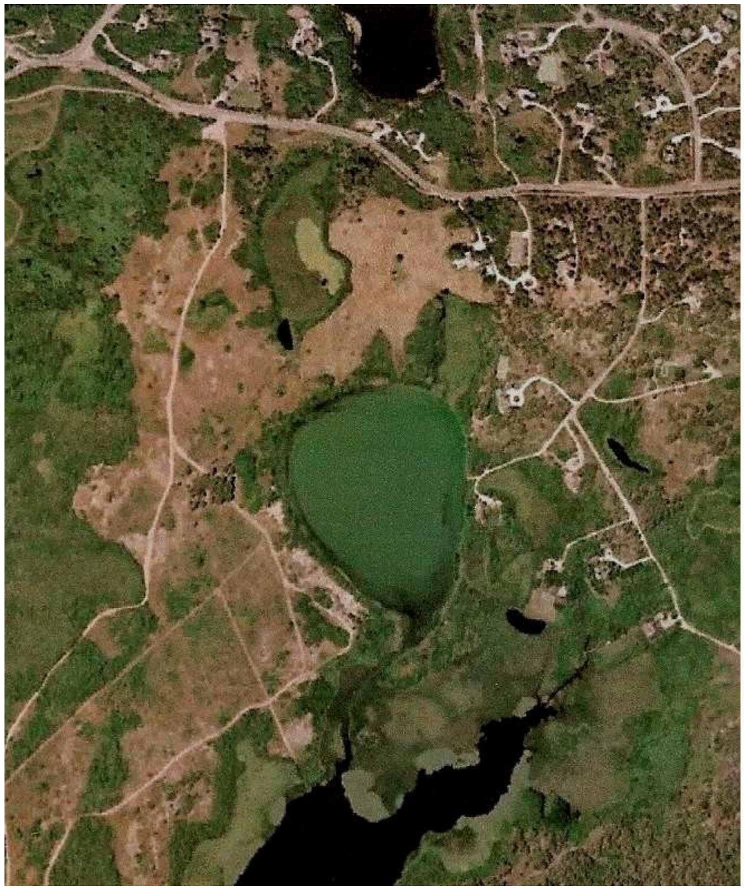
Head of Hummock Pond

The 2010 Water Quality Program

A Summary of Physical, Chemical and Biological Monitoring



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Head of Hummock Pond

The 2010 Water Quality Program

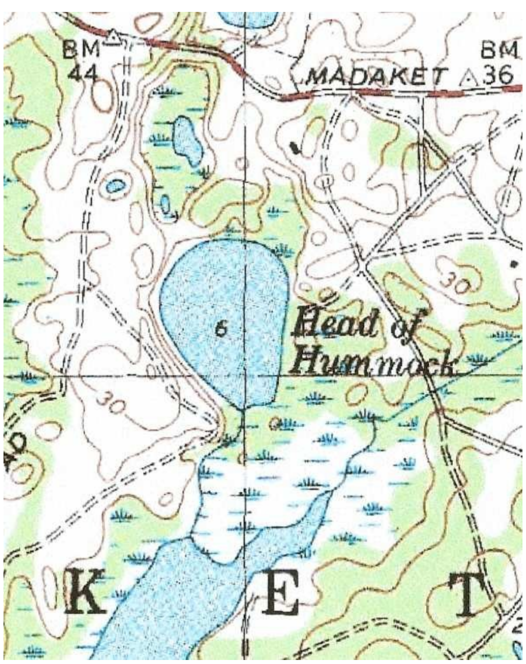
Chapter 1

Executive Summary

1.0 Project Location, Boundary and Background

Head of Hummock Pond, referred to in this report as HHP, is located in Nantucket County, Massachusetts, and appears on the United States Geological Survey (USGS) 7.5 minute quadrangle map, Nantucket, with an outflow located at an approximate latitude of 41°16'37" and longitude of 70°08'01" (Figure 1.1). HHP is considered to be part of Hummock Pond and the two ponds are connected by the HHP outlet channel which winds through an extensive wetland and enters Hummock Pond at the northwest end. HHP and its watershed are located within the Town of Nantucket. Stewardship of the pond is under jurisdiction of the Town. HHP and Hummock Pond are used primarily for contact recreation including boating, kayaking, fishing, sailing and swimming. Both ponds also provide important habitat for a variety of waterfowl, including migrating and over-wintering resident populations.

Figure 1.1 USGS quadrangle map showing Head of Hummock Pond (HHP) in relation to Hummock Pond and the channel that connects the two water bodies.



Hummock Pond is listed as one of seven Great Ponds that are located within Nantucket County by the MA Department of Environmental Protection. Beginning in 1994, the Nantucket Marine and Coastal Resource Department initiated monthly monitoring of water quality parameters on Hummock Pond during the ice-free period of the year, focusing on temperature, dissolved oxygen, salinity, Secchi depth, water depth and nutrient chemistry, and issued annual reports each year. No HHP stations were sampled, however, as part of this annual program until the mid-2000.

The first evidence of water quality information being collected from HHP was included with a summary of 2004-2005 physical and chemical data collected from Hummock Pond, which was reported and discussed by Knoecklein (2006). Subsequently, Conant (2007, 2008) continued to sample Hummock Pond and included an HHP station which was mentioned in the 2006 and 2007 annual reports issued by the Marine and Coastal Resource Department. During 2009, the UMass Boston Field Station and Nantucket Land Council funded a cooperative study of Hummock Pond (Sutherland et al., 2010), which included a station on HHP. The HHP data collected during 2009 indicated that the pond water quality at certain times of the year could be characterized as hyper-eutrophic, or extremely productive.

1.1 Purpose of the 2010 Project

A primary goal of the 2010 project was to expand the four-month 2009 sampling effort and gather additional detailed information that would either confirm or refine the water quality evaluation from the previous year. In particular, the 2010 project was initiated much earlier in the season so that the sequence of water quality events in HHP could be documented as the growing season progressed from the period following ice-out through late fall. A secondary goal during 2010 was to evaluate water quality in the pond prior to, and following, the spring and fall openings to the Atlantic Ocean and determine whether the opening event has a positive or negative effect on water quality. The specific objectives of the 2010 project were to

- Define the 2010 water quality of HHP and compare it to the 2009 water quality, and

- Evaluate any HHP historical water quality data and determine whether any significant trends are developing over time.

The primary factor that motivated the continued investigation of HHP in 2010 was the extremely poor 2009 water quality. In addition, there was serious concern about the predominance of Cyanobacteria populations in HHP during 2009 and the potential public health and safety issues associated with chronic blooms of these organisms. This concern is related to an accumulating body of evidence linking bloom toxins with the development of sporadic ALS disease in individuals who have resided in close proximity to ponds affected by 'bloom' conditions for some undefined period of time.

1.2 2010 Project Description

The Nantucket Land Council (NLC) provided the funding necessary to implement the 2010 project. The plan was to sample HHP every two weeks for an eight month period, beginning in early April and continuing through mid-November. A total of 21 sampling trips were conducted, with a full regimen of physical, chemical and biological information collected on 16 trips. There were 5 additional trips to collect extra temperature and dissolved oxygen profile data. A single sampling station was set up over the deep region of HHP and permanently marked with a float and anchor to insure that the same location was sampled each time.

1.3 Presentation of the 2010 Report

Chapter 1 provides an Executive Summary of the 2010 Project and its findings, as well as some goals for improving HHP water quality, and a summary of the Program recommendations.

Chapter 2 explains details of the 2010 sampling program that was conducted on HHP and the methodology used during the sampling program.

Chapter 3 describes the 2010 water quality of HHP as evaluated through analysis of physical, chemical and biological data.

Chapter 4 compares the 2009 and 2010 data to evaluate overall water quality using the two-year database as a reference.

Chapter 5 compares the 2009-2010 data with the recent historical data collected from HHP by previous investigators since 2004.

Chapter 6 provides a project summary, discussion, conclusions and recommendations that will lead to improved water quality in HHP.

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

1.4 2010 Project Findings and Conclusions

HHP is categorized as a hyper-eutrophic body of water with concentrations of total phosphorus and chlorophyll *a* far enough beyond the eutrophic/ hyper-eutrophic boundary to be cause for concern. The high levels of total phosphorus measured in HHP during the growing season apparently are generated within the system, given the extreme levels of primary productivity in the form of phytoplankton biomass that sinks to the lower waters where decomposition, oxygen depletion and phosphorus mobilization can complete the remainder of the internal cycling process. The high seasonal concentrations of chlorophyll *a* measured in the HHP during 2010 and also in 2009 reflect the extensive bloom conditions of Cyanobacteria observed and measured during the two years of investigation.

The primary source of the high total nitrogen concentrations documented in HHP during the past two years is not well understood. With such a small watershed and only a few homes within the area that contributes groundwater to the pond, it is essential that the relative contribution of internal versus external cycling of nitrogen, and possibly phosphorus, be determined for HHP before any long-term remediation is designed or implemented.

The neurotoxin microcystin (MC), which is produced by Cyanobacteria, was detected in HHP during the mid-summer and fall of 2010. Although the MC occurred in concentrations below recommended maximum levels for drinking water and recreational use, there still should be concern over the public health and safety issues associated with this substance. In many instances, the greatest damage resulting from Cyanobacteria blooms occurs during calm, windless periods on the pond or after cells die and float to the pond surface where they lyse and release their toxic contents into the surrounding water and air. Surface aggregations of cells can become concentrated after being blown shore-ward by winds, increasing the concentration factor of the MC toxin by several thousand-fold. This situation then can pose a serious threat for consumption by wildlife, cattle, and pets, or through air-borne wind dissemination of spores in the form of aerosols.

The different Cyanobacteria populations identified in HHP during 2010 and 2009 and the intensity of the mid-summer and fall blooms during the past two years emphasize the reckless and random response of the pond to excessive nutrient concentrations and the deteriorated condition of the entire ecosystem. There is no ecological balance in the system; everything in the pond occurs at or toward an extreme level. The pond requires some serious remedial attention directed toward the water quality problems that continue to be manifested each year.

Based upon the previous two years of water quality data and the recent historical information that has been collected from HHP and summarized in this report, it appears HHP has exceeded its assimilative capacity with regard to the plant nutrient nitrogen.

Immediate and appropriate remedial action directed toward HHP should be able to successfully reverse the current trend of poor water quality, while the lack of any remedial action will allow the system to self-perpetuate and get progressively worse each year, which is difficult to imagine, given the current extremely poor conditions in the pond.

Just controlling either nitrogen loading or internal cycling within HHP will do little to change the current seasonal sequence of events since Cyanobacteria are well-known for their nitrogen-fixing capability which gives them a highly competitive advantage over the other groups of phytoplankton in the ecosystem.

Therefore, a multi-faceted approach toward water quality management is required for HHP.

1.5 Recommendations

(1) Head of Hummock Pond requires some focused attention directed toward a series of water quality issues that have been manifested for part of the past decade, including considerable nutrient enrichment and severe, extended blooms of Cyanobacteria that produce toxins and pose a public safety threat.

(2) Environmental stewardship of HHP falls under the jurisdiction of the Town of Nantucket. In the absence of Town interest or the fiscal ability to participate in either water quality monitoring or other issues related to HHP, it would seem appropriate for some other local organization to exercise long-term vision toward water quality management and remediation for a body of water that obviously requires some dedicated attention. A logical candidate for this oversight role would be the Nantucket Land Council, Inc., an organization that has sponsored the past two years of investigation on HHP and has a strong vision toward both stewardship and environmental management on the Island.

(3) The water quality monitoring program that was developed and implemented on HHP during 2010 should be maintained during 2011 to continue documenting water quality issues on the pond and the response of pond water quality to long-distance circulation achieved by the SolarBee™ unit scheduled for installation during April 2011.

(4) Enhanced groundwater monitoring should be implemented in the HHP watershed including the installation of additional subsurface wells, funds for certified nutrient analyses, and studies to determine the direction of subsurface flows that will define the exact

contributory areas and will help develop a priority system for future Title 5 septic system inspections.

(5) Continue water quality sampling of Hummock Pond and Head of Hummock Pond before and after the opening to the Atlantic Ocean in order to fully evaluate the effect of the bi-annual opening on pond water quality.

(6) Continue to sample both phycocyanin and microcystin in HHP during the mid-summer and fall of each year and also set up adjacent terrestrial samplers in the watershed to determine the risk to local residents from wind-borne microcystin spores transmitted in aerosol form.

(7) Install a continuous water level recorder on HHP which is tied into an ASML (above mean sea level) datum to assist with preparation of a water budget for the pond.

(8) Continue to maintain close watch over the Hummock Pond aquatic plant community to provide early detection of introduced invasive species such as *Myriophyllum spicatum* (Eurasian watermilfoil) or *Hydrilla verticillata* (Esthewaite waterweed).

1.6 Literature Cited

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Head of Hummock Pond

The 2010 Water Quality Program

Chapter 2

Description of the Program and the Methodology

2.0 Background

Head of Hummock Pond (HHP) is a small body of water connected to the much larger Hummock Pond by a long, narrow channel traversing a wetland. Knoecklein (2006) first described the eutrophic condition of HHP following the completion of a comprehensive water quality investigation of Hummock Pond during 2004-2005. Follow-up water quality studies of Hummock Pond by the Nantucket Marine Coastal Resources Department (Conant, 2007, 2008) included an HHP station and reported extremely high nutrient concentrations in the water column during the 2007 growing season. Another water quality study of Hummock Pond conducted during a 4-month period in 2009 (Sutherland and Oktay, 2010) also sampled an HHP station and documented hyper-eutrophic conditions for certain water quality parameters. Most disturbing during the 2009 study were the extensive Cyanobacteria blooms documented in HHP, the associated negative implications of ecological food web changes and the public health and safety risk for individuals using the Pond recreationally and living in close proximity to the Pond.

2.0.1 Purpose of the 2010 sampling program

A detailed 2010 sampling program on HHP seemed essential as a result of the disturbing water quality documented in 2009. The report author (JWS) and Cormac Collier, Executive Director of the Nantucket Land Council, Inc. (NLC), developed a monitoring plan to (1) document water quality conditions during the growing season, (2) determine whether the events detailed in 2009 were repeated during 2010, and (3) compare the severity of the water quality conditions between 2009 and 2010.

2.0.2 Description of the 2010 sampling program

Water quality was monitored from early April through mid-November at a single station located above the deep area of HHP, just southwest of the pond center. The site was close to the 2009 sampling location on HHP. Following the start of the 2010 sampling season, a permanent marker buoy was placed at the sampling site to provide easy location reference during subsequent visits. Site latitude-longitude was recorded on most sampling visits using a SporTrak Pro Magellan GPS unit. The average latitude-longitude readings for the series of 2010 sampling visits to the pond were 41.16546 and 70.08032, respectively.

Water quality sampling was conducted on about a bi-weekly basis. The Pond was sampled a total of 16 times, and the sampling dates are listed below.

HHP – 2010 Sampling Dates	
April	7th, 21st
May	18th
June	1st, 15th, 29th
July	13th, 27th
August	9th, 25th, 31st
September	8th, 22nd
October	11th, 19th
November	15th
pond opened April 8th, October 21st	

The data and samples collected regularly from the sampling station on HHP during each sampling visit included the following

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

Table 2.1 provides a summary of the water quality parameters that were monitored in HHP during the 2010 sampling season.

2.1 Methodology

This section explains the field procedures used to collect samples and the processing that occurred, following collection, usually at the UMass Boston Nantucket Field Station Laboratory. In addition, certain pieces of equipment necessary for sampling, such as the Jon boat, oars, anchor and a meter were borrowed from the UMass Laboratory and made the 2010 HHP Program possible.

Table 2.1 Parameters monitored from early April through mid-November 2010 to assess the short-term water quality of HHP.

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
Phycocyanins and microcystins

2.1.1 Routine sample collection and processing

Sample collection occurred at the permanent HHP station. The boat was anchored at the site. Total depth of the water column was measured with a weighted Secchi disk on a marked line and then recorded. Latitude-longitude was recorded on sampling visits using a SporTrak Pro Magellan GPS.

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 direct sunlight in order to avoid surface glare which would interfere with the readings. The disk was lowered into the water column to the depth at which it just disappeared, and this depth was noted. The disk then was raised from out of the range of visibility to the depth where it first re-appeared, and this depth was noted. The average of the 2 depths was recorded as the Secchi depth transparency on that sampling date.

Vertical profiles of water temperature-dissolved oxygen were measured in-situ at 1-foot intervals 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 pond following a determination of whether the water column was stratified either thermally or based on 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 sampler. The collected samples were transferred to clean, pre-rinsed 1-liter polyethylene (PE) sample bottles and then stored on ice and in the dark until processing, which usually occurred within 2 hours of collection.

A subsample of water collected from the upper and lower levels of the water column was analyzed on-site for specific conductance, total dissolved solids, and pH using an Ultrameter II^{TM} (Myron L Company). Data were recorded on individual field sheets (shown in Appendix 1).

The water collected for nutrient chemistry, microcystin, phycocyanin, chlorophyll a and the phytoplankton samples usually were processed at the UMass Boston Nantucket Field Station immediately following each pond visit. The nutrient chemistry sample was processed by pouring off separate 75-100 mL aliquots of raw sample into 4-125 mL PE containers with snap lids labeled with either **TP**, **TN**, **NH3-N** and **NO3-N** and the accession numbers (sample label code) for the 2010 Nantucket sampling program. The accession format was **10-NIP-###**, with **###** being a series of consecutive numbers, starting at 001, that identified each set of samples collected. The water sample collected for phycocyanin-microcystin analysis was processed by pouring off separate 100 mL aliquots of raw sample into 4–125 mL PE containers with snap lids labeled with **MC1**, **MC2**, **MC3** and **MC4** and with accession numbers for the 2010 Nantucket sampling program.

The samples for chlorophyll a determination were concentrated by filtration through a 0.45µm glass fiber filter, with 0.2 mL MgCO3 suspension added for preservation during the final filtration phase. The filters were kept frozen and in the dark until delivery to the analytical laboratory.

The processed nutrient 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 is NYS-certified to process and analyze the nutrient chemistry and chlorophyll a included in this investigation. A Chain of Custody form (Appendix 1) accompanied the samples to the analytical lab.

The phycocyanin-microcystin samples were placed in a cooler with ice packs and shipped via FedEx (2^{nd} day delivery) to the University of New Hampshire (UNH), Center for Freshwater Biology (CFB), in Durham, NH. UHN-CFB has initiated a Citizen-based Cyanobacteria Monitoring Program (CCMP) that provides assistance to lake associations and drinking water facilities in tracking of cyanobacteria and microcystins in various bodies of water. A Chain of Custody form also accompanied these samples.

Phytoplankton samples were stored in 125 mL amber PE bottles, preserved with basic Lugol's solution and sent to Ms. Jill Scaglione at Aquatic Analysts Inc. in Middleville, NJ for analysis. Ms. Scaglione is certified in phytoplankton identification.

2.2 Analytical Techniques

The methods for water column measurements and field collections on HHP are summarized in Table 2.2. The analytical procedures for water chemistry and biological samples are presented in Table 2.3.

Table 2.2 Physical, chemical and biological parameters included in the 2010 HHP 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;
Chemical Characteristics (pH, conductivity, NO_3, NH_4, TN, TP)	Integrated epilimnetic sample; hypolimnetic grab sample at least 1 ft above bottom sediment	Ion Chromatograph, Atomic Absorption, Autoanalyzer, Spectrophotometer, pH meter
Biological Characteristics - Phytoplankton	Integrated photic zone sample (Integrated epilimnetic sample archived)	chlorophyll a, species identification and enumeration, biomass
Biological Characteristics - Phytoplankton	Integrated photic zone sample (Integrated epilimnetic sample archived)	phycocyanin and microcystin analysis

The report author (JWS) collected most of the data and samples in the field and conducted the processing. On two separate occasions, the samples were collected by an intern from the UMass Boston Nantucket Field Station who had been trained, on-site, with the specific collection techniques.

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 2.3. Chlorophyll a, retained on a filter, was broken down by grinding, extracted in 90% acetone, centrifuged, and determined fluorometrically (Table 2.3).

Table 2.3 Chemical parameters and analytical methods for the 2010 study of water quality in HHP.

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

2.2.1 Phytoplankton Identification-Enumeration

The protocol used for microscopic phytoplankton identification and enumeration is detailed below.

Counting method. At least 200 mL of properly preserved (with Lugol's or glutaraldehyde solution) sample is required for analysis. An inverted microscope is used 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, 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, and then analyzed at 1000x using oil immersion in order to accurately count cells below 10-20 um in size which may be present. 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 usually is counted to get a precision level of a least 95%. Results are recorded as number of cells per taxa present, with approximations being used for multicellular (colonial) taxa. Dead cells or empty diatom frustules are not counted.

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

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

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

Biovolume (mg^3 mL^{-1})-biomass (mg m^{-3}) conversion. Phytoplankton data derived on a volume-per-volume basis are more useful than numbers per milliliter (density) since algal cell sizes can differ in various bodies of water or within the same body of water at different times of the year. Average measurements were made from approximately 20 individuals of each taxa 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^{-1}) of any species is calculated by multiplying the average cell volume in cubic micrometers by the number of cells per milliliter. Results are recorded as biomass (mg/m^{-3}) by dividing total biovolume (mg^3/mL^{-1}) by 1,000.

Author's Note: In general discussions of the 2010 HHP phytoplankton community, the term 'taxa' is used rather than the term 'species' since it was not always possible to provide a definitive identification of cells to species level. The term 'species' is used when there is discussion concerning cells or colonies that were positively identified.

2.2.2 Phycocyanin and microcystin analysis.

At the UNH-CFB lab, cyanobacteria were determined with phycocyanin fluorescence standardized as equivalent *Microcystis aeruginosa* cells mL^{-1}. The liver toxin, microcystin, was analyzed with the ELISA plate technique. The general procedure for these analytical techniques is as follows:

1. Samples were received in 4-100 mL containers
2. Samples were integrated in the lab and mixed thoroughly.
3. Fluorescence of phycocyanin was measured using a Turner Design hand-held Fluorometer (fluorescence to determine the relative concentration of cyanobacteria).
4. Samples were frozen and thawed in triplicate to lyse cells.
5. Water samples were concentrated 10-fold by lyophillization.
6. Microcystin concentrations were determined using the Envirologix Quantiplate Kit for Microcystins, Portland, ME (tests results are equivalent to all variants of microcystin and nodularins)
7. Detection range (with standards) between 25 and 2500 ng MC L^{-1} (lower limit of detection for concentrated water (x10) is, thus, 2.5 ng MC L^{-1})

Samples were collected for phycocyanin and microcystin analysis on 12 different dates and shipped to the analytical laboratory at UNH CFB.

2.3 Literature Cited

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Head of Hummock Pond

The 2010 Water Quality Program

Chapter 3

The Water Quality Results for 2010

3.0 Introduction

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

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

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

3.1 Results

This chapter presents a summary and discussion of the HHP water quality data collected during 2010. Chapter 4 compares the 2010 and 2009 water quality data collected by the report author. Chapter 5 compares the 2009-2010 water quality data with recent historical data from HHP.

3.1.1 2010 sampling characteristics

There were 16 sampling trips to HHP during 2010 to collect profile data and samples for chemical and biological analysis. The fact that integrated chemistry samples were collected on 13 of the 16 site visits means that a more thorough description of true 'water column' characteristics can be provided since integrated samples are a cross-sectional view of the pond as compared with grab samples which only sample a specific depth in the water column.

3.1.2 Physical characteristics

General. HHP is a pear-shaped body of water oriented in a north-south direction with the wide portion located north and the narrow portion on the south (Figure 3.1).

Figure 3.1 Aerial view of HHP; note the algal bloom in progress when photo was taken (from Google Maps).

Within the range of normal summer water levels, HHP is about 260 m wide and 340 m long, and occupies a surface area of about 64000 m^2, or 6.5 hectares[1]. For the purpose of calculating an approximate volume, if the pond outline is considered to be an exaggerated circle, then the radius is 140 m and the rough volume for a bowl (the pond in cross-sectional view) can be calculated using the equation for one-half the volume of a sphere

$$V = \frac{2}{3}\,\pi\,(r^3)$$

Using this equation, the approximate volume of HHP is 5,772,827 m^3, or 4680 acre-feet. One acre-foot is the volume of water sufficient to cover an acre of land to a depth of 1 foot. Putting the above HHP calculation in layman's terms, the volume of water contained in HHP within normal summer water levels would be sufficient to cover 4680 acres of land to a depth of 1 foot.

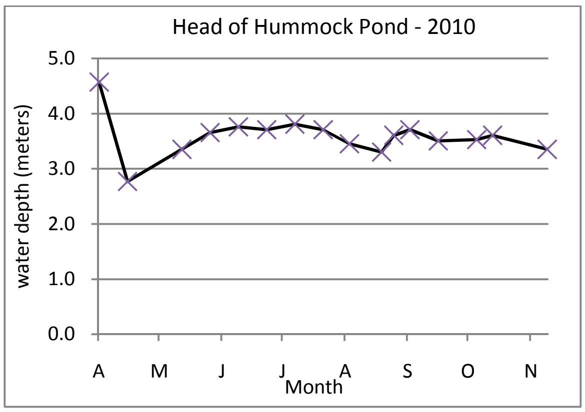
The outlet of HHP is located at the south end and consists of a narrow channel about 3 m wide that traverses a wetland over a distance of about 250 m

[1] 1 hectare = 2.47 acres; 1 acre = 0.4047 hectare

before it enters the main body of Hummock Pond at the northeast end.

Water depth. Water depth was recorded at the permanent marker buoy during each 2010 sampling visit but there was no depth survey conducted. Figure 3.2 summarizes average water depth at the sampling station marker during 2010.

Figure 3.2 The water depths measured at the HHP sampling station during 2010.



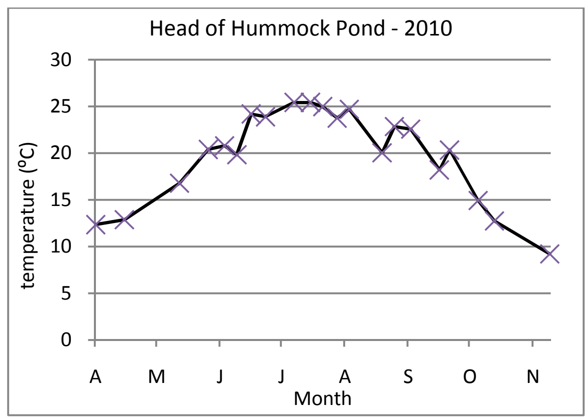
Except for the two April measurements, which represent high (4.6m) and low (2.8m) depth readings that occurred prior to, and following, the opening of Hummock Pond to the Atlantic Ocean, the average of water depths at the station during the remainder of the season was about 3.5 m (11.5 ft).

Thermal cycle. About three times as much temperature profile data was collected from HHP during 2010 as compared with 2009; 21 site visits in 2010 versus 8 site visits in 2009. The increased amount of temperature data in 2010 provided the first indication that the *dimictic* circulation pattern identified in HHP during 2009 was incorrect. After analyzing the 2010 temperature data, there is no doubt that HHP is a *cold polymictic* water body that circulates from surface to bottom throughout the ice-free period of the year when the direction and speed of sustained surface winds are sufficient to maintain water movement throughout the pond. Individual temperature profile graphs are presented in Appendix 1; summary data are presented here.

HHP exhibits temporary stratification during spring and early summer as the water column warms up, and by late July-early August, the water column is isothermal from surface to bottom. There was a brief period during mid-to-late August when the average water temperature decreased from ≈25°C to ≈20°C and then increased again. Thereafter, there was progressive cooling of the water column as the ambient air temperatures on the Island decreased during late September and October.

Figure 3.3 presents a summary of the average water column temperature at the HHP sampling station during the 2010 sampling season.

Figure 3.3 The average monthly water temperature measured in HHP during 2010.

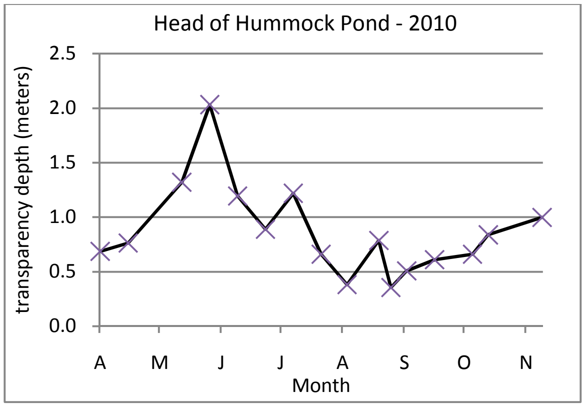


The maximum average temperature was about 25°C and occurred on July 13th, 21st, and 27th and August 9th. Overall, the 2010 pattern of average HHP water temperature resembled a bell-shaped curve, with minimum temperatures during the spring and fall and maximum temperature during the mid-summer.

Transparency. HHP water transparency was low during 2010, averaging 0.87 m, and influenced by the presence of Cyanobacteria from about early July through the end of the season (Figure 3.4).

The greatest transparency (2+m) occurred on June 1st, when the average water column temperature reached 20°C, and may indicate a brief 'clearing' period when the phytoplankton assemblage changed from cold-water forms (diatoms) to species more adapted to warm water (greens and Cyanobacteria).

Figure 3.4 The Secchi depth transparency measured in HHP during 2010.

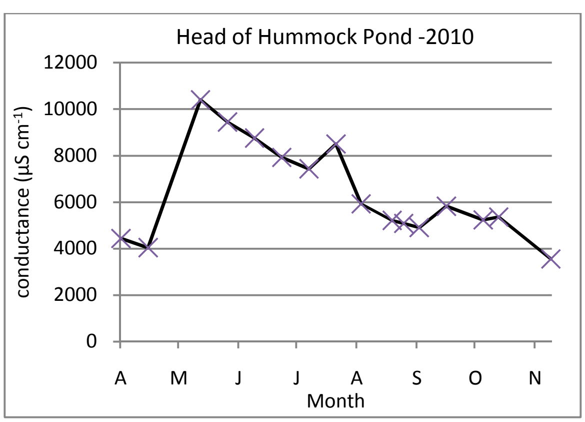


3.1.3 Chemical characteristics

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

HHP conductance levels measured during 2010 were moderately high, ranging from ≈3,500–10,000 µS/cm and reflecting estuarine conditions and salt water intrusion from the spring opening of Hummock Pond to the Atlantic Ocean. Figure 3.5 summarizes the 2010 seasonal conductance values in HHP.

Figure 3.5 The specific conductance measured in HHP during 2010.



Following the winter of 2009-2010, the conductance measured on April 7th, prior to the opening on April 8th, was 4,437 µS cm^{-1}. The next HHP conductance reading was taken on April 21st, after the closure of Hummock Pond, and was slightly lower at, 4,044 µS cm^{-1}. The third conductance reading taken on May 18th was the highest reading of the 2010 season, 10,400 µS cm^{-1}. The fact that the May reading yielded the highest conductance value about 4 weeks following the spring closure of Hummock Pond suggests that a considerable amount of time is required for the salt water intrusion from the Atlantic Ocean to mix thoroughly with the entire volume of Hummock Pond and also to mix with HHP through the wetland connection. Following this high conductance reading on May 18th, there was a consistent decline in concentration throughout the remainder of the sampling season (Figure 3.5).

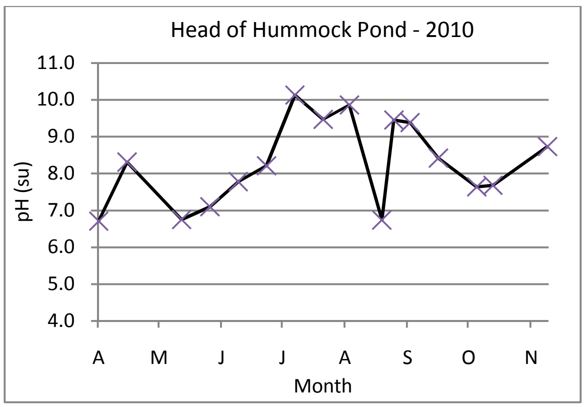
pH. 'pH' is a mathematical transformation of the hydrogen ion $[H^+]$ concentration and expresses the acidity or basicity of water. The lowercase 'p' in pH refers to 'power' or exponent, and pH is defined as the negative logarithm of the hydrogen ion concentration. A change of one pH unit represents a ten-fold change in hydrogen ion concentration. Conditions become more acidic as pH decreases; more basic as pH increases.

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

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

HHP exhibited extremely high pH values throughout the water column during 2010 (Figure 3.6); the seasonal average was 8.7 s.u. Nine (9) of the 16 pH readings taken in 2010 were above 8.0 s.u.; five (5) readings were greater than 9.0 s.u.

Figure 3.6 The pH measured in HHP during 2010.

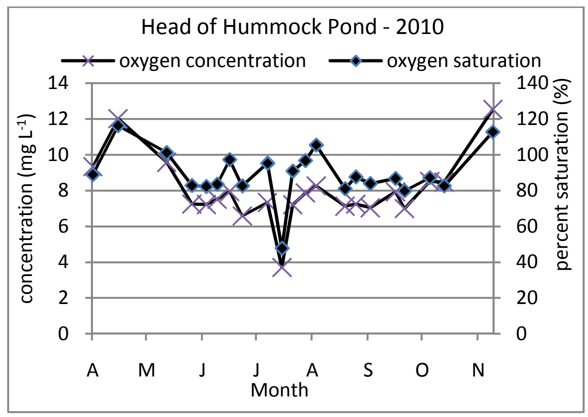


The high pH readings in HHP suggest considerable imbalance between pond respiration and photosynthesis which probably results from the intense Cyanobacteria bloom that occurred in the pond during most of the growing season. Additional sampling during the dark period of the day would be required to determine whether pH levels in the pond decrease to lower levels when there is no photosynthesis occurring and whether carbon dioxide is being replenished by respiration.

Oxygen concentration-percent saturation. Oxygen constantly is consumed in lakes and ponds, and the two primary mechanisms that replenish oxygen supply are exchange with the atmosphere at the air-water interface and photosynthetic activity of plant material, both phytoplankton and rooted plants, living 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 pond.

HHP exhibited oxygen concentration and saturation patterns during 2010 that were similar to 2009 and are characteristic of a north temperature polymictic water body with high levels of algal productivity. The average water column concentrations and percent saturation of dissolved oxygen for the 2010 sampling dates are summarized in Figure 3.7. Detailed graphs showing individual depth profiles of oxygen percent saturation on each sampling date are presented in Appendix 1.

Figure 3.7 Average concentration-percent saturation of dissolved oxygen measured in HHP during 2010.



The upper portion of the HHP water column usually was either near-saturation or super-saturated with dissolved oxygen (≈100-140%) during most of the 2010 season (Figure 3.7), which is a characteristic of high photosynthetic activity and oxygen production. Deeper regions of the pond usually exhibited low levels of dissolved oxygen saturation, primarily as a result of the decomposition of dead or dying organic material (algal cells) settling down from the highly productive upper regions. The oxygen saturation gradient that occurred from surface to bottom on each sampling date was a visual display of the relative rates of photosynthesis and decomposition occurring in the pond at that moment in time. There were five (5) sampling dates during September-October when oxygen saturation essentially was the same from surface to bottom. This condition probably was the result of a previous wind event and mixing of the water column which would break down any depth gradient of saturation. The graphs showing this condition are presented in Appendix 1.

The average temperature in HHP was >18°C from late May-early June until early-to-mid October, indicating an extended (4½-month) growing season when most of the photosynthetic activity occurred in the pond. The chlorophyll *a* values in HHP during the corresponding time period ranged from 2–162 µg L^{-1} and averaged 77.6 µg L^{-1}, an extremely high level that suggests phytoplankton bloom conditions.

In summary then, the seasonal depth profile of oxygen concentration/saturation in HHP during 2010 was characteristic of waters that experience, concurrently, significant algal blooms and decomposition from high productivity. During most of the growing season, the upper waters contain high densities of phytoplankton which are continually undergoing photosynthesis and respiration throughout the day-and-night cycles, respectively, and supersaturate the surrounding water with dissolved oxygen. The brief life cycle of individual phytoplankton cells leads to a constant supply of dead or dying material (cells and colonies) that settle down into the lower waters and decompose, using up the available oxygen in the lower pond regions and causing an oxygen deficit.

3.1.4 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 consists of organic 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 (ON) + Ammonia-nitrogen (NH_3-N) + Nitrate-nitrogen (NO_3-N) + Nitrite (NO_2)

Amino acids and proteins are naturally-occurring organic forms of nitrogen. All forms of nitrogen are harmless to aquatic organisms except un-ionized ammonia and nitrite, which can be toxic to plants and fish. **Nitrite** usually is not a problem in water-bodies, however, since it is readily converted to **nitrate** if enough oxygen is present for oxidation.

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

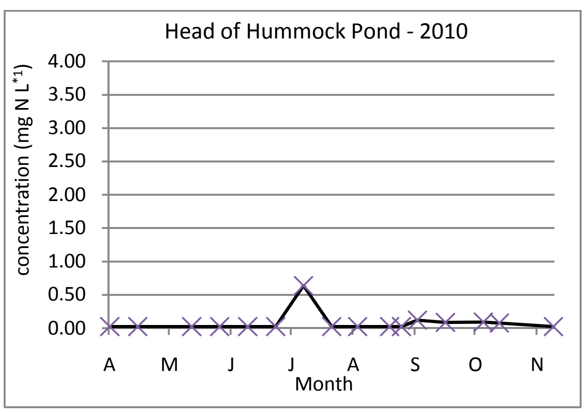
Nitrate-nitrogen, **NO_3-N**, is produced by bacterial conversion of organic and inorganic nitrogenous compounds from a reduced state to an oxidized state and is readily assimilated by algae and other green plants. **Nitrate** and **ammonia**, collectively, provide most of the nitrogen available for 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 characteristics of the nitrogen dynamics in HHP during 2010 are as follows:

- Nitrate concentrations were similar to 2009 values and increased slightly as the season progressed, a pattern observed in 2009,
- Ammonia concentrations were higher than in 2009 and exhibited a seasonal variation which was not observed during 2009,
- Organic nitrogen concentrations exceeded 2009 values, indicating high levels of plankton productivity in HHP,
- Total nitrogen concentrations in the upper and lower regions of HHP were high and indicate large amounts of organic nitrogen contained within the pond ecosystem, primarily in the form of phytoplankton and seston.
- The average concentration of total nitrogen suggests that HHP is a highly productive pond when evaluating seasonal water quality and comparing the results to other lakes and ponds.

The average nitrate concentration in HHP was low during 2010; nitrate-nitrogen averaged 0.08 mg N L^{-1} for the season (Figure 3.8). The nitrate level was at the level of detection during most of the season.

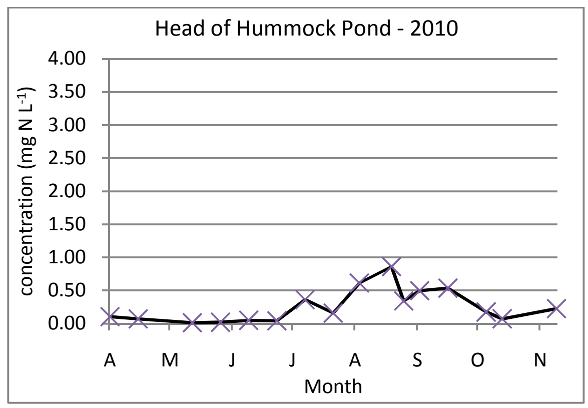
Figure 3.8 Nitrate-nitrogen concentrations measured in HHP during 2010.



The highest nitrate value, 0.64 mg N L^{-1}, was recorded on July 13th; thereafter, water column concentrations remained below 0.1 mg N L^{-1} except for the September 8th reading of 0.12 mg N L^{-1}.

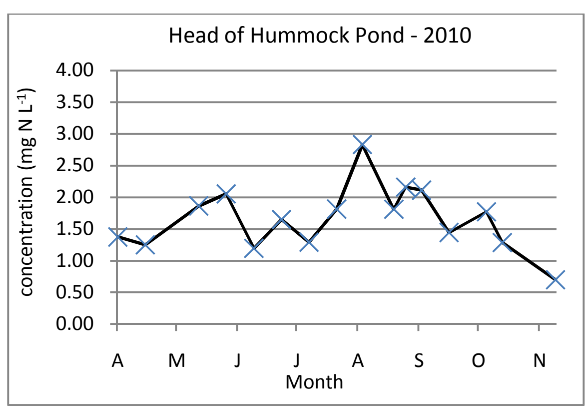
Ammonia-nitrogen values averaged 0.26 mg N L^{-1} during 2010; concentrations generally were low at the beginning and end of the season (Figure 3.9) and were elevated from early-to-mid July through late September. The period of elevated ammonia-nitrogen concentrations corresponds to the period when the highest pH values were recorded in HHP during 2010, averaging 9.1 s.u. on seven sampling dates. In view of the high pH values in HHP during this time, it is likely that most of the ammonia-nitrogen was in the form of NH_4OH, and in concentrations toxic for biological growth. This factor also would explain the relatively low nitrate-nitrogen conditions during the mid-summer, since any available nitrate-nitrogen would be utilized in the absence of available ammonia-nitrogen.

Figure 3.9 Ammonia-nitrogen concentrations measured in HHP during 2010.



A simple method for calculating organic nitrogen in water is to subtract ammonia+nitrate concentrations from the TN concentration. The result of this exercise for the HHP data is shown in Figure 3.10.

Figure 3.10 Organic nitrogen concentrations calculated for HHP during 2010.

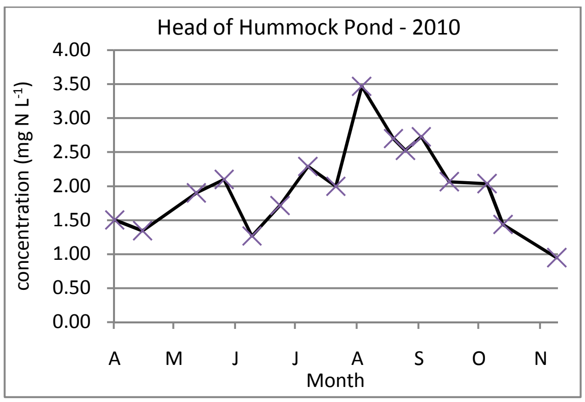


The average concentration of organic nitrogen in HHP during 2010 was 1.66 mg N L^{-1}, 50 percent higher than the average value calculated for 2009

(1.1 mg N L^{-1}). Although some portion of the organic nitrogen is in soluble, or dissolved, form, the organic nitrogen concentrations are high and correspond to high densities and biomass of phytoplankton in the water column throughout the sampling period.

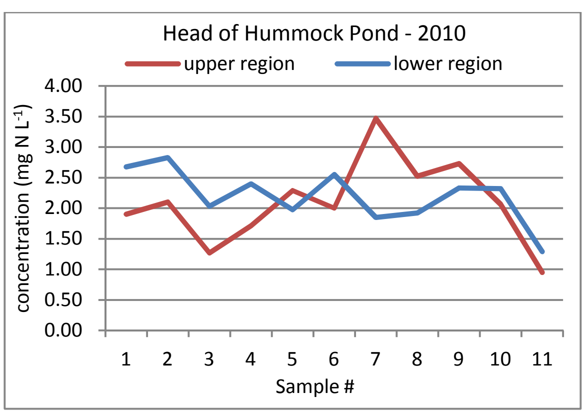
The seasonal pattern of HHP total nitrogen (TN) concentration measured during 2010 is shown in Figure 3.11. TN values generally increased during the first two-thirds of the season, reached a maximum of 3.5 mg N L^{-1} on August 9th, and then declined rapidly during the remainder of the season. The average value for 2010 was 2.0 mg N L^{-1}.

Figure 3.11. Total nitrogen concentrations measured in HHP during 2010.



There were 11 dates in 2010 when TN samples were collected from upper and lower regions of HHP. As shown in Figure 3.12, TN concentrations consistently were higher in the lower region during early 2010.

Figure 3.12 Total nitrogen concentrations measured in the upper and lower regions of HHP during 2010.



Around mid-to-late July, the relative concentrations of the samples 'switched' and the upper region TN samples were higher in concentration than the lower region TN samples (Figure 3.12). This trend continued until later in the season when the lower level TN samples became higher in concentration once again.

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

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

Particulate phosphorus can include three forms (1) phosphorus in living organisms (e.g. plankton), (2) mineral phases of rock and soil with absorbed phosphorus, and (3) phosphorus adsorbed onto dead particulate organic matter. The relative importance of each form seems to vary in ponds, probably as a function of allochthonous material (from outside the system) containing phosphorus, which enters the pond at different times of the year.

A 'typical' pond would receive significant inputs of phosphorus during periods of high runoff, such as spring snowmelt. In fact, in many north temperate lakes and ponds in the northeastern 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). A system such as HHP has a different hydrologic cycle and does not receive large inputs of TP via storm-water runoff due to the 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 total phosphorus (TP) to HHP probably occurs through groundwater flow at a rate which either increases or decreases based upon patterns of precipitation. 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 pond. The flow of groundwater in the watershed would vary based upon precipitation patterns during the year.

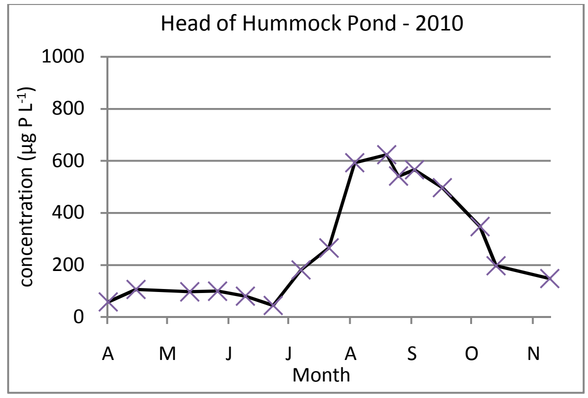
The TP dynamics observed in HHP during 2010 include the following:

- Concentrations of TP exhibited a seasonal pattern, and were moderate from early April until mid-July and then high through the remainder of the sampling season,
- The fact that TP concentrations remained high during the sampling period indicates that a continual source of TP was available in the water column, either in the form of autochthonous or allochthonous (from inside the system) material.
- Concentrations of TP in the lower waters of HHP usually were greater than TP concentrations in the upper water levels any sampling date, which probably reflects the mobilization of TP from the bottom sediments during periods of anoxia.

The TP concentration in HHP was moderate-to-high during 2010 and exhibited a pronounced seasonal pattern (Figure 3.13). The average TP concentration was 278.0 µg P L^{-1}, for the 16 sampling dates.

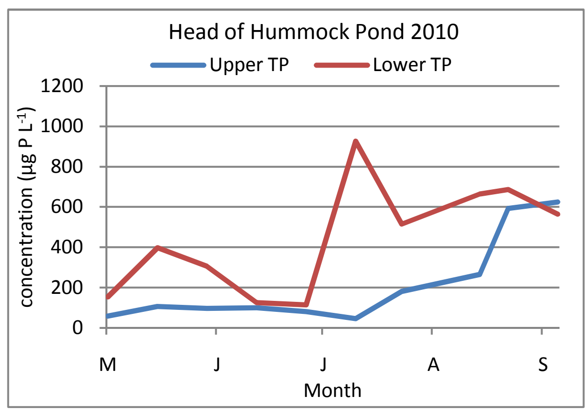
Considering all of the physical, chemical and biological conditions measured in HHP during 2010, the likely source of high TP concentrations is the persistent 'bloom' condition coupled with the decomposition of organic matter in the lower waters, which results from the development of anoxic conditions and mobilization of TP bound up in the bottom sediments.

Figure 3.13 Total phosphorus concentrations measured in HHP during 2010.



Water samples collected just off the bottom of HHP during 2010 generally had higher concentrations of TP than samples collected from the upper region of the water column (Figure 3.14).

Figure 3.14 Total phosphorus concentrations measured in upper and lower regions of HHP in 2010.



Higher concentrations of TP can occur in this lower region of the pond from the decomposition of organic matter and the mobilization of phosphorus from the bottom sediments during periods of anoxia.

3.1.5 Phytoplankton

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

The 2010 phytoplankton collections in HHP began earlier than in 2009 which meant a more accurate evaluation of the community since more of the community transitions were documented during the growing season. A total of 15 samples were collected during 2010 as compared with 8 samples collected during 2009. Under ideal circumstances, several years of monitoring would be required before the phytoplankton community could be characterized accurately. The unique nature of individual growing seasons in a body of water such as HHP is described later on in this section as the community dynamics are presented and described.

The 2010 phytoplankton community observed in HHP exhibited several important features that characterize the general water quality of the pond. These features may be summarized as follows

- There was a distinct seasonal succession of phytoplankton groups starting early in 2010,
- *Density* – the abundance of phytoplankton cells exhibited a seasonal pattern during 2010,
- *Biomass* – there was an 8 to 10-fold range of cell biomass n the HHP phytoplankton community during 2010,
- There was distinct seasonality of chlorophyll *a* in HHP during 2010,
- Intense Cyanobacteria blooms occurred during mid-summer and fall 2010 and the prevalent bloom species was *Anabaena spiroides*,
- The liver toxin, microcystin, was detected in all 2010 samples submitted for analysis.

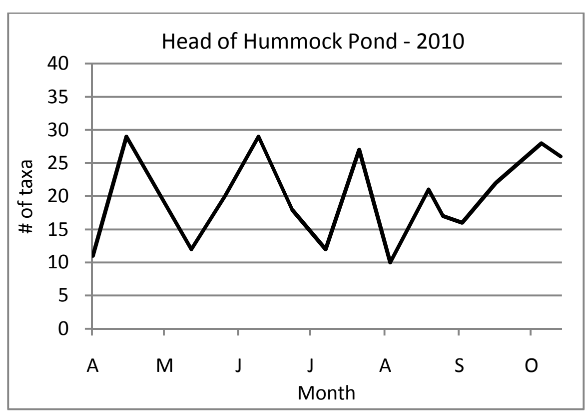
The phytoplankton community characteristics, both individually and collectively, observed during 2010 reflect high productivity and very poor water quality.

Description of the assemblage. There were 59 taxa identified in the 2010 phytoplankton samples; all of the major algal groups were represented (Table 3.1). The total number of taxa present in the phytoplankton community fluctuated between high values of 25-30 and low values of 10-12 throughout the study period (Figure 3.15). Community richness averaged 19.9 (±6.8) taxa for the entire 2010 sampling period, which was about one-third the total taxa identified in the pond assemblage.

Table 3.1 The major groups and taxa of phytoplankton identified in HHP during 2010.

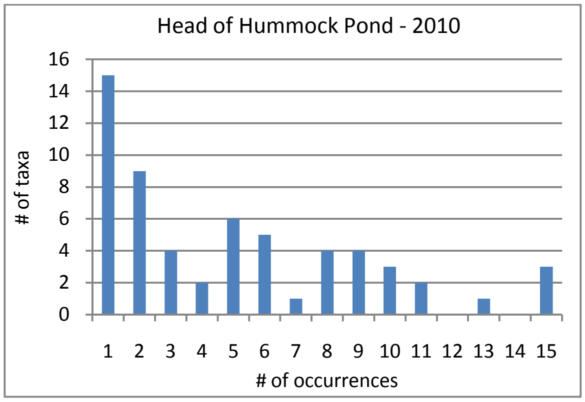
Cyanobacteria (Cyanophytes)	Bacillariophytes
Anabaena spioides	*Achnanthes* sp.
A. elenkinii	*Achnanthidium* sp.
Aphanocapsa elachista	*Amphiprora* sp.
Gleocapsa rupestris	*Amphora* sp.
Microcystis inserta	*Aulacoseria granulata*
Chlorophytes	*Chaetoceros* sp.
Ankistrodesmus falcatus	*Cocconeis* sp.
Botryococcus braunii	*Cyclotella* sp.
Chlamydomonas spp.	*Cymbella* sp.
Closterium spp.	*Fragilaria crotonensis*
Coelastrum cambricum	*Fragilaria* sp.
Cosmarium spp.	*Gomphonema acuminatum*
Dictyosphaerium ehrenbergianum	*G. olivaceum*
Eudorina elegans	*G. truncatum*
Kirchneriella lunaris	*Hippodonta* sp.
Mougeotia sp.	*Navicula* spp.
Oocystis borgei	*Neidium* sp.
O. parva	*Nitzschia* sp.
Pandorina morum	*Pinnularia* sp.
Pediastrum duplex	*Planothidium* sp.
Pyramimonas tetrarhyncus	*Rhoicosphenia curvata*
Scenedesmus arcuatus Lemmerman	*Stauroneis* sp.
S. bijuga	*Stephanodisus* sp.
S. quadricauda	*Surirella* sp.
Selenastrum minutum	*Synedra acus*
Tetraedron minimum	*S. fulgens*
Pyrrhophytes (Cryptophyceae)	*S. ulna*
Cryptomonas ovata	*Tabellaria fenestrata*
Rhodomonas sp.	*Thalassiosira* sp.
Pyrrhophytes (Dinophyceae)	**Chrysophytes**
Peridinium cinctum	*Ochromonas* sp.
	Euglenophytes
	Trachelomonas spp.

Figure 3.15 The seasonal pattern of the number of phytoplankton taxa that occurred in HHP during 2010.



The occurrence of each phytoplankton taxon in the 2010 samples was ranked to determine how many times the taxon occurred in the 15 samples. The results of this ranking are presented in Figure 3.16.

Figure 3.16 The ranking of phytoplankton taxon occurrence in HHP during 2010.



Most taxa occurred only once, or a few times, while a few taxa occurred in more than one-half of the total samples (Figure 3.16). Fifteen (15) taxa, or 25 percent of the total (59), occurred only on a single sampling date, and 42 taxa (75 percent of total) occurred in less than one-half of the samples. Only 3 taxa occurred on all 15 sampling dates.

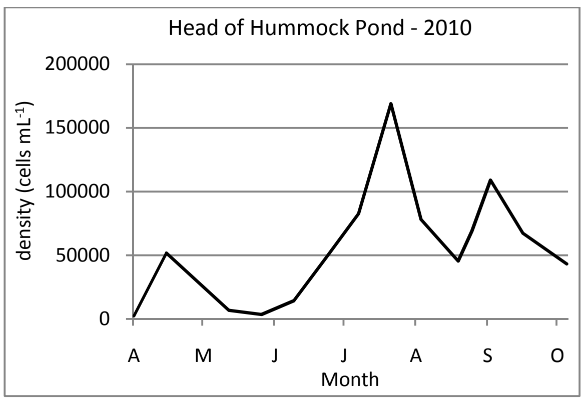
Table 3.2 lists the phytoplankton taxa that occurred most frequently in the 2010 samples and some characteristics for each taxon including cell biomass, seasonality, and number of times the taxon was dominant in the community out of 15 sampling dates. Cyanobacteria were the most frequent density and biomass dominants in the community; only six (6) other taxa were observed to be either biomass or density dominants during the season.

Table 3.2 Characteristics of the most commonly occurring phytoplankton taxa by major group in HHP during 2010.

Major Group	Cell Biomass	Number of times the taxa			2009
Taxon-species	(μm^3)	Occurred	BM dominant	DN Dominant	Seasonality
Cyanobacteria (Cyanophyta)					
Anabaena spiroides	165.0	10	10	10	summer, fall
Anabaenopsis elenkinii	130.8	10	6	6	summer, fall
Chlorophyta					
Oocystis parva	135.0	9	0	2	summer, fall
Pyramimonas tetrarhyncus	100.0	15	2	6	all year
Scenedesmus quadricauda	100.0	8	0	0	spring, fall
Bacillariophyta					
Achnanthes sp.	80.0	9	0	0	summer, fall
Chaetoceros sp.	*	8	0	0	summer, fall
Cocconeis sp.	500.0	10	0	0	all year
Cyclotella sp.	268.0	15	1	1	all year
Navicula spp.	350.0	15	0	0	all year
Planothidium sp.	80.0	11	0	0	all year
Stephanodisus sp.	2000.0	8	1	0	all year
Synedra acus	350.0	9	0	0	all year
S. ulna	350.0	8	0	0	all year
Euglenophyta					
Trachelomonas spp.	1144.5	11	5	3	all year
Pyrrhophyta					
Cryptomonas ovata	3890.7	9	5	1	all year
Rhodomonas sp.	870.7	13	5	1	all year
BM = biomass; DN = density; * = biomass unknown					

Density. During 2010, the density of phytoplankton in the water column ranged between 2,447 and 169,140 cells mL^{-1}, and averaged 54,653 cell mL^{-1} for the entire study period. Figure 3.17 presents the 2010 seasonal pattern of phytoplankton cell density and shows that three (3) separate peaks occurred. The first peak was on April 21st following the closure of Hummock Pond after the spring opening to the Atlantic Ocean. The second peak occurred on July 27th and was the highest density recorded during 2010. From that point in time, the phytoplankton density in HHP exhibited a consistent decline until the third peak, which occurred on September 8th.

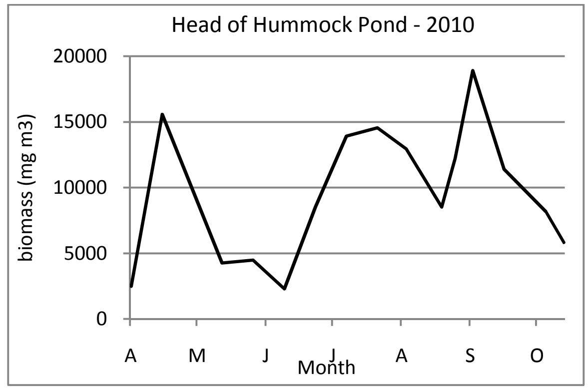
Figure 3.17 The seasonal pattern of phytoplankton density in HHP during 2010.



Biomass. Cell biovolume was used to evaluate phytoplankton taxon biomass, or productivity, since cell counts and conversion into density does not account for the significant size difference among various phytoplankton taxa. The misleading nature of density as a community descriptor becomes evident when viewing the cell biomass listed in Table 3.2 and noting the difference between the sizes of, for example, *Cryptomonas ovata* cells and other phytoplankton taxon listed in the table. Sizeable differences in relative biomass explain how small numbers of cells can make a taxon a dominant member in the phytoplankton community.

During 2010, phytoplankton community biomass ranged from 2,483 to 18,902 mg m^{-3}, and averaged 9,609 mg m^{-3} for the entire study period. The 2010 seasonal pattern of phytoplankton biomass exhibited three (3) separate biomass peaks which are shown in Figure 3.18.

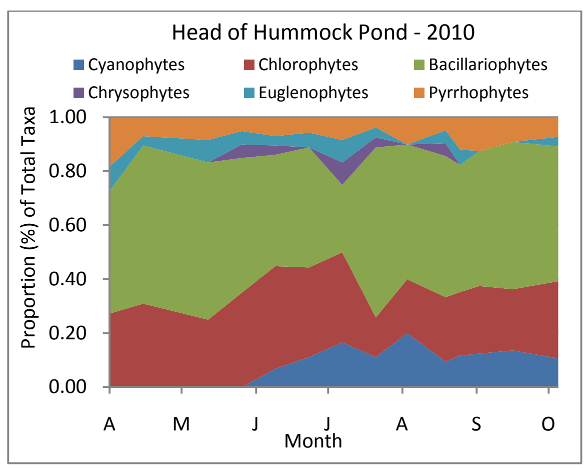
Figure 3.18 The seasonal pattern of phytoplankton biomass in HHP during 2010.



Seasonality and associations. The extended period of sampling from early spring through late fall 2010 revealed a pattern of seasonal succession of various phytoplankton taxa, and also patterns of density and biomass that were quite similar to each other.

Figure 3.19 summarizes the proportion of the total phytoplankton community represented by the different major groups.

Figure 3.19 The seasonal distribution of major phytoplankton groups in HHP during 2010.

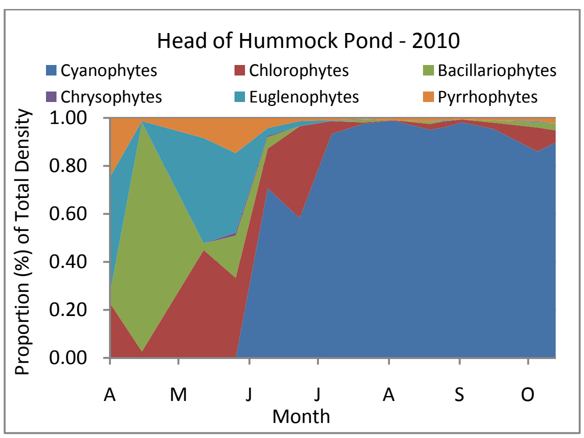


Chlorophytes, Bacillariophytes and Pyrrhophytes were present all year and their proportion of representation varied in the community. The Cyanobacteria were not detected in the community until late spring-early summer, and the Chrysophytes only occurred during the mid-summer period, being absent during the spring and fall (Figure 3.19).

Phytoplankton density (Figure 3.20) and biomass (Figure 3.21) present the 2010 community dynamics in slightly different perspectives. While both community variables portray an accurate seasonal pattern of succession, the biomass summary is a more accurate representation of the instantaneous community conditions since size of the individual cells is taken into account.

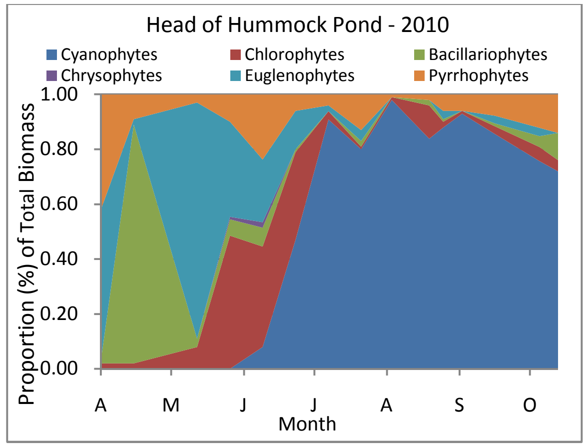
As far as seasonal succession, the Euglenophytes, Bacillariophytes, Cryptophytes, Chrysophytes and Chlorophytes dominated at various times during spring and early summer. Thereafter, there was a transition to total dominance by Cyanophytes from about mid-June through the remainder of the season until mid-October when the last phytoplankton sample was collected.

Figure 3.20 The seasonal pattern of phytoplankton community density in HHP during 2010.



Diversity. Seasonal phytoplankton diversity in HHP was measured using the Shannon-Wiener function[2] which calculates diversity, **[H]**, using number of taxa and the allotment of individuals among the taxa on each sampling date. An increase in either factor will increase the diversity value.

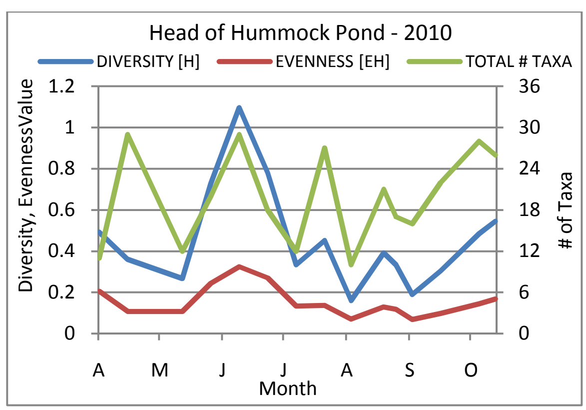
Figure 3.21 The seasonal pattern of phytoplankton community biomass in HHP during 2010.



Once diversity **[H]** was calculated for each sampling date, a value was calculated for **[H_{max}]**, which is the diversity value under conditions of maximum equitability or allotment on a sampling date. The next step in the process was to calculate equitability, **[E]**, the ratio of **[H]/[H_{max}]**, for each sampling date, which locates the community somewhere along a scale from 0 (least equitable) to 1 (most equitable).

Community diversity **[H]**, equitability **[E]**, and total taxa during 2010 are presented in Figure 3.22.

Figure 3.22 The seasonal pattern of phytoplankton community parameters in HHP during 2010.



Dominance. Usually only 1 to 3 phytoplankton taxa were dominant in the HHP community (Table 3.3). The most frequent dominant taxa during 2010 were *Anabaena spiroides* (occurred on 10 dates), *Anabaenopsis elenkinii* (6 dates), and *Trachelomonas* spp., *Cryptomonas ovata* and *Rhodomonas* sp. (5

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

dates each). There were four taxa dominant on June 1st and June 15th, and six taxa dominant on June 29th. During these sampling dates, there was a community transition occurring as the assemblage was changing from cold-water to warm-water forms, which explains the greater number of dominant taxa.

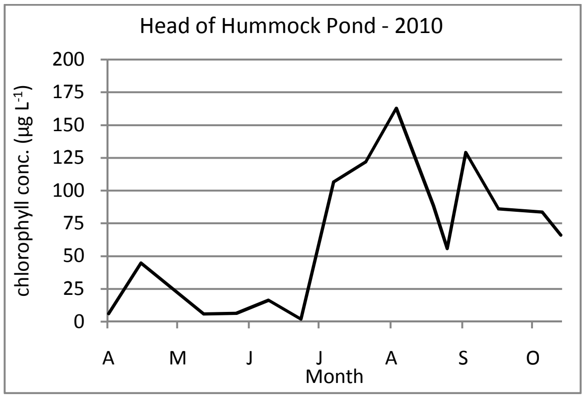
Table 3.3 Ranking of phytoplankton taxa dominance, using biomass, in HHP during 2010.

Sampling Date	Biomass	Taxon (Major Group)	% of Total Biomass
04/07/10	1	*Trachelomonas* spp. (Euglenophyta)	55
	2	*Cryptomonas ovata* (Cryptophyta)	27
	3	*Rhodomonas* sp. (Cryptophyta)	15
04/21/10	1	*Cyclotella* sp. (Chrysophyta)	83
	2	*Rhodomonas* sp. (Cryptophyta)	6
05/18/10	1	*Trachelomonas* spp. (Euglenophyta)	86
	2	*Pyramimonas tetrahyncus* (Chlorophyta)	7
06/01/10	1	*Trachelomonas* spp. (Euglenophyta)	35
	2	*Mougeotia* sp. (Chlorophyta)	30
	3	*Eudorina elegans* (Chlorophyta)	17
	4	*Cryptomonas ovata* (Cryptophyta)	10
06/15/10	1	*Trachelomonas* spp. (Euglenophyta)	23
	2	*Peridinium cinctum* (Pyrrhophyta)	15
	3	Coelastrum cambricum (Chlorophyta)	15
	4	*Rhodomonas* sp. (Cryptophyta)	9
06/29/10	1	*Anabaenopsis elenkinii* (Cyanophyta)	28
	2	*Pyramimonas tetrahyncus* (Chlorophyta)	20
	3	*Anabaena spiroides* (Cyanophyta)	19
	4	*Trachelomonas* spp. (Euglenophyta)	14
	5	*Pandorina morum* (Chlorophyta)	11
	6	*Rhodomonas* sp. (Cryptophyta)	6
07/13/10	1	*Anabaena spiroides* (Cyanophyta)	80
	2	*Anabaenopsis elenkinii* (Cyanophyta)	9
07/27/10	1	*Anabaena spiroides* (Cyanophyta)	73
	2	*Rhodomonas* sp. (Cryptophyta)	13
	3	*Anabaenopsis elenkinii* (Cyanophyta)	6
08/09/10	1	*Anabaena spiroides* (Cyanophyta)	92
	2	*Anabaenopsis elenkinii* (Cyanophyta)	6
08/25/10	1	*Anabaena spiroides* (Cyanophyta)	78
	2	*Pediastrum duplex* (Chlorophyta)	10
	3	*Anabaenopsis elenkinii* (Cyanophyta)	5
08/31/10	1	*Anabaena spiroides* (Cyanophyta)	83
	2	*Anabaenopsis elenkinii* (Cyanophyta)	5
09/08/10	1	*Anabaena spiroides* (Cyanophyta)	91
09/22/10	1	*Anabaena spiroides* (Cyanophyta)	85
	2	*Cryptomonas ovata* (Cryptophyta)	6
10/11/10	1	*Anabaena spiroides* (Cyanophyta)	74
	2	*Cryptomonas ovata* (Cryptophyta)	9
10/19/10	1	*Anabaena spiroides* (Cyanophyta)	70
	2	*Cryptomonas ovata* (Cryptophyta)	12
	3	*Stephanodiscus* sp. (Chrysophyta)	5

Chlorophyll *a*. Chlorophyll *a* samples collected on 15 sampling dates in 2010 averaged 70.36 µg L^{-1}, and ranged from 6.05 to 162.72 µg L^{-1}. The average mid-summer concentration for 10 sampling dates when the pond water temperature ≥18°C was 77.63 µg L^{-1}. Chlorophyll *a* concentrations were low-to-moderate from April through June, then exceeded 100 µg L^{-1} from mid-July until mid-August (Figure 3.23).

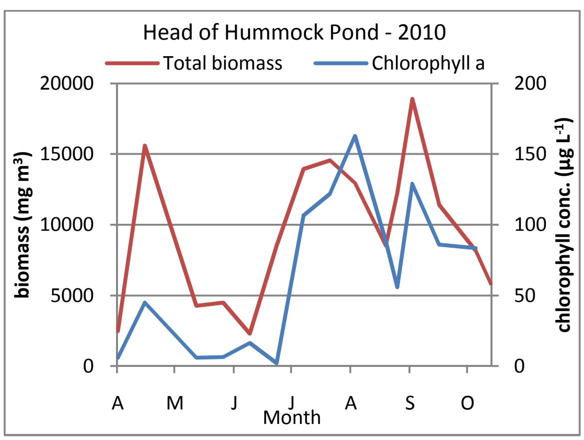
Thereafter, the chlorophyll concentration averaged about 85 µg L^{-1} for the rest of the season.

Figure 3.23 The seasonal pattern of chlorophyll *a* concentration in HHP during 2010.



Good correlation existed between chlorophyll *a* concentrations and phytoplankton community biomass during 2010 (Figure 3.24), meaning that biomass is an excellent indicator of productivity and trophic condition of the ecosystem.

Figure 3.24. The seasonal pattern of phytoplankton biomass and chlorophyll *a* in HHP during 2010.



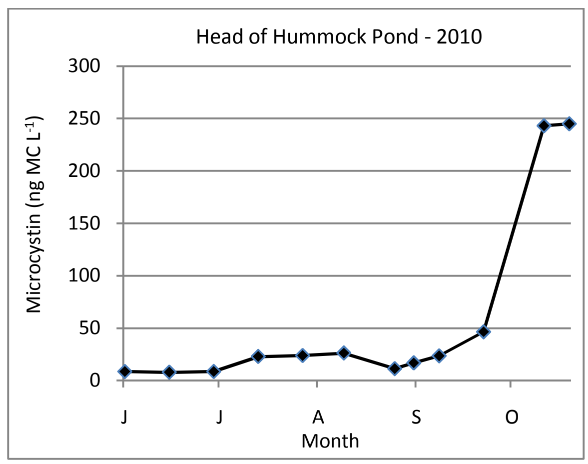
The 2010 HHP algal associations provide some additional important information about the general trophy of the pond. The community during spring and early summer was comprised of Euglenophytes, Cryptophytes and Chrysophytes which are adapted to cold-water environments. These groups actually occurred throughout the entire sampling period, being a minor component of the community when Cyanophytes were dominant in mid-summer, and then exhibiting greater community influence during fall and the return of cold water conditions.

The seasonal succession of Chlorophytes and Cyanophytes during late spring and summer as community dominants is further evidence of the enhanced trophy (productivity) of the HHP ecosystem; the complete dominance of the Cyanophytes during mid-summer and early fall indicates eutrophic conditions.

UNH-CFB report on phycocyanin-microcystin. This material was provided by the University of New Hampshire, Center for Freshwater Biology, the facility where the 2010 samples were analyzed.

The liver toxin, microcystin (MC), was detected in all samples from HHP, with the lowest levels in June and the highest levels during October (Figure 3.25).

Figure 3.25 The seasonal pattern of microcystin (MC) in HHP during 2010.



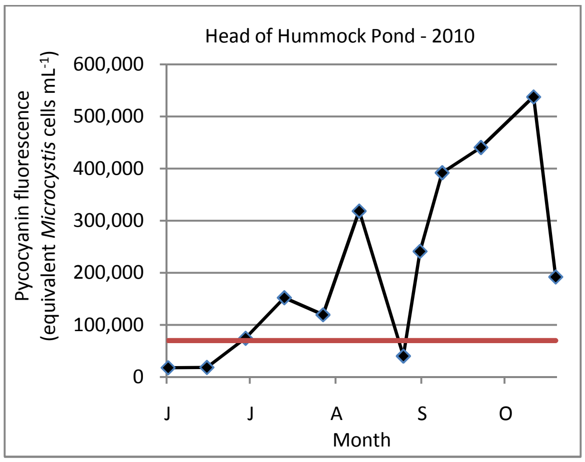
On all occasions, MC concentrations were below the recommended maximum levels for drinking water and recreational use based upon WHO[3] and MDPH[4] criteria. MC was elevated on October 11th when the results from phycocyanin fluorescence indicated that Cyanobacteria concentrations also were highest (≈7 times the recommended maximum level of 50 ng MC

[3] World Health Organization recommends <1000 ng microcystins L^{-1} in drinking water.

[4] Massachusetts Department of Public Health recommends maximum levels of < 14,000 ng microcystins L^{-1} or 70,000 cells of cyanobacteria mL^{-1} in recreational water.

L^{-1}) (Figure 3.26). MC levels remained at about 250 ng MC L^{-1} on October 19th, although Cyanobacteria concentrations had decreased according to the phycocyanin levels. This may designate a period of Cyanophyte die-off when toxins are released from the cells and degrade.

Figure 3.26 The seasonal pattern of phycocyanin fluorescence in HHP in 2010. Red line indicates 70,000 cells cyanobacteria mL^{-1} threshold for recreational use set by the Massachusetts Department of Public Health.



The MC concentrations measured in HHP represent average values for the water column. One of the most serious risks from Cyanobacteria occurs when, under calm weather conditions, the colonies float to the water surface and are blown shore-ward by the wind, which can result in a concentration factor of several thousand-fold. For example, assuming a 1000X concentration, the level of MC in HHP on September 23rd, if aggregated near the shore could result in a MC level 46 times the World Health Organization drinking water standard and well above the MA DPH limit for recreational use, with even potentially higher levels occurring in October.

It also is important to note that MC, even at levels below the WHO drinking water standard, should serve as a warning that toxigenic Cyanobacteria are present and that the level of a single toxin such as MC generally is an underestimate of the total risk to human health. Since many Cyanobacteria are capable of producing more than one toxin, it would be useful to test for other cyanotoxins, such as anatoxins or saxitoxins, highly potent neurotoxins that may also be present in HHP. Based on the consistent presence of MC in HHP and the elevated levels in the fall, future aerosol sampling also would be advised in order to evaluate the risk of land-based exposure to cyanotoxins released from the pond following concentration and die-back of cells and colonies of Cyanophytes.

There appear to be some discrepancies when comparing the data for phycocyanin fluorescence with the Cyanobacteria cell densities and biomass from the processed phytoplankton samples. For example, phycocyanin fluorescence indicates the presence of Cyanobacteria in the water column on June 1st and MC also was detected on that date. However, the phytoplankton cells counts show no Cyanobacteria present in the water at that time. This paradox of the HHP phytoplankton probably can be explained by the presence of pico-cyanobacteria[5], extremely small cells or colonies of Cyanobacteria which are below the limit of detection with the conventional microscopy techniques that are used to identify and count the HHP samples. There also is no information on which, if any, of the six species of Cyanobacteria identified in the 2010 phytoplankton samples produce the toxin microcystin (MC).

3.1.6 Trophic Status

'Trophic' means nutrition or growth. The trophic state of ponds refers to biological production, plant and animal, that occurs and the level of production is determined by several factors but primarily by phosphorus supply to the pond and by the volume and residence time of water in the pond. Different indicators that can be used to describe trophic state include phosphorus, water clarity, chlorophyll, rooted plant growth and dissolved oxygen.

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

[5] *Pico*- a prefix used in the metric system denoting a factor of 10^{-12} or 0.000000000001.

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

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

Carlson's Trophic State Index (TSI) characterizes the trophic status (health) of a water body (Carlson, 1977). Since they tend to correlate, the three independent variables most often used to calculate the Carlson index include chlorophyll pigments, total phosphorus and Secchi depth (water clarity).

Individual TSI values are calculated using the following equations:

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

Of the three variables, chlorophyll probably yields the most accurate index since it is the most accurate predictor of biomass in the ecosystem. This was true in HHP during 2010. Phosphorus may be a more accurate predictor of the summer trophic status of a pond than chlorophyll if measurements also are made during the winter months, which did not occur in HHP. Secchi depth probably is the least accurate predictor but is the most affordable and easiest to obtain since it is a subjective visual determination.

Following are the relationships between Trophic Index), chlorophyll, phosphorus, Secchi depth, and Trophic Class (after Carlson, 1996):

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

There was sufficient water quality information collected from HHP during 2010 to calculate the Carlson TSI using all three variables. However, instead of using all of the data collected during the 2010 study, it was decided to use only the summer values when the average water column temperature in HHP was 18°C or greater. This temperature criterion lowered the number of sampling dates from 16 to 10, and included the period from June 1st through September 27th.

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

Chlorophyll *a*
Average summer chlorophyll *a* = 77.63 µg/L
Chlorophyll *a* TSI = 9.81*[ln (77.63)] + 30.6
TSI = (9.81)(4.4) + 30.6
TSI = 73.3

Total phosphorus
Average summer total phosphorus = 349.3 µg/L
Total phosphorus TSI = 14.42*[ln (349.3)] + 4.15
TSI = (14.42)(5.9) + 4.15
TSI = 88.6

Secchi depth
Average summer Secchi depth = 0.86 m
Secchi TSI = 60 – [14.41*[ln (0.86)]
TSI = 60 – (14.41)(-0.15)
TSI = 62.1

Chlorophyll _a_ and phosphorus place HHP within the hyper-eutrophic category. Secchi depth being a subjective reading, is not as robust 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 2010, the TSI index for this variable probably would be considerably greater if we were able to factor in the average of the summer readings for the 2 zones of the water column. However, the two zones could not be factored together since relative volumes of the regions are not known.

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Head of Hummock Pond

The 2010 Water Quality Program

Chapter 4

A Comparison of 2009 and 2010 Water Quality

4.0 Introduction.

This chapter compares the 2010 HHP water quality data with the 2009 data collected from the pond (Sutherland and Oktay, 2010). When multiple years of data are available for a body of water, it is beneficial to compare datasets and determine whether water quality is consistent from one year to the next or whether trends are beginning to develop. Although two contiguous years of data is not sufficient to determine water quality trends, there is inherent value in examining the data to see where similarities and differences may occur between the two contiguous years.

4.1 Analysis of Results

A simple and basic method for evaluating different sets of water quality data is to compare mean, or average, values for each member in the suite of analytes collected each year. In the case of the water quality data for HHP, there is a 4-month (July-October) dataset collected during 2009 and an 8-month (April-November) dataset collected during 2010. There were 8 sampling visits in 2009 and 16 sampling visits in 2010.

The 2010 dataset is twice as extensive as the 2009 dataset which can impart certain biasing effects on the data analysis. In order to compensate for the significant duration difference in the 2009 and 2010 studies, the 2010 dataset has been summarized in two different formats: (1) to represent the entire sampling period (April-November) and (2) to represent the comparable 4-month period (July-October) that was monitored in 2009.

The following sections provide the results and discussion of the summarized data. The chapter format is similar to Chapter 3 which described the physical, chemical and biological characteristics of HHP interpreted from the 2010 water quality data.

4.2 Comparison of 2009 and 2010 Data

Only those constituents of the water quality data that provide meaningful interpretation are considered here.

4.2.1 Sampling characteristics

Since the 2010 sampling effort on HHP was twice the 2009 effort, it allowed a more comprehensive interpretation of the seasonal progression of water quality for the suite of sampled parameters. In view of this discrepancy in the length of the two sampling periods, there are instances in the following presentation of material where the discussion includes the total samples collected each year and other instances where just the samples collected during comparable 4-month periods are discussed.

4.2.2 Physical characteristics

The results comparing analyses of the HHP physical and chemical data for 2009 and 2010 are presented in Table 4.1. The summary of biological data is presented later in this chapter.

Water depth. Water depth has been included in this discussion to highlight a basic inadequacy in the suite of parameters collected from HHP, namely, the absence of any reliable water level information. Although water depths were recorded on each sampling date, these depths are not useful unless there is some point of reference for the exact pond level in relation to an ASML (above mean sea level) datum. No such reference point currently exists.

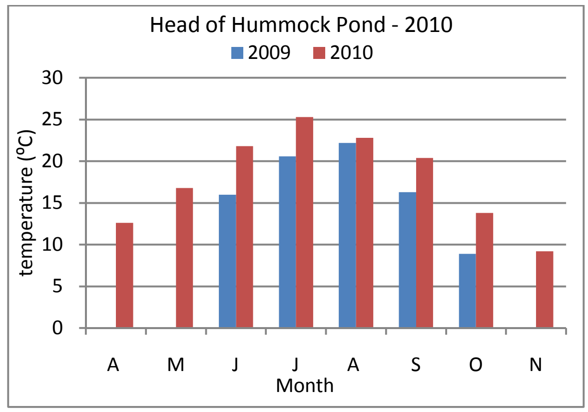
In order to understand the hydrology of HHP, it is essential that the installation of a continuous water level recording system on the pond be considered a priority. These level data are particularly important during the spring and fall opening of Hummock Pond to the Atlantic Ocean, when the pond hydrologic conditions are significantly altered over a brief period of time. A continuous record of level information provides the basis for interpreting the important components of the HHP hydrologic cycle which is influenced primarily by (1) water input via precipitation as rain or snow, (2) groundwater flow, and (3) loss of water through evaporation and transpiration through aquatic plants.

A map of relative water depth for HHP was produced from the aquatic plant survey conducted on HHP and Hummock Pond during August 24th-25th 2009. A total of 15 depth measurements were recorded on HHP during the plant survey, each depth sounding taken within a discrete 1-acre imaginary grid which overlaid the pond surface using a Trimble GeoXH 2008 series handheld GPS unit with sub-meter accuracy to record the coordinates of the depth location. The 15 depth soundings taken during August 2009 ranged from 3.0 feet to 11.1 feet and had a mean value of 8.0 feet, which is not an accurate measurement of average pond depth but which does describe a general characteristic at a point in time at a particular pond water level.

Thermal cycle. Three times more temperature profile data were collected from HHP during 2010 as in 2009; 21 site visits versus 8 site visits, respectively. The increased data collected in 2010 provided the first indication that the 2009 HHP circulation pattern labeled as *dimictic* was incorrect. Based upon interpretation of the extensive 2010 data, HHP is a *cold polymictic* pond that circulates from surface to bottom throughout the ice-free period of the year when the direction and speed of sustained surface winds are sufficient to maintain water movement throughout the pond.

With regard to differences in water column temperature between the two years, Figure 4.1 summarizes the average monthly water column temperatures recorded during 2009 and 2010. It is apparent that June, July, September and October 2010 were considerably warmer (≈5°C) than the same months in 2009. This considerable difference in water column temperature would extend the duration and, perhaps, the intensity of the growing season, which could directly affect the water quality of the pond through increased robustness of the phytoplankton community.

Figure 4.1 Summary of average monthly temperature in HHP during 2009 and 2010.



Transparency. The 2010 water transparency in HHP was low (annual average = 0.87 m) and influenced by the presence of Cyanobacteria from about early July through mid-November. The 2010 transparency conditions were similar to 2009 conditions when the average transparency was 0.84 m (Table 4.1). A comparison of 4-month transparency data for 2009 and 2010 reveals that algal blooms, the primary factor affecting transparency in HHP, were more severe during 2010, with an average of 0.69 m compared with 0.84 m in 2009.

Table 4.1 A summary of physical and chemical parameters in HHP during 2009 and 2010. The 2010 data are summarized for the entire season and also a 4-month period comparable to the 2009 season.

	AVERAGE FOR THE ENTIRE SAMPLING PERIOD								
	Secchi	TP (µg L^{-1})	NO_3	NH_4	NO_3+NH_4	TN (mg L^{-1})	Org N	spC (µS cm^{-1})	pH
2009	0.84	491	(0.072)	(0.167)	(0.239)	1.283	(1.094)	2668	8.25
2010	0.87	278	0.081	0.259	0.340	2.002	1.662	6379	8.27
	AVERAGE FOR COMPARABLE 4- MONTH SAMPLING PERIODS								
	Secchi	TP (µg L^{-1})	NO_3	NH_4	NO_3+NH_4	TN(mg L^{-1})	Org N	spC (µS cm^{-1})	pH (su)
2009	0.84	491	(0.072)	(0.167)	(0.239)	1.283	(1.094)	2668	8.25
2010	0.69	386	0.114	0.366	0.480	2.297	1.817	6142	8.70

4.2.3 Chemical characteristics

Specific conductance and pH. Conductance levels in HHP were about 2.5 times higher during 2010 than in 2009, regardless of whether considering average values for the entire season or the comparable 4-month dataset (Table 4.1). Since the spring and fall opening of Hummock Pond to the Atlantic Ocean is the only significant input of salt-water to the pond on an annual basis, it appears that the greater 2010 conductance levels means that there was greater salt-water intrusion during the spring 2010 opening than during the spring 2009 event. Regardless of the conductance values during early spring of either year, there was a consistent and progressive decline in concentrations as the season progresses.

The average pH values in HHP during 2009 and 2010 were essentially the same, regardless of which dataset was considered. It is noteworthy, however, that the report author has never recorded such high pH values in any body of water during 30 years of water quality work throughout New York State. These extremely high pH values result from the algal bloom which is removing carbon dioxide during photosynthesis and increasing the pH to levels where some water column constituents, such as ammonia, can become toxic. pH levels in excess of 9.0 were measured during 2009 and 2010; levels > 9.0 were measured on 5 occasions in 2010, and a reading >10.0 was measured on a single 2010 date.

Oxygen concentration and saturation. The patterns of concentration and saturation during 2009 and 2010 were similar and characteristic of a water body that contains very high levels of algal productivity. The upper region of the water column usually was either near-saturation or super-saturated with dissolved oxygen, while the lower waters usually exhibited low levels of dissolved oxygen saturation as a result of decomposing organic matter settling down from the highly productive upper regions. During extended periods with no wind and no mixing of the water column, the area of the pond adjacent to the bottom would become anaerobic and provide conditions suitable for the mobilization of plant nutrients from the sediment into the water column.

4.2.4 Plant Nutrients

Nitrogen. The average nitrate concentrations in HHP during 2009 and 2010 were the same order of magnitude; nitrate-nitrogen averaged 0.07 mg N L^{-1} for 2009 as compared with 0.08 mg N L^{-1} in 2010. The nitrate-nitrogen concentration for the comparable 4-month period during 2010 was slightly higher and averaged 0.11 mg N L^{-1}.

Ammonia-nitrogen values averaged 0.17 mg N L^{-1} during 2009 and were about 50 percent higher during 2010, averaging 0.26 mg N L^{-1}. Ammonia-nitrogen averaged 0.37 mg N L^{-1} during the comparable 4-month period in 2010, which is more than two times the 2009 average. As explained in Chapter 3, it is likely that most of the ammonia-nitrogen in HHP was in the form of NH_4OH and toxic to biological growth as a result of extremely high pH levels in the pond at that time. The average pH during comparable 4-month periods was higher in 2010 (8.7) than in 2009 (8.3), which could explain the greater amount of ammonia-nitrogen in the water rendered unusable due to toxicity.

Total nitrogen (TN) averaged 1.28 mg N L^{-1} during 2009 and was about 50 percent higher during 2010, averaging 2.00 mg N L^{-1}. The average 2010 TN concentration during the comparable 4-month period was even higher at 2.30 mg N L^{-1}. The higher 2010 TN values in HHP reflect higher productivity as substantiated by higher phytoplankton community biomass and chlorophyll _a_.

Phosphorus. Total phosphorus (TP) averaged 491 µg P L^{-1} during 2009 and was about 50 percent lower during 2010, averaging 278 µg P L^{-1} for the entire season. The average TP concentration during the comparable 4-month period in 2010 was 386 µg P L, which still was below the 2009 average value.

4.2.5 Phytoplankton

The 2010 data have been summarized to reflect the entire 8-month sampling season and the same 4-month sampling season that compares with the period of sampling during 2009. Some, but not all, of the phytoplankton community parameters are summarized in Table 4.2.

Assemblage. There were 55 different taxa in the 2009 HHP phytoplankton assemblage while the 2010 assemblage contained 59 different taxa; 40 taxa were common to both assemblages.

Table 4.2 A summary of phytoplankton community parameters in HHP during 2009 and 2010. The 2010 data are summarized for the entire season and a 4-month period comparable to the 2009 season.

	ENTIRE SEASON			4-MONTH PERIOD	
Category	2009	2010		2009	2010
Avg. Chlorophyll *a* (µg mL^{-1})	39.8	69.7		39.8	90.2
Avg. # taxa	25.1	19.7		25.1	19.7
Avg. Density (cells mL^{-1})	211134	54653		211134	74083
Avg. Biomass (mg m^{-3})	6696	9609		6696	11502
Avg. Diversity (H]	0.750	0.461		0.750	0.398
Avg. Evenness (E_H)	0.236	0.155		0.236	0.134
Cyanophytes					
Avg. # taxa	3.6	1.7		3.6	2.3
Avg. Density (cells mL^{-1})	208261	46773		208261	69121
Proportion of total density	0.97	0.66		0.97	0.91
Avg. Biomass (mg m^{-3})	4289	6455		4289	9663
Proportion of total biomass	0.59	0.55		0.59	0.82
Chlorophytes					
Avg. # taxa	9.4	5.5		9.4	5.0
Avg. Density (cells mL^{-1})	2134	2983		2134	3578
Proportion of total density	0.02	0.13		0.02	0.07
Avg. Biomass (mg m^{-3})	882	641		882	588
Proportion of total biomass	0.16	0.11		0.16	0.06
Bacillariophytes					
Avg. # taxa	8.5	10.1		8.5	10.0
Avg. Density (cells mL^{-1})	320	3744		320	556
Proportion of total density	0.0	0.09		0.0	0.01
Avg. Biomass (mg m^{-3})	252	1062		252	186
Proportion of total biomass	0.04	0.08		0.04	0.02
Chrysophytes					
Avg. # taxa	1.0	0.3		1.0	0.3
Avg. Density (cells mL^{-1})	142	16		142	9
Proportion of total density	0.0	0.0		0.0	0.00
Avg. Biomass (mg m^{-3})	107	7.2		107	4.2
Proportion of total biomass	0.02	0.0		0.02	0.00
Euglenophytes					
Avg. # taxa	0.9	0.7		0.9	0.6
Avg. Density (cells mL^{-1})	14	587		14	232
Proportion of total density	0.0	0.09		0.0	0.00
Avg. Biomass (mg m^{-3})	16	671		16	266
Proportion of total biomass	0.0	0.15		0.0	0.03
Pyrrhophytes					
Avg. # taxa	1.4	1.5		1.4	1.5
Avg. Density (cells mL^{-1})	253	599		253	599
Proportion of total density	0.01	0.04		0.01	0.01
Avg. Biomass (mg m^{-3})	1090	773		1090	796
Proportion of total biomass	0.18	0.12		0.18	0.07

Since the period of monitoring in 2010 was twice as long as in 2009, many of the new taxa identified in the 2010 assemblage occurred during the spring and early summer, a part of the year not sampled during

2009. The 2009 phytoplankton assemblage contained an average of 25 taxa for the eight sampling dates (Table 4.2). The 2010 phytoplankton assemblage contained an average of about 20 taxa regardless of whether the entire sampling period or the 4-month comparable period was considered.

Density. Density provides the first evidence of significant differences between the 2009 and 2010 phytoplankton communities. The average density for 2009 was 211,134 cells mL^{-1} for the 4-month period (Table 4.2) while the average density in 2010 for the comparable period of time was about one-third the 2009 average (74,083 cells mL^{-1}). As shown in Table 4.2, the average cell density was even less for the entire 8-month period of monitoring in 2010 (54,653 cells mL^{-1}). Cyanobacteria were the major component of the mid-summer and fall communities during 2009 (97 percent) and 2010 (91 percent). The extended period of monitoring during the spring of 2010 revealed that other phytoplankton groups besides Cyanobacteria were important in seasonal succession, including Chlorophytes, Bacillariophytes and Euglenophytes.

Biomass. Although the 2010 phytoplankton community averaged fewer cells, the average community biomass was almost twice as large in 2010 (9609 mg m^{-3}) as in 2009 (6696 mg m^{-3})(Table 4.2). The difference was even more striking when comparing similar 4-month periods in 2009 (6696 mg m^{-3}) and 2010 (11,502 mg m^{-3}). Cyanophytes were far more dominant in the 2010 (82 percent) mid-summer and fall community than realized during the same period in 2009 (59 percent). The importance of other phytoplankton groups in the 2010 spring and early summer community is evident from the reduced importance of Cyanobacteria (55 percent) during the 8-month period and the significance of other groups in the community including Chlorophytes (11%), Bacillariophytes (8%), Euglenophytes (15%) and Pyrrhophytes (12%).

Seasonality. The phytoplankton community associations documented during 2010 provide important information about the general trophy of the pond. There were no spring data collected during 2009 which limited the community evaluation to summer and fall only. In spite of the intrusion of salt-water into the pond during the spring 2010 opening to the Atlantic Ocean, the taxa that became prominent following this event were cold-water forms that would be expected to occur as the pond was warming toward the summer growing period. Important early taxa consisted of Euglenophytes, Cryptophytes, Chrysophytes, Bacillariophytes (diatoms), and Chlorophytes, and the density and biomass of these organisms varied during the spring and early summer of 2010. Diatoms and cryptomonads are well-adapted to cold-water. Cyanobacteria were not detected in the HHP phytoplankton community until the fifth sampling date on June 15th 2010. The appearance of greens (Chlorophytes) and Cyanophytes during the warmest period of the year is a condition typical of mesotrophic-to-eutrophic conditions.

Dominance. It is particularly noteworthy that the dominant taxa during the mid-summer and fall of 2010 were almost completely different than the dominant taxa in the 2009 community. The only exceptions to this situation included *Pandorina morum* and *Anabaena spiroides*; these were the only dominant taxa common to both the 2009 and 2010 communities. Community dominance during the two successive years is summarized in Table4.3.

Diversity. The extended 2010 sampling season had the effect of increasing phytoplankton community diversity by a slight amount when compared with the 4-month period from mid-summer through fall. The 4-month value for **[H]** was 0.398 while the value for the entire 8-month period was 0.461 (Table 4.2). This increase was probably due to the increased number of taxa that were important in the phytoplankton community during the spring and early summer of 2010. In spite of this particular spring 2010 characteristic, both phytoplankton community diversity **[H]** and evenness **[E]** during mid-summer and fall 2010 were substantially reduced when compared to the 2009 community characteristics (Table 4.2). This condition probably is due to the increased dominance of the

Cyanobacteria in the community during 2010 (average proportion of biomass = 0.82) as compared with 2009 (average proportion of biomass = 0.59) (Table 4.2).

Table 4.3. A summary of phytoplankton community dominant taxa that occurred in HHP during 2009 and 2010. Shaded taxa were common to the 2009 and 2010 communities.

2009 Community Dominants	2010 Community Dominants
Taxa (Group)	Taxa (Group)
Anabaena flos-aquae (Cyanophyta)	*Anabaena spiroides* (Cyanophyta)
Anabaena spiroides (Cyanophyta)	*Anabaenopsis elenkinii* (Cyanophyta)
Microcystis aeruginosa (Cyanophyta)	Coelastrum cambricum (Chlorophyta)
Gonyostomum semen (Chloromonadophyta)	*Eudorina elegans* (Chlorophyta)
Ankistrodesmus falcatus (Chlorophyta)	*Mougeotia* sp. (Chlorophyta)
Closterium spp. (Chlorophyta)	*Pandorina morum* (Chlorophyta)
Eudorina elegans (Chlorophyta)	*Pediastrum duplex* (Chlorophyta)
Pandorina morum (Chlorophyta)	*Pyramimonas tetrahyncus* (Chlorophyta)
Spirogyra sp. (Chlorophyta)	*Cyclotella* sp. (Chrysophyta)
Dinobryon spores (Chrysophyta)	*Stephanodiscus* sp. (Chrysophyta)
Peridinium cinctum (Pyrrhophyta)	*Cryptomonas ovata* (Cryptophyta)
	Rhodomonas sp. (Cryptophyta)
	Peridinium cinctum (Pyrrhophyta)
	Trachelomonas spp. (Euglenophyta)

Chlorophyll *a*. The 2010 summer and fall average chlorophyll *a* concentration (90.2 µg L^{-1}) was over two times the average concentration during the same period in 2009 (39.8 µg L^{-1})(Table 4.2). Since average cell density during this 4-month period was one-third the average cell density during 2009, the only explanation for the higher average chlorophyll *a* concentration is the higher average cell biomass in 2010, which was two times the 2009 value (11,502 mg m^{-3} versus 6,696 mg m^{-3}) for the same period.

4.2.6 Trophic Status

As shown below, there were only slight differences among the TSI indices calculated for 2009 and 2010 using chlorophyll *a*, total phosphorus and Secchi depth transparency data for each sampling period.

	Trophic State Index (TSI) Based Upon		
Sampling	Chlorophyll *a*	Total	Secchi
P 2009	69.8 (E)	P 93.6 (HE)	D 63.2 (E)
2010	73.3 (HE)	88.6 (HE)	62.1 (E)

The 2009 TSI for chlorophyll *a* (69.8) places the pond on the threshold of eutrophy-hypereutrophy, while the 2010 TSI (73.3) is within the range of hyper-eutrophy. The 2009 and 2010 TSI values for total phosphorus are well within the hyper-eutrophic range while Secchi depth transparency, is less robust a calculator, and the TSI values for both years results in a eutrophic classification.

4.3 Summary

The comparison of 2009 and 2010 data from HHP revealed certain water quality differences that were summarized in this chapter. The plant nutrients, nitrogen and phosphorus, exhibited some variation between the two years. The average TN concentration was considerably higher in 2010 than in 2009, while the average 2010 TP concentration was considerably lower than in 2009. However, the relative differences in the plant nutrient data in HHP during 2009 and 2010 are insignificant in terms of the overall water quality of the pond, which was very poor during both years.

Perhaps the most noteworthy finding from the comparison of the 2009-2010 water quality data was the significant difference in the composition of the phytoplankton community. The taxa that were dominant during 2010, almost without exception, were different than the dominant taxa in 2009. One consistent feature of the two years was the existence of a major Cyanobacteria bloom from mid-summer through fall, although the dominant Cyanobacteria taxa were different.

We continue to document poor water quality in HHP on an annual basis and the next logical step is to develop and initiate some sort of remediation for the pond. However, it is not possible to address the high nutrient conditions in the HHP without a better understanding of the overall internal and external nitrogen and phosphorus dynamics. We need to increase our present level of knowledge with regard to (1) the pond bottom sediments and the availability and extent of nitrogen and phosphorus mobilization, and (2) the influence of groundwater input on the nitrogen and phosphorus budgets in the pond. There will be more discussion regarding pond studies and possible remediation in the final chapter of this report.

4.4 Literature Cited

Sutherland, J.W. and S.D. Oktay. 2010. Hummock Pond Water Quality. 2009. A Summary of Physical, Chemical and Biological Monitoring. 74 pp. + Appendix 1.

Head of Hummock Pond

The 2010 Water Quality Program

Chapter 5

A Review of Historical and Current Water Quality Data

5.0 Introduction.

There is some limited historical water quality data collected from HHP during the past decade that should be summarized and reviewed in an effort to identify water quality trends. These data will be presented and discussed here and compared with the 2009-2010 data in the context of water quality trends that may be occurring in HHP.

5.1 Analysis and Summary of Historical Data

Water quality data for HHP first appear in a report by Knoecklein (2006) where data from 2004 and 2005 are discussed. Subsequent to these data, Conant (2007, 2008) collected samples and information from a station on HHP during 2006 and 2007. Table 5.1 provides a brief summary of all known water quality data collected from the pond.

Table 5.1. A summary of all known water quality data collected from Head of Hummock Pond.

Year	Sampling Frequency	Analytes	Investigator
2004	2 times (August, September)	trans, temp, DO, TP, N series	Knoecklein
2005	8 times; monthly (March-October)	trans, temp, DO, TP, N series	Knoecklein
2006	8 times; monthly (April-November)	trans, temp, DO, TP, N series	Conant
2007	7 times; monthly (April-October)	trans, temp, DO, TP, N series	Conant
2009	8 times; biweekly (late June-late October)	trans, temp, DO, TP, N series; chl a; phyto	Sutherland
2010	16 times; biweekly; April-November)	trans, temp, DO, TP, N series; chl a; phyto; MC	Sutherland
Codes: trans (transparency); temp (temperature); DO (dissolved oxygen); TP (total phosphorus; N series (nitrogen series);			

c *a*;

The duration and frequency of sampling varied among the years reported. There also is more interest in the mid-summer and early fall of each sampling period since this is the 'growing season' and represents the period of concern for water quality. In view of these conditions, the period of July through October was selected for comparison of water quality data among the various years since 2005 to standardize the data. The 2004 data were excluded from most of the following analysis since only two sampling dates occurred in HHP that year.

As described in Chapter 4 where comparisons of the 2009 and 2010 data were presented, the most basic method for evaluating different sets of water quality data is a comparison of mean, or average, values for the analytes of interest in the suite of parameters collected each year. That procedure was used to compare the data collected from HHP since 2005.

There is one other discrepancy among the data collected from HHP that should be mentioned here. Samples collected during 2004-2007 were grab samples, which are collected from a specific depth and, as such, represent the water chemistry only at the depth from which the sample was taken.

In contrast to this 'grab sample' technique, the samples collected during 2009-2010 are integrated samples which represent a composite of the water chemistry from the pond surface down to a lower depth just above the bottom of the pond. Grab samples can provide misleading chemistry results since the depth at which samples are taken can contain high concentrations of phytoplankton located at a particular level in the water column where there are optimal light conditions for photosynthesis during the daylight hours. The higher concentrations of these organisms in the collected water samples can bias the analytical results for parameters such as TP, TN and chlorophyll *a*.

5.2 Review of Historical Data

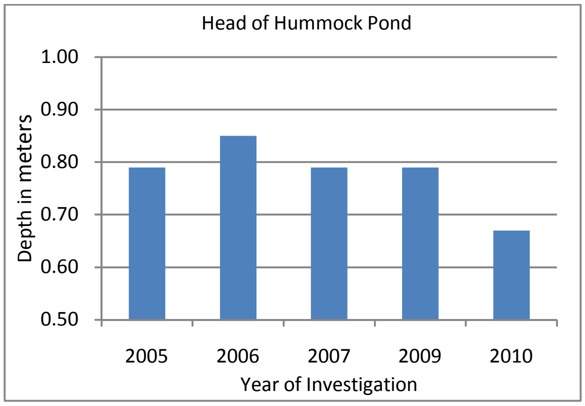
5.2.1 Physical characteristics

Transparency. Average Secchi depth data are summarized below for the years when these data are available for the period from June-October.

Year	Average transparency (m^{-1})
2005	0.79
2006	0.85
2007	0.79
2009	0.79
2010	0.67

The average transparency always has been less than 1.0 m and there has been a trend of decreasing transparency even though the period of record is only a few years in duration (Figure 5.1).

Figure 5.1. A summary of average mid-summer and fall Secchi depth transparency data available for HHP.



Based upon the average transparency values during the past six years and the distinct relationship between phytoplankton community biomass and water column transparency revealed during the past two years of study, it appears that algal blooms, and most likely Cyanobacteria, have been prevalent in HHP since data collection began in 2005.

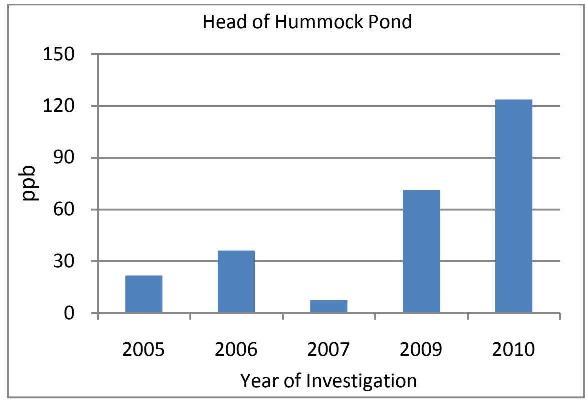
5.2.2 Plant Nutrients

Nitrogen. The average **nitrate-nitrogen** (NO_3-N) data available for HHP during the June-October period are summarized below.

Year	Average NO_3-N (mg N L^{-1})
2005	0.02
2006	0.04
2007	0.01
2009	0.07
2010	0.12

Knoecklein (2006) reported most nitrate/nitrite samples from HHP during 2004-2005 were below the detection limit of 20 ppb (0.02 mg L^{-1}). Conant (2007) reported an average nitrate-nitrogen concentration of 0.04 mg N L^{-1} in 2006 samples and an average concentration of 0.01 mg N L^{-1} in 2007. The average nitrate concentrations in HHP during 2009 and 2010 are consistent with levels reported by Knoecklein and Conant (Figure 5.2); nitrate-nitrogen averaged 0.07 mg N L^{-1} for 2009 as compared with 0.12 mg N L^{-1} for the 4-month period during 2010.

Figure 5.2. A summary of average mid-summer and fall nitrate-nitrogen data available for HHP.



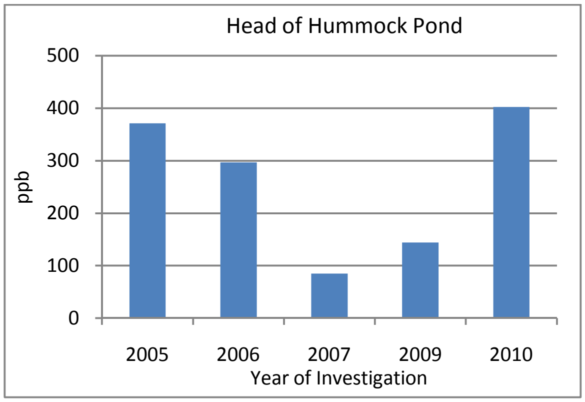
Low, or undetectable, nitrate- nitrogen levels often are reported from lakes and ponds during mid-summer and indicate that available nitrogen in the form of nitrate is being consumed by phytoplankton uptake as soon as it is released into the water column. Although there appears to be an increasing concentration of average nitrate-nitrogen in HHP in mid-summer and fall during the past several years, it is too soon to determine whether an actual trend is developing.

The average **ammonia-nitrogen** (NH_4-N) values reported for HHP during the July-October period are summarized below.

Year	Average NH_4-N (mg N L^{-1})
2005	0.37
2006	0.30
2007	0.09
2009	0.14
2010	0.40

The average ammonia-nitrogen values for 2005 (Knoecklein 2006) and 2010, 0.37 mg N L^{-1} and 0.40 mg N L^{-1}, respectively, are the highest reported values from the available ammonia-nitrogen data. 2007 was the lowest reported average value at 0.09 mg N L^{-1}. There does not appear to be any trend for average ammonia-nitrogen in HHP during the period of available data (Figure 5.3).

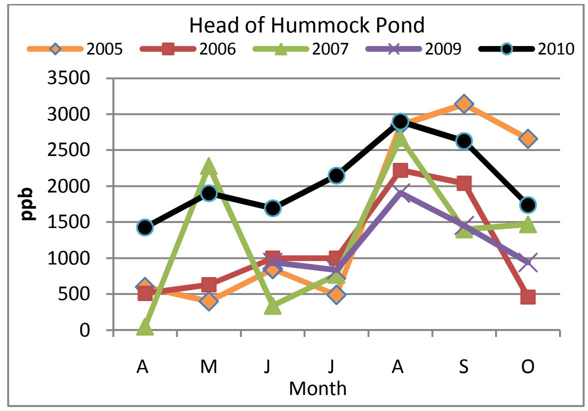
Figure 5.3. A summary of mid-summer and fall average ammonia-nitrogen data available for HHP.



The data collected during 2009 and 2010 suggest that the amount of ammonia-nitrogen measured in HHP at any given time may be directly related to water column pH. Unfortunately, we only have pH data from 2009-2010 that support this hypothesis. In other words, high water column pH would increase the amounts of ammonia-nitrogen in the form of NH_4OH, which is toxic to biological growth. The average water column pH during comparable 4-month periods was higher in 2010 (8.70) than in 2009 (8.25), which could explain the greater amount of ammonia-nitrogen in the water column (0.40 versus 0.14 µg N L^{-1}) that would be unusable as a result of toxic conditions.

The monthly pattern of **total nitrogen** (TN) concentrations in HHP has been constructed from previous and current data in Figure 5.4. The pattern during the early years (2005-2006) was a low concentration during early spring and summer which gradually increased to a mid-summer and early fall peak. This pattern was partially displayed during 2009, although there were no spring and early summer data collected (Figure 5.4). The pattern in 2006 was a bi-modal, with peaks in the spring and again in the mid-summer. The pattern during 2010 was most dramatic, starting in April with a very high average TN concentration (≈1,500 ppb) which continued to increase to ≈3,000 ppb TN in August and then declined thereafter.

Figure 5.4. Average monthly concentrations of total nitrogen from available HHP data.



Knoecklein (2006) reported an average **total nitrogen** (TN) concentration of 1.47 mg N L^{-1} in HHP from a series of eight monthly samples collected in 2005; however, the July, August, September and October samples that year remained consistently high (average = 2.28 mg N L^{-1}) and did not decline at the end of the season (Figure 5.4). Conant (2007) reported an average TN concentration of 0.99 mg N L^{-1} in HHP from a series of eight monthly samples collected in 2006; the pattern of concentration was a bell-shaped curve with low values in spring and fall, and the highest values during mid-summer (Figure 5.4). However, the pattern was completely different in a series of seven monthly samples from 2007; TN values were lowest in late spring and early summer, while the highest values occurred in early spring and mid-summer, and remained high during the fall. The average value for 2007 was 1.28 mg N L^{-1}.

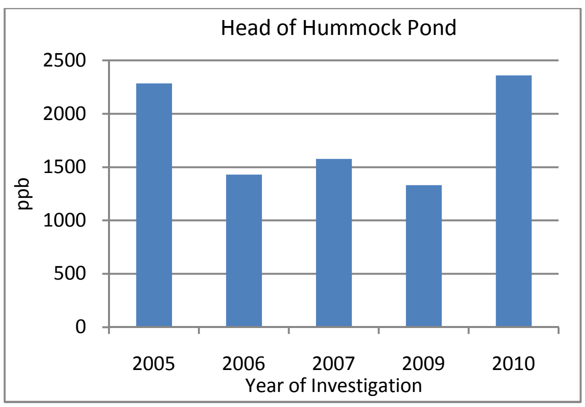
Conant's 2006 pattern of TN was the most similar to the 2009 and 2010 results (Figure 5.4), with the highest values occurring during mid-summer and the lower values during spring and fall, while his 2007 pattern of TN was similar to the pattern reported by Kneocklein for 2005 when TN values remained high through the fall period..

A summary of HHP average TN concentrations for data available during the July-October period are presented below.

Year	Average TN (mg N L^{-1})
2005	2.28
2006	1.43
2007	1.58
2009	1.33
2010	2.36

The average values reported for 2005 (Knoecklein 2006) and 2010 (this report), 2.28 mg N L^{-1} and 2.36 mg N L^{-1}, respectively, are the highest reported values from the available TN data. Although the values for 2006, 2007 and 2009 are lower than the 2005 and 2010 values, they are considered to be high TN levels for freshwater and estuarine systems world-wide. Figure 5.5 summarizes the average 4-month TN concentrations, standardized for the period July through October, for 2005-2010.

Figure 5.5. A summary of mid-summer and fall average total nitrogen data available for HHP.

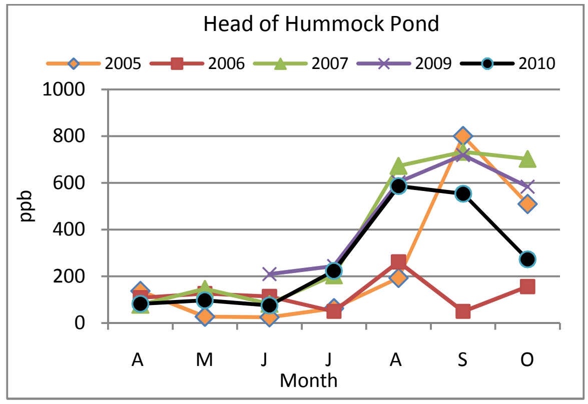


The annual average TN values in HHP exhibit considerable fluctuation; the TN values have been high since 2004 and probably for a much longer period of time, although there are no data prior to 2004 to confirm this belief.

The high TN values documented in HHP during the past decade emphasize the nutrient-rich condition of the system and the need to better understand the dynamics of this ecosystem. Currently, it is not possible to estimate external versus internal loading of nitrogen to the pond without more information on groundwater flow and nutrient concentrations, the annual precipitation patterns, and some basic understanding of the pond hydrologic cycle.

Phosphorus. As with total nitrogen (TN), the monthly pattern of HHP average total phosphorus (TP) concentrations has been constructed from previous and current data (Figure 5.6).

Figure 5.6. Average monthly concentrations of total phosphorus from available HHP data.



The seasonal pattern during most years is essentially the same, i.e., concentrations are low in spring-early summer and then increase dramatically during mid-summer and fall. An exception to this pattern occurred in 2006 when the TP concentrations remained below 200 ppb for most of the year. An interesting feature of Figure 5.6 is the early seasonal increase in TP concentrations during 2007, 2009 and 2010. During those years, TP increased in the water column a full month ahead of the seasonal increases that occurred during 2005 and 2006. The reason for these shifts in the pattern is not known; it could be the result of warmer water temperatures occurring earlier in the season or a change in the pattern of precipitation and groundwater flow into the pond.

The average **total phosphorus** (TP) concentrations for HHP data are presented below. These values represent comparable 4-month averages for the sets of data available.

Year	Average TP (µg P L^{-1})
2005	392
2006	156
2007	578
2009	531
2010	424

The highest 4-month average values occurred during 2007 and 2009, 578 and 531 µg P L^{-1}, respectively. Although the average values for the other years are lower, there still should be cause for concern since all of these average values are indicative of very poor water quality. There has not been any pattern in the average TP concentration (Figure 5.7).

The limited TP data for HHP suggests that seasonal concentrations can fluctuate quite a bit and that average values for any season probably depend upon a variety of factors including the extent of water exchange when Hummock Pond is opened to the Atlantic Ocean, the pattern and amount of precipitation that occurs during spring and summer, and the dominant taxa of phytoplankton that set up in the pond early in the spring following the opening event. As with TN, it probably is safe to say that TP concentrations in the pond have been high for quite some time; however, there are no data available to substantiate this belief.

A worst case TP scenario in HHP may have occurred in 2004. Only 2 sets of HHP data were reported that year by Knoecklein (2006) and a summary was not included with the above material due to the limited data-set. However, Knoecklein reported the highest values of TP recorded in HHP during August and September 2004 at 1230 µg P L^{-1} and 2200 µg P L^{-1}, respectively (average value=1715 µg P L^{-1}). These exceptionally high values emphasize the dramatic fluctuations that can occur in the pond and the unstable nature and dynamic of the ecosystem.

5.2.3 Phytoplankton

The first comprehensive collection of phytoplankton data from HHP occurred during 2009 and continued during 2010. Although there is no detailed record of this important biological component within the HHP ecosystem, the water quality record since 2004 seems to indicate that Cyanobacteria blooms have been a common occurrence in the pond since that time. Knoecklein (2006) does mention a single phytoplankton sample collected from HHP during a bloom observed during August, September and October in 2005, but does not identify exactly when the sample was collected. The sample contained *Anabaena* and *Microcystis* spp. at densities of about 90,000 cells mL^{-1}. Both of those genera have been reported in HHP during the past two seasons.

5.2.4 Trophic Status

The Trophic Status Index (TSI) could only be calculated for the Secchi depth and TP data since there was no chlorophyll a data collected prior to 2009. As presented below, there were only slight differences among the TSI indices calculated for either TP or Secchi depth data. All of the TP TSIs were within the hyper-eutrophic range, while all of the Secchi TSIs were within the eutrophic range.

	Trophic State Index (TSI) Based Upon	
Sampling Period	**Total Phosphorus**	**Secchi Depth**
2005	84.9 (HE)	60.0 (E)
2006	79.7 (HE)	60.9 (E)
2007	91.4 (HE)	61.8 (E)
2009	93.6 (HE)	63.2 (E)
2010	88.6 (HE)	62.1 (E)

5.3 Summary

The current water quality of HHP is very poor and it appears that the pond has exhibited poor water quality for at least the past seven years and probably much longer, although there are no data available prior to 2004 to substantiate this claim. Degraded water quality, however, usually does not happen over a brief period of time. Nutrient dynamics in a system such as HHP often can remain within normal limits of acceptable water quality for long periods of time in the absence of any external perturbations from sources such as storm-water runoff or groundwater contaminated with nutrients. Storm-water does not contribute contaminated water to HHP in the usual sense of watershed-runoff dynamics that occur in other bodies of water. The likely source of pollution to HHP is contaminated groundwater either from (1) historical agricultural practices within the watershed, or (2) adjacent and improperly functioning septic systems within the watershed. One other possibility is the extensive wetland area that borders the narrow channel connecting HHP with Hummock Pond, and the ability of wetlands to act as either 'sources' and 'sinks' of nutrient materials depending upon water level, water flow, wind dynamics, etc.

5.4 Literature Cited

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Head of Hummock Pond

The 2010 Water Quality Program

Chapter 6

2010 Project Summary, Discussion, Conclusions and Recommendations

6.0 2010 Project Summary

HHP was studied in 2010 to determine whether the poor water quality documented in 2009 would recur, particularly the extensive bloom of Cyanobacteria that dominated the phytoplankton community during the mid-summer and fall. In addition to high levels of the plant nutrients, phosphorus and nitrogen, measured in the water column throughout the mid-summer and fall of 2009, a more alarming discovery was the presence of several species of Cyanobacteria that have been linked to the production of neurotoxins, substances which can be harmful to humans, pets, farm animals and wildlife.

The 2010 sampling program on HHP was expanded to include almost the entire ice-free period, from early April until mid-November, thus documenting the seasonal progression of water quality in the pond for one complete growing cycle. HHP was sampled at bi-weekly intervals, while temperature and dissolved oxygen profile data were collected more frequently. Samples were collected for physical, chemical and biological parameters including temperature, dissolved oxygen, nutrient chemistry, chlorophyll *a*, and the phytoplankton community, the same parameters sampled during 2009. In addition, there was a special study of the neurotoxin, microcystin, which, if detected, would indicate the presence of neurotoxin-producing Cyanobacteria in the water.

As documented in 2009, HHP continued to exhibit elevated levels of total phosphorus and total nitrogen during 2010, validating the 'eutrophic' status attached to this body of water by earlier investigations (Conant, 2006, 2008; Knoecklein, 2006) and by the 2009 study. If the pond's inventory of historical data are considered in the trophic state analysis along with the 2009-2010 information, it appears that HHP has been in a hyper-eutrophic state at least since 2004, and probably for much longer, although this condition cannot be proved.

The 2010 growing season in HHP was more substantial than the 2009 season based upon the higher temperature of the water column for an extended period (about 5^{o}C higher for a period of 3 months). There was an immediate, noticeable response to these warmer conditions by the phytoplankton community in the form of a greater standing crop, estimated from chlorophyll *a* concentration, during the mid-summer and fall. The average 2010 mid-summer and fall concentration was almost 2.5 times the value during 2009 for the same period, and the average phytoplankton community biomass during 2010 was almost twice the average biomass during 2009.

With regard to plant nutrients, a comparison of similar 4-month sampling periods during 2009 and 2010 revealed that the average TP concentration during 2010 was substantially lower than in 2009, even though the average 2010 chlorophyll *a* concentration was over twice the 2009 value. In contrast, the average TN measured during 2010 was almost two times the 2009 average concentration.

In spite of having considerable recent and historical nutrient data for HHP, essential information is lacking that would permit a thorough evaluation of (1) the extent to which phosphorus and nitrogen regeneration occur within the system and (2) the role of nutrient input to the pond from the surrounding watershed.

The phytoplankton community documented during the spring and early summer of 2010 was diverse and exhibited a 'typical' seasonal succession from cold-water forms that would be expected to occur during the spring in this type of pond. Some forms identified early in the season are considered salt-tolerant and likely are remnants from the period of opening the pond to the Atlantic Ocean. About 70 percent of the total phytoplankton forms identified in HHP during 2009 and 2010 were common to both years of the study. The more remarkable feature of the 2009-2010 phytoplankton communities was the unique nature of the dominant forms during each year; only two dominant taxa were common to both years; all other dominant forms were unique to either 2009 or 2010.

A major finding from the 2009 HHP study was the absence of any rooted aquatic plants growing on the bottom of the pond during a survey in conducted in August. Apparently, this 'condition' was a factor of the abbreviated 2009 sampling season. Rooted aquatic plants were noted growing on the bottom in HHP during the spring and early summer of 2010, although an aquatic plant survey was not conducted. On several occasions, pieces and whole plants were attached to the boat anchor when it was retrieved from the bottom following sample collection. There also were plants noticed growing in more shallow areas of the pond where the bottom was visible.

All of the living plants observed in HHP during 2010 were coontail, *Ceratophyllum* spp., a common species found in Hummock Pond during the 2009 aquatic plant survey. Around mid-July in 2010, however, viable plants no longer were growing on the pond bottom. Instead, the material brought up with the anchor was dead, decaying plant material which indicated that light and dissolved oxygen conditions beneath the intense Cyanobacteria bloom were unsuitable for plant growth. The absence of live plants also was noted in shallow areas of the littoral zone where viable plants previously had been noted. This sequence of events probably occurs each year as Cyanobacteria bloom conditions develop in HHP and shade the light necessary for aquatic vegetation to grow on the bottom.

The total dominance of Cyanobacteria once again in 2010 confirms the deteriorated condition of the HHP ecosystem. Although the total assemblage of HHP phytoplankton was diverse in terms of total numbers of taxa identified in 2010, all major groups except the Cyanobacteria were scarce throughout the mid-summer and fall regardless of whether cell density or biomass was considered.

The five species of Cyanobacteria identified in HHP during 2010 are listed below. Two of the species, *Anabaena spiroides* and *Microcystis incerta*, also were present in the 2009 assemblage. The three other species were new occurrences in 2010. The Cyanobacteria species of primary concern in HHP during 2009, *Microcyctis aeruginosa*, was not identified in any of the 2010 samples.

Head of Hummock Pond
Anabaena spiroides*
Anabaenopsis elenkinii
Aphanocapsa elachista
Gloeocapsa rupestris
*Microcystis incerta**
* occurred in HHP during 2009

The liver toxin, microcystin (MC), was detected in all 2010 samples submitted for analysis. The lowest concentrations occurred in June and the highest concentrations were in October. On all sampling dates, MC concentrations were below the recommended maximum levels for drinking water and recreational use (WHO and MPPH guidelines).

Although MC was detected in all samples collected during the summer and early fall, we do not know which species was (were) producing this neurotoxin. With the exception of *Gloeocapsa*, all of the other Cyanobacteria genera listed above have been implicated in the production of toxins. Special studies would have to be conducted to isolate the species responsible.

The MC detected in HHP during 2010 could have been produced by Cyanobacteria below the size limit of detection, and there is evidence from 2010 to support this statement. Although MC was detected in the first sample collected and submitted on June 1^{st}, Cyanobacteria were not detected in any of the processed phytoplankton samples until June 15^{th}. These results suggest the presence of MC-producing pico-cyanobacteria which require fluorescence microscopy for observation and identification.

Cyanobacteria are ubiquitous and the body of knowledge surrounding these organisms and their toxins is growing at a rapid rate. As of 2008, when a major NATO document was released on algal toxins, there were 46 species of cyanobacteria identified that produce toxins. Some researchers believe that it would be prudent to assume any cyanobacteria population can have a toxic potential in the aquatic ecosystem in which it is located.

6.1 Discussion

Previous investigations of HHP were the first to reveal the nutrient enrichment problems related to poor water quality and eutrophication (Knoecklein, 2006; Conant, 2007, 2008). Water quality data collected during the past two years have confirmed the results from the earlier work that HHP suffers from a nutrient enrichment involving both TP and TN. In addition to these plant nutrients, the recent intensive sampling of the pond has documented the occurrence of extensive Cyanobacteria blooms and the presence of forms that produce potentially-harmful toxins, including the neurotoxin microcystin.

Howes et al. (2006) have attributed 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 many areas, the embayments have nutrient levels that either are approaching or have exceeded assimilative capacity, which causes decline in ecological health of the water body. The primary nutrient causing the increased impairment is nitrogen from wastewater disposal, fertilizers and changes in groundwater hydrology associated with watershed development. Sesachacha Pond on Nantucket Island has been described as a coastal system suffering from nitrogen enrichment, compounded by inadequate tidal exchanges when the system is opened to the Atlantic Ocean for management purposes (Howes et al. 2006).

Based upon historical information, water quality data collected since the mid-2000s, the setting of the geologic watershed, and land use and local hydrology, it appears that HHP is experiencing the same high nutrient dilemma as Sesachacha Pond and other coastal embayments. However, there are far less background information and supporting data available for HHP than the corresponding information for Sesachacha Pond presented by Howes et al. (2006). It is not possible to explain with any certainty, therefore, the primary source of nutrient enrichment that affects HHP.

Potential sources of nutrients to HHP were discussed by Knoecklein (2006). The total HHP groundwater drainage basin is about 77 hectares, 6.5 hectares of which include the surface area of the pond. Most of the remaining 71 hectares of groundwater drainage, about 55 hectares, flows toward Maxey Pond (4 hectares) and Waqutuquaib Pond (3.5 hectares). The direct contributory watershed for HHP, therefore, is relatively small (16 hectares) and 6 or fewer homes are within the watershed divide that contributes directly to the pond.

Whether these homes are contributing an external load directly from wastewater treatment systems to HHP via groundwater flow (allochthonous source) or whether HHP is mobilizing nitrogen internally (autochthonous source), and 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, is not known. It also is entirely possible that some combination of these two contributory factors is affecting HHP.

These are some of the questions that must be answered before any long-term remediation plan can be developed for HHP.

The water quality results from 2009 and 2010 suggest that a significant amount of phosphorus is remobilized within HHP (autochthonous source) during the summer months, based upon the oxygen depleted zone in HHP and the extremely high TP concentrations measured in the lower waters during most of the mid-summer and fall.

The other area that should be a major concern as far as the water quality of HHP is the development of Cyanobacteria blooms that totally dominate the mid-summer and fall phytoplankton assemblage. Cyanobacteria are ubiquitous organisms, being found in almost every habitat, and the presence of small numbers in the phytoplankton assemblage of aquatic ecosystems is part of a natural process and sequence of events. When present in large numbers as with 'bloom' conditions, however, Cyanobacteria can induce physical, chemical and biological changes in the aquatic environment in which they occur and eventually impart severe negative changes to the ecosystem which may require some direct remedial action to reverse or overcome. This appears to be the current situation in HHP. The water quality of the pond has gone beyond the point where it is able to correct its own problems.

Intense concentrations (blooms) of Cyanobacteria in the water column decrease transparency, thereby reducing the depth of the photic zone and the volume of water that supports other photosynthetic organisms. In addition, these high concentrations of Cyanobacteria in the water column result in high rates of cell die-off which settle to the bottom and then cause 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 bottom region that depend on oxygen for survival, as well as the indirect effect of toxic gas release and nutrient mobilization into the water column. In a shallow system, such as HHP, there is wind-induced mixing with the upper levels of water which reduces the oxygen saturation levels and transports mobilized nutrients into the upper levels of the pond for phytoplankton uptake. 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 cyanobacteria floats on the surface of the 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 water body. 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. In addition to being toxic and dangerous to animals, such as cattle, dogs and cats, cyanotoxins should be considered a public safety risk to the extent that contact and consumption of pond water be avoided by humans and as well as breathing air down-wind of the pond which contains toxin spores borne as aerosols from the scum concentrated at the surface of the pond.

Based upon the water quality data and sequence of events documented during the past two years, the recurring Cyanobacteria bloom in HHP has become problematic to the point that some direct remedial action is required to break the cycle and encourage other forms of phytoplankton to become dominant in the pond ecosystem

6.2 Conclusions

HHP is a hyper-eutrophic body of water with concentrations of total phosphorus and chlorophyll *a* far enough beyond the boundary between eutrophy and hyper-eutrophy to be cause for serious concern. The high levels of total phosphorus measured in HHP during the growing season 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 can complete the remainder of the internal cycle. The high seasonal concentrations of chlorophyll *a* measured in the HHP during 2009 and 2010 reflect the extensive bloom conditions of Cyanobacteria that were observed and measured during the previous two years of study.

The primary source of the high total nitrogen concentrations documented in HHP during the past two years is more difficult to explain. As acknowledged in Knoecklein (2006), the HHP watershed is small and only a few homes are within the watershed divide that contributes groundwater 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 pond and decomposing under anoxic conditions. Some combination of the two contributing mechanisms also is possible.

The Cyanobacteria identified in HHP during 2010 were quite different from the 2009 assemblage when species were found that are known to produce microcystin (MC), a neurotoxin. Rather than speculate through another sampling season about the production of MC within the pond, samples were collected and analyzed and shown to contain microcystin throughout the sampling period, albeit the MC was present in concentrations below the recommended maximum levels for drinking water and recreational use.

When considering, collectively, all of the data compiled from HHP since 2004, the bottom line in terms of water quality is (1) severe nutrient enrichment problems and (2) annual Cyanobacteria blooms that appear to pose a public health and safety risk for individuals either using the pond recreationally or living near the pond where there is potential exposure to air-borne toxins being spread as aerosols. The ecosystem is so severely affected that aquatic plants are unable to successfully grow on the bottom through an entire season. The severe water quality problems on the pond appear to have been in existence for the better part of the past decade, and probably much longer, although this claim is not supported with any available data.

6.3 Recommendations

(1) Head of Hummock Pond requires some focused attention directed toward a series of water quality issues that have been manifested for part of the past decade, including considerable nutrient enrichment and severe, extended blooms of Cyanobacteria that produce toxins and pose a public safety threat.

(2) Environmental stewardship of HHP falls under the jurisdiction of the Town of Nantucket. In the absence of Town interest or the fiscal ability to participate in either water quality monitoring or other issues related to HHP, it would seem appropriate for some other local organization to exercise long-term vision toward water quality management and remediation for a body of water that obviously requires some dedicated attention. A logical candidate for this oversight role would be the Nantucket Land Council, Inc., an organization that has sponsored the past two years of investigation on HHP and has a strong vision toward both stewardship and environmental management on the Island.

(3) The water quality monitoring program that was developed and implemented on HHP during 2010 should be maintained during 2011 to continue documenting water quality issues on the pond and the response of pond water quality to long-distance circulation achieved by the SolarBee™ unit scheduled for installation during April 2011.

(4) Enhanced groundwater monitoring should be implemented in the HHP watershed including the installation of additional subsurface wells, funds for certified nutrient analyses, and studies to determine the direction of subsurface flows that will define the exact contributory areas and will help develop a priority system for future Title 5 septic system inspections.

(5) Continue water quality sampling of Hummock Pond and Head of Hummock Pond before and after the opening to the Atlantic Ocean in order to fully evaluate the effect of the bi-annual opening on pond water quality.

(6) Continue to sample both phycocyanin and microcystin in HHP during the mid-summer and fall of each year and also set up adjacent terrestrial samplers in the watershed to determine the risk to local residents from wind-borne microcystin spores transmitted in aerosol form.

(7) Install a continuous water level recorder on HHP which is tied into an ASML (above mean sea level) datum to assist with preparation of a water budget for the pond.

(8) Continue to maintain close watch over the Hummock Pond aquatic plant community to

provide early detection of introduced invasive species such as *Myriophyllum spicatum* (Eurasian watermilfoil) or *Hydrilla verticillata* (Esthewaite waterweed).

6.4 Literature Cited

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Head of Hummock Pond

The 2010 Water Quality Program

Appendix

Materials Referenced in the Report

Head of Hummock Pond Field Sheet
Chair of Custody Form
2010 Temperature Profile Data
2010 Dissolved Oxygen Saturation Profile Data

HEAD OF HUMMOCK POND
2010 WATER QUALITY SAMPLING

STATION # ______________ DATE __________ TIME START ____________ TIME STOP ____________

CONDITIONS ____

TOTAL DEPTH ___________ WATER COLOR _______________ LAT ______________________

SECCHI DEPTH __________ TEAM INITIALS _______________ LONG ______________________

COMMENTS ____

DEPTH	TEMP	D.O.	D.O.	spC	TDS	pH	ORP
(ft)	(^oC)	(mg/L)	(% sat)	(μmhos)	(ppm)	(s.u.)	(mv)
0							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

SAMPLE #	SAMPLE DEPTH	COMMENTS

OTHER ____

____

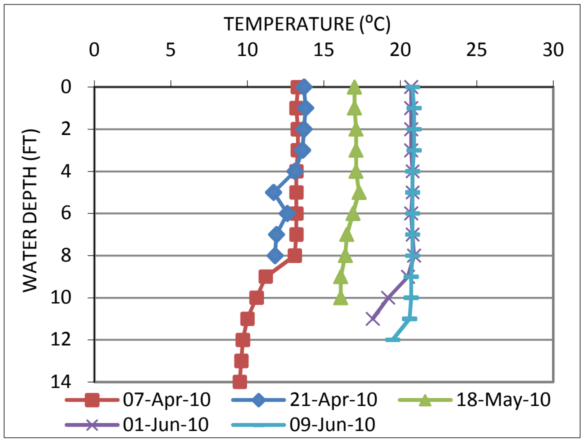
CHAIN OF CUSTODY RECORD

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

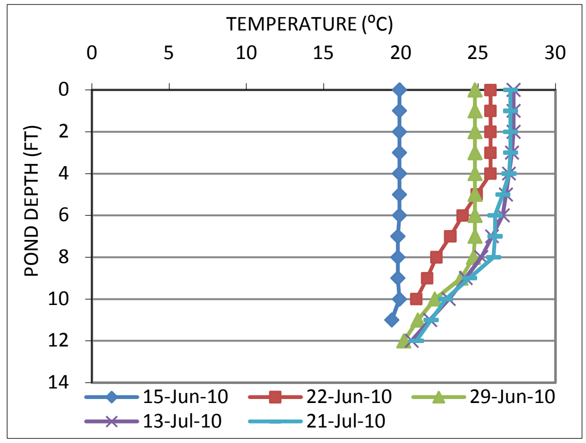
CUSTODY OF SAMPLES

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

A series of graphs displaying the temperature profile data collected on 21 different dates during 2010 at the permanent marker buoy on HHP. Data from several different dates are included on each graph. The scale of temperature (in ^{o}C) is across the top, X-axis, of the graph; the Y-axis on the left of each graph is the depth of the water column in the pond, with the surface at the top and the bottom area on the lower portion of the axis. Slight differences in total depth are due to natural variations in water level; the extreme differences in depth on April 7th and April 21st are water levels prior to, and following, the opening and closing of Hummock Pond to the Atlantic Ocean, respectively.



A



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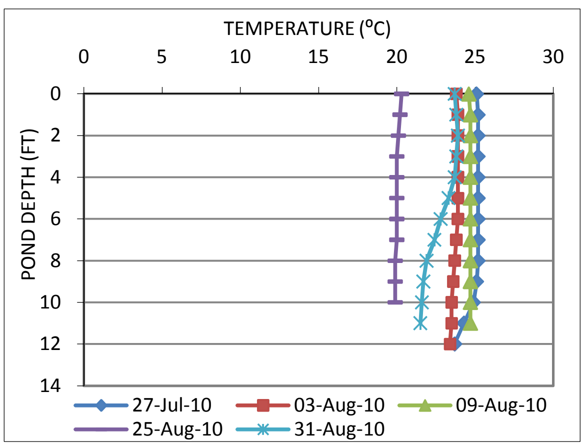
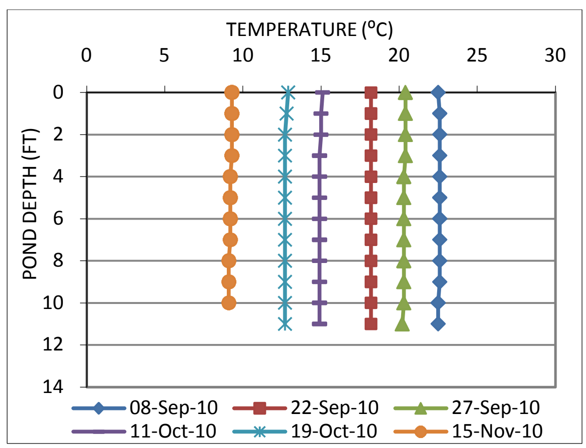
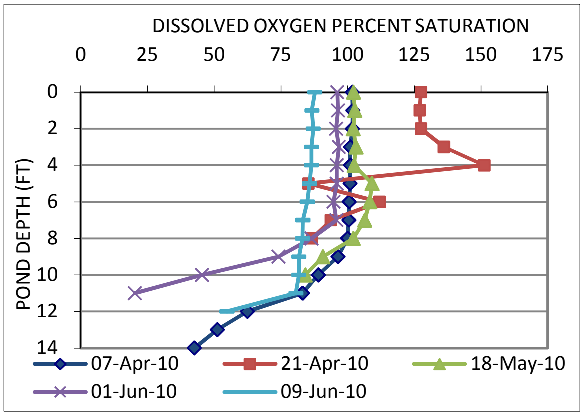


C



D

A series of graphs displaying the dissolved oxygen percent saturation profile data collected on 19 different dates during 2010 at the permanent marker buoy on HHP. Data from several different dates are included on each graph. The scale of dissolved oxygen percent saturation is across the top, X-axis, of the graph; the Y-axis on the left of each graph is the depth of the water column in the pond, with the surface on the top and the bottom area on the lower portion of the axis. Slight differences in total depth are due to natural variations in water level; the extreme differences in depth on April 7th and April 21st are water levels prior to, and following, the opening and closing of Hummock Pond to the Atlantic Ocean, respectively.



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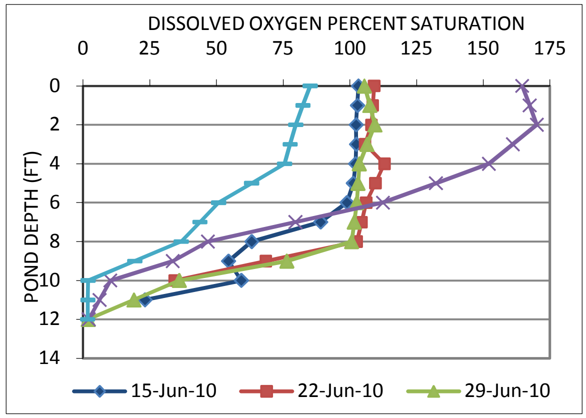

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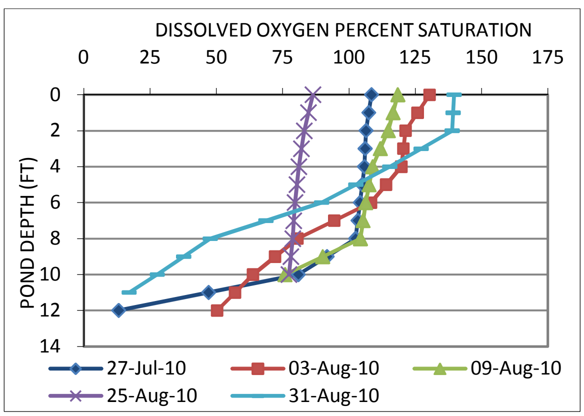
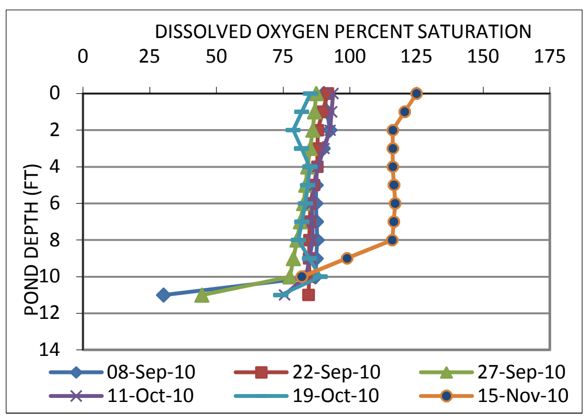


C



D