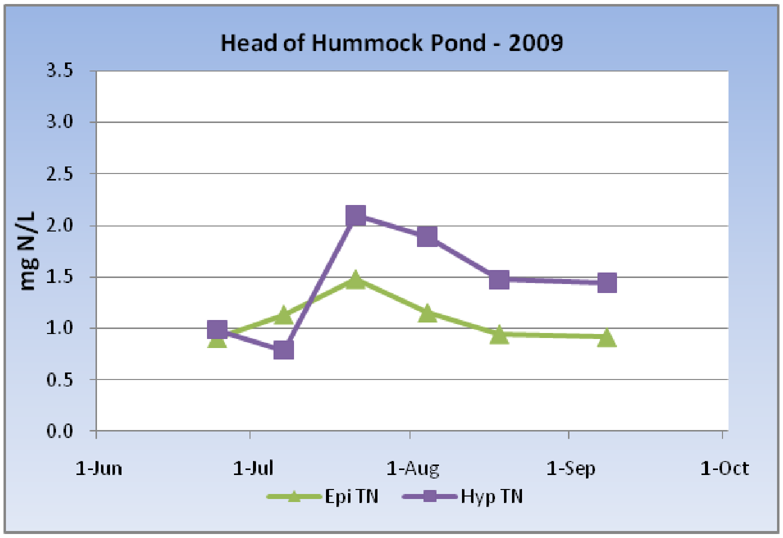



Figure 17. The pattern of water column total phosphorus concentrations measured at the Hummock and Head of Hummock Pond stations during 2009.

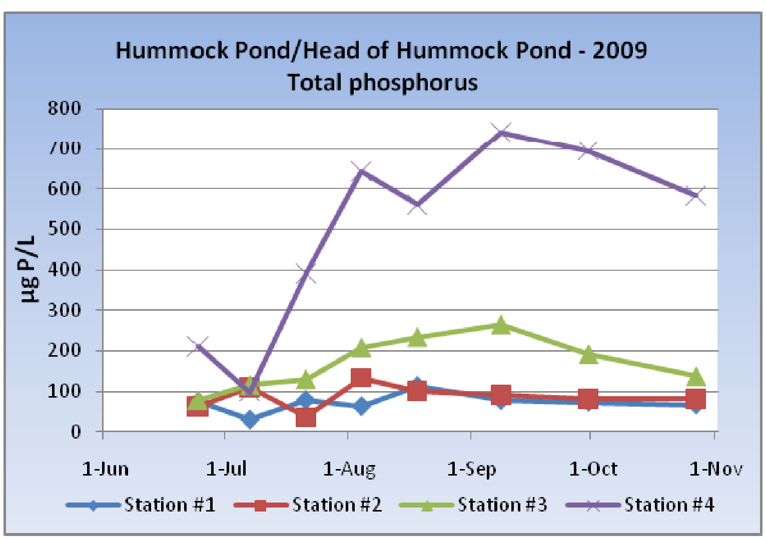


Figure 18. A comparison of total phosphorus concentration measured in the upper and lower regions of Head of Hummock Pond during 2009.

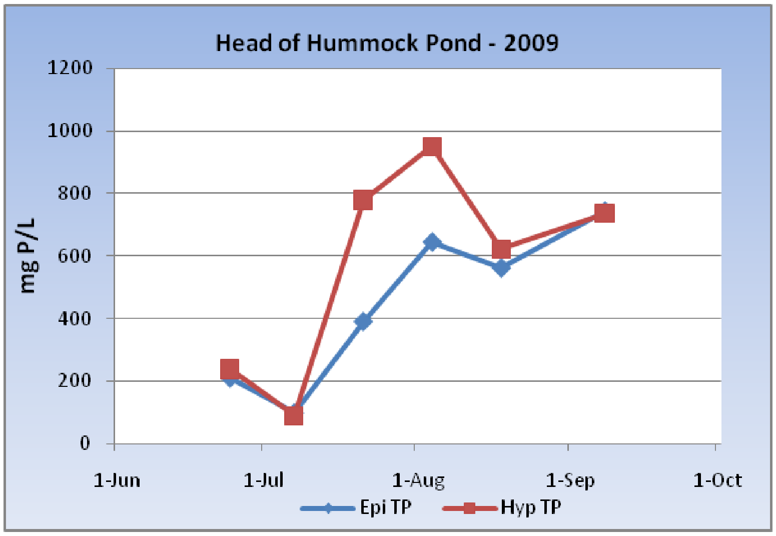



Figure 19. The pattern of water column number of phytoplankton taxa in Hummock Pond during 2009.

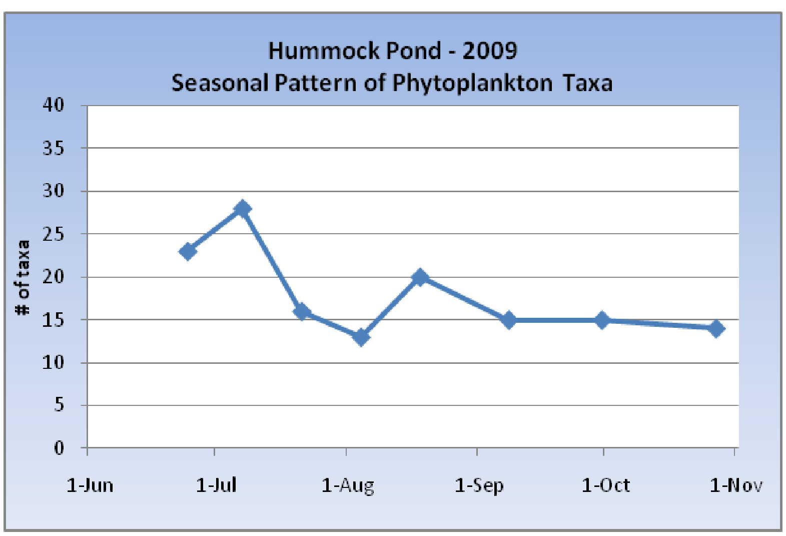


Figure 20. A ranking of phytoplankton taxa occurrence in Hummock Pond during 2009.

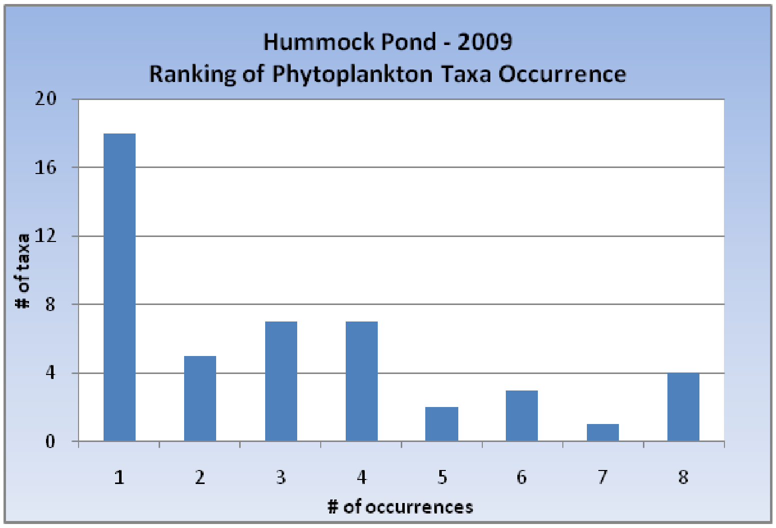



Figure 21. The pattern of density exhibited by major groups of phytoplankton in Hummock Pond during 2009.

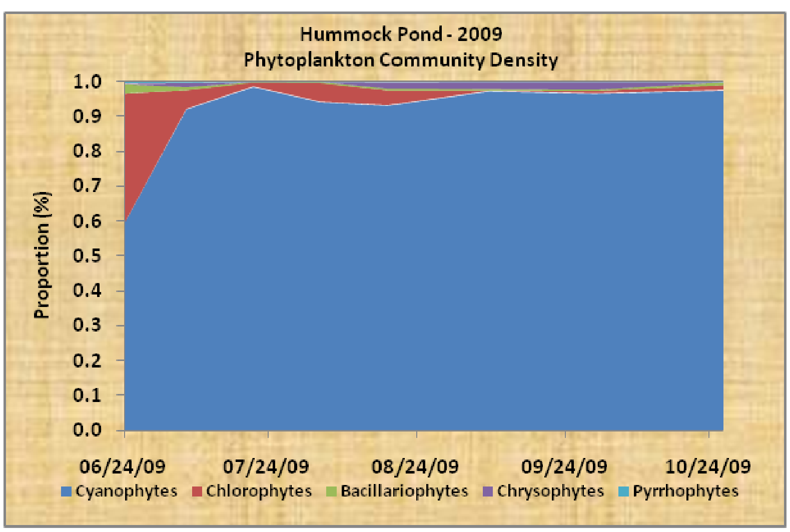


Figure 22. The pattern of biomass exhibited by major groups of phytoplankton in Hummock Pond during 2009.

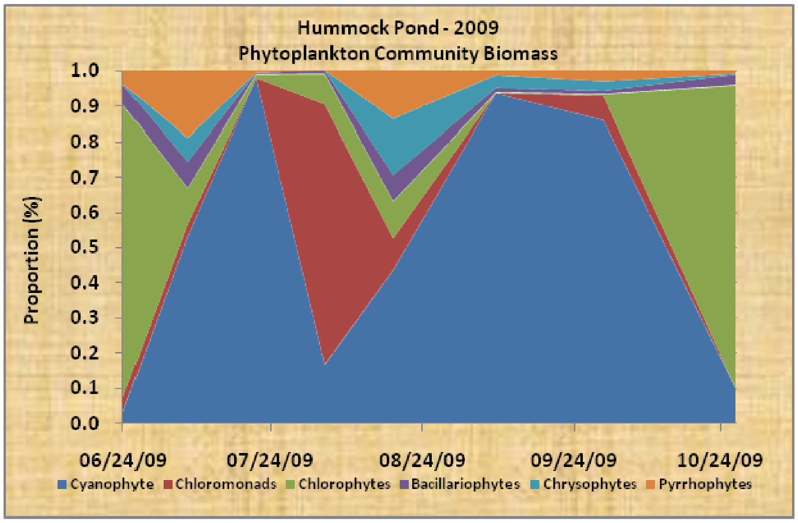



Figure 23. The pattern of phytoplankton community statistics measured in Hummock Pond during 2009.

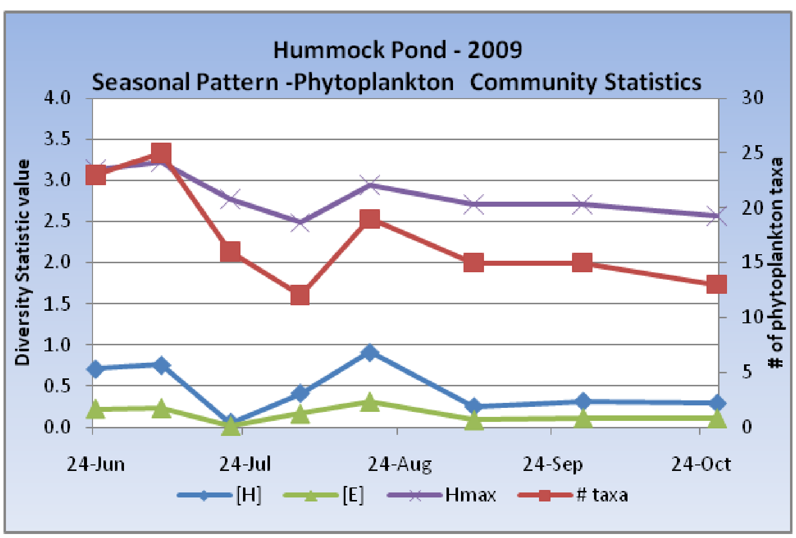


Figure 24. The pattern of chlorophyll *a* concentration in Hummock Pond during 2009 compared with phytoplankton density and biomass.

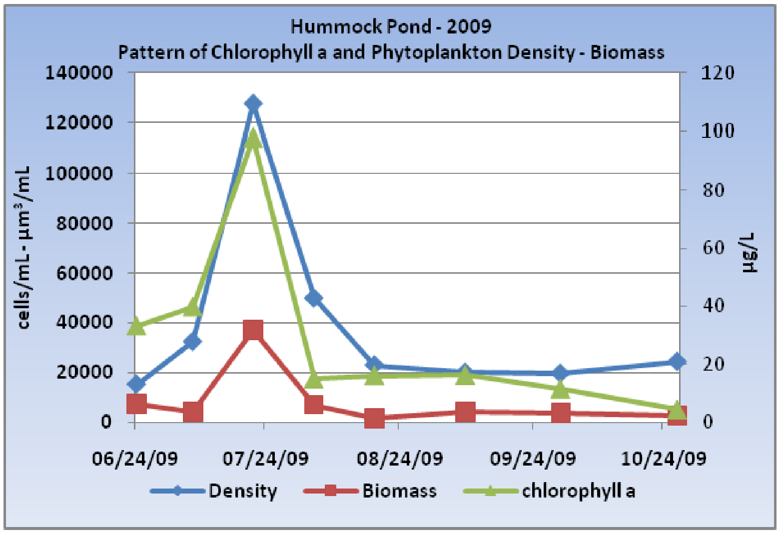



Figure 25. The pattern of water column number of phytoplankton taxa in Head of Hummock Pond during 2009.

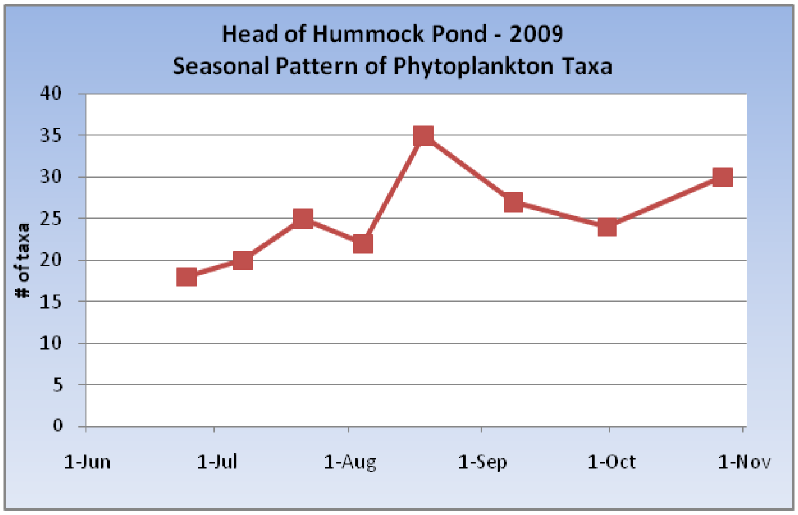


Figure 26. A ranking of phytoplankton taxa occurrence in Head of Hummock Pond during 2009.

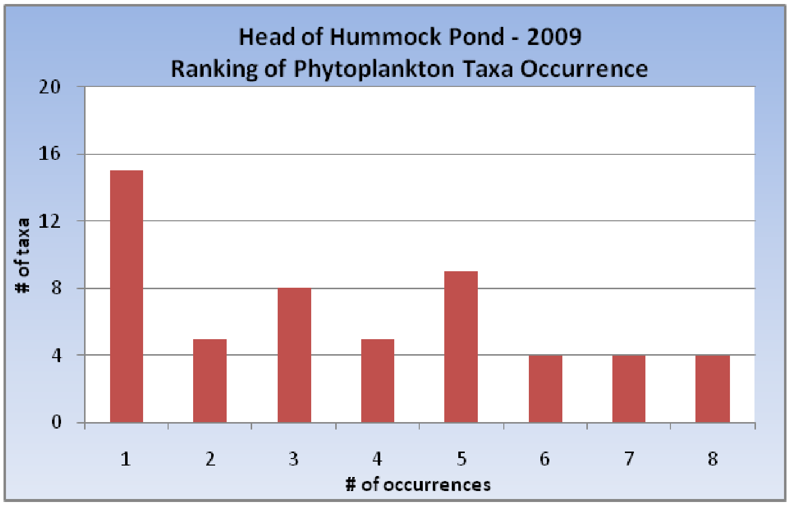



Figure 27. The pattern of density exhibited by major groups of phytoplankton in Head of Hummock Pond during 2009.

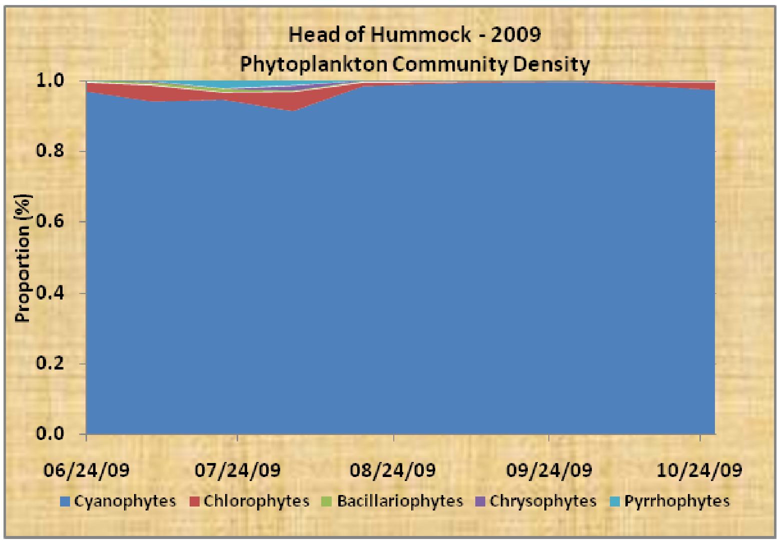


Figure 28. The pattern of biomass exhibited by major groups of phytoplankton in Head of Hummock Pond during 2009.

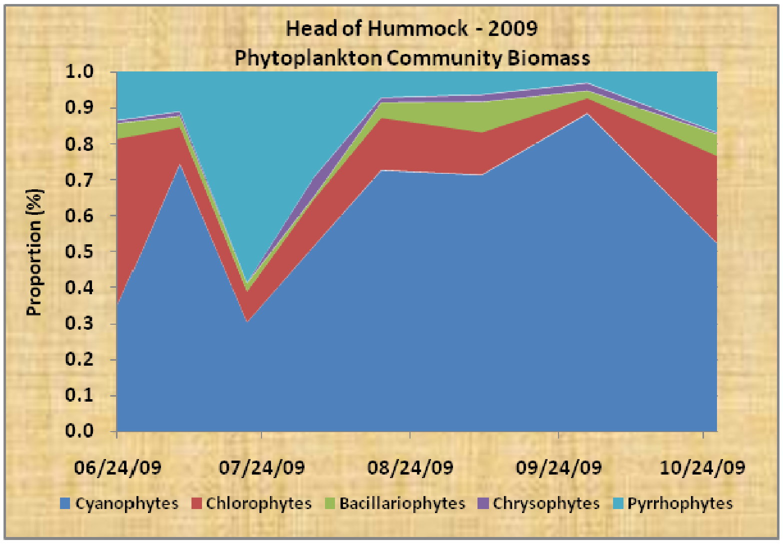



Figure 29. The pattern of phytoplankton community statistics measured in Head of Hummock Pond during 2009.

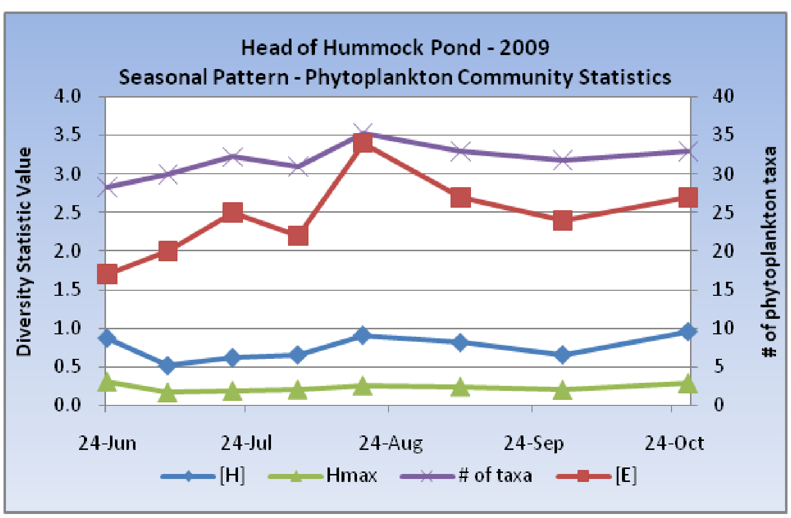


Figure 30. The pattern of chlorophyll a concentration in Head of Hummock Pond during 2009 compared with phytoplankton density and biomass

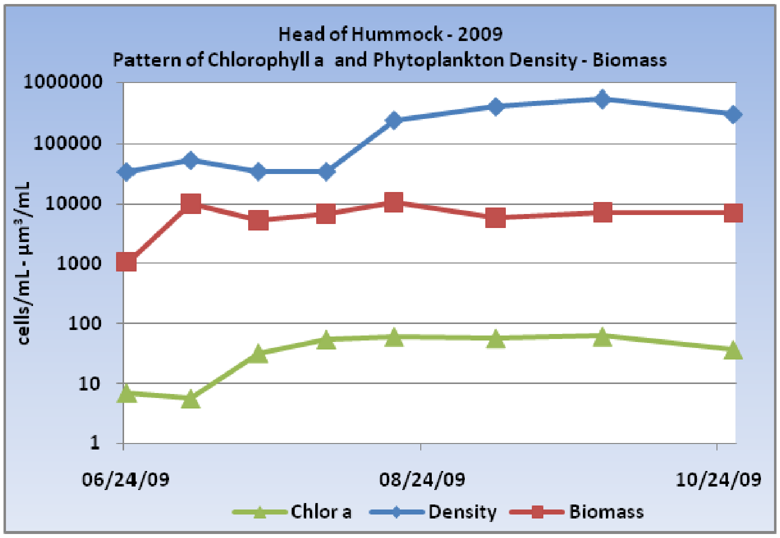


Figure 31. A map of Hummock and Head of Hummock Ponds showing the distribution and abundance of aquatic plants documented during a survey on 25 and 26 August 2009.

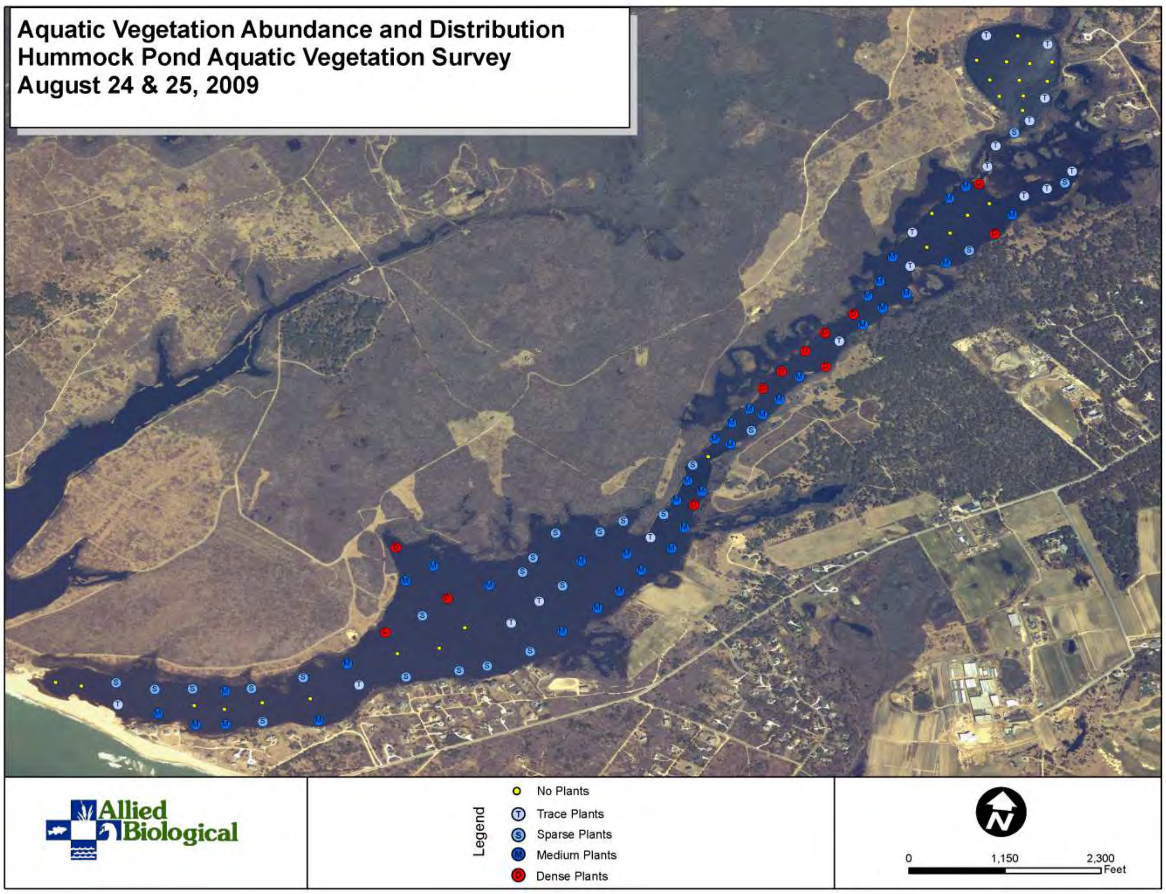


Figure 32. A summary of the average station total phosphorus concentration in Hummock and Head of Hummock Ponds during 2009.

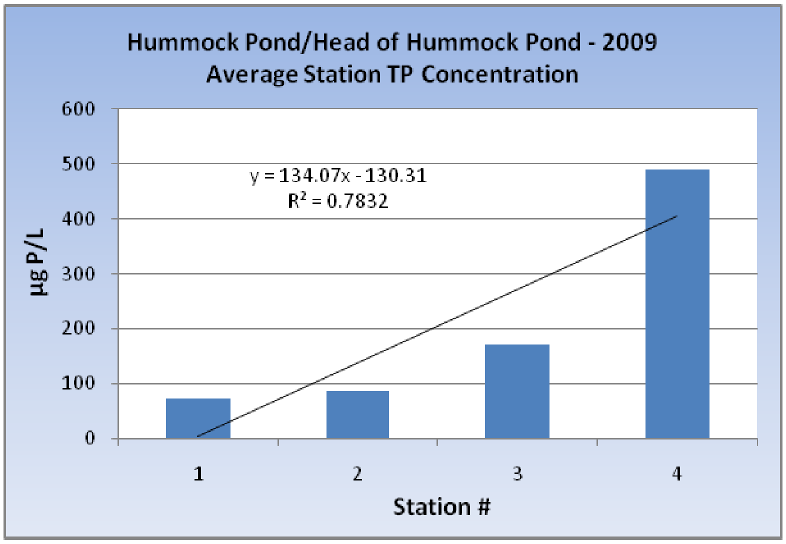
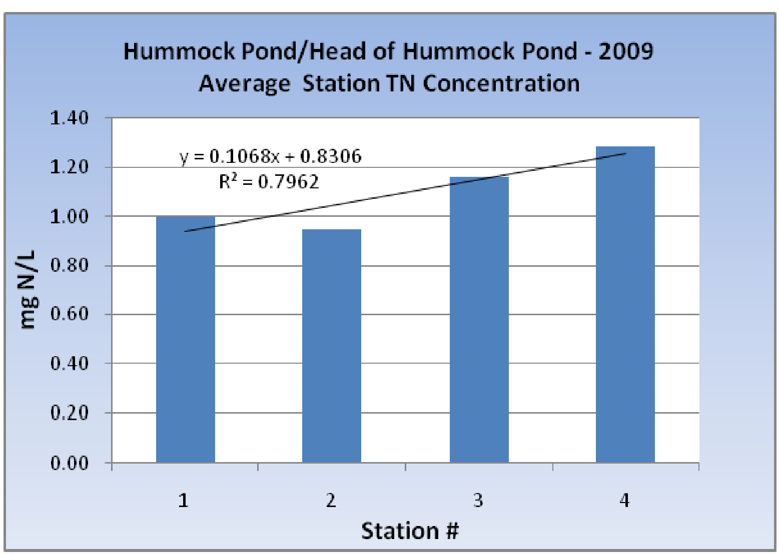



Figure 33. A summary of the average station total nitrogen concentration in Hummock and Head of Hummock Ponds during 2009.



# Appendix 1

Project Field Sheets

Chain of Custody Form

Vegetation Field Sheet

Vegetation Rake Information

## HUMMOCK POND
## 2009 WATER QUALITY SAMPLING

**STATION #** ____________________ **DATE** ____________ **TIME** ____________

**CONDITIONS** ______________________________________________________________

**TOTAL DEPTH** __________ **WATER COLOR** __________ **LAT** ____________

**SECCHI DEPTH** __________ **TEAM INITIALS** __________ **LONG** ____________

**COMMENTS** ______________________________________________________________

| DEPTH | | | | | | | |
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| SAMPLE # | SAMPLE DEPTH | COMMENTS |
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**OTHER** ______________________________________________________________

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## 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) |
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### 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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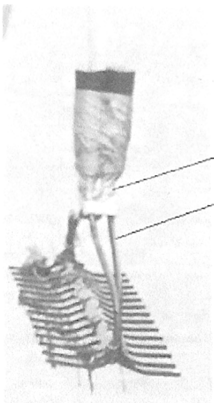


## Instructions for making two-sided rake

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